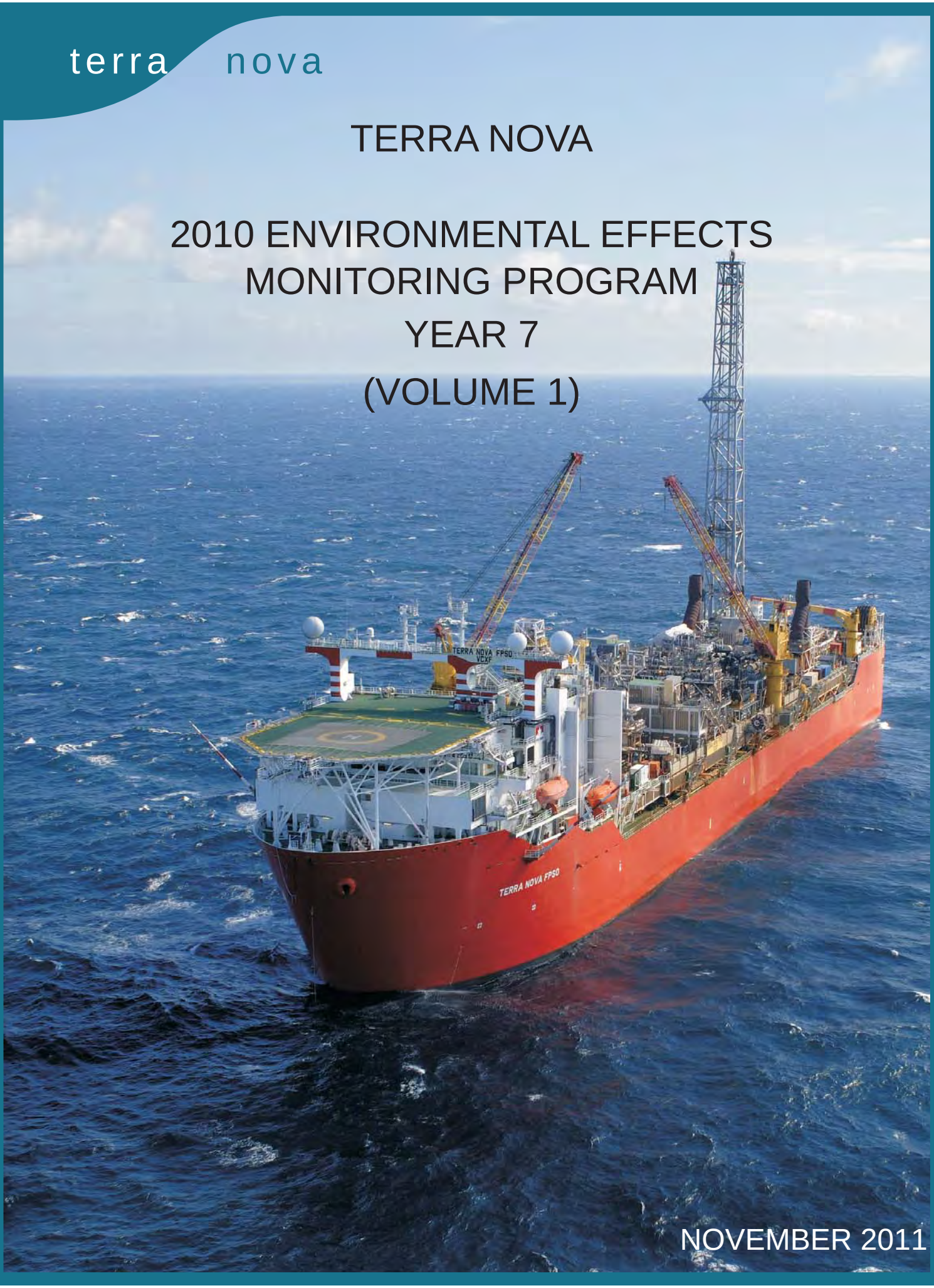
terra nova

TERRA NOVA

2010 ENVIRONMENTAL EFFECTS MONITORING PROGRAM YEAR 7 (VOLUME 1)



NOVEMBER 2011

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 1996) and addendum document (Suncor Energy[1] 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. 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[2].

The first, second, third, fourth, fifth and sixth EEM Programs were conducted in 2000, 2001, 2002, 2004, 2006 and 2008. This report discusses the results of the seventh EEM Program, conducted in the summer and fall of 2010, and relates these to findings of previous EEM years (Suncor Energy 2001, 2002, 2003, 2005, 2007, 2009) and to the baseline (1997) program (Suncor Energy 1998a).

In 2010, 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) and phytoplankton pigment (chlorophyll and phaeophytin) data were collected at 16 stations in a Study Area, located within approximately 5 km of the FPSO, and at eight stations located in two Reference Areas approximately 20 km to the southeast and southwest of the Terra Nova site. Water samples were analyzed for physical and chemical characteristics, as well as for phytoplankton pigment concentration. CTD and pigment data were also collected at all 53 sediment stations.

Samples of a commercial bivalve species (Iceland scallop) and a flatfish species (American plaice) were collected in the Study Area and in the South East Reference Area. These samples were analyzed for chemical body burden and taste. Analyses

[1] For simplicity, historical submissions under the name Petro-Canada will now be referenced as Suncor Energy.

[2] The term contamination is used in this report to indicate elevated levels of a chemical as compared to background levels (GESAMP 1993).

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 2010. Although contamination has increased in EEM years overall, contamination in 2010 (and 2008) was reduced compared to levels observed in 2004 and 2006. Reduction in contamination coincided with reduced drilling activities in the field after 2006. In 2010, maximum barium and $>C_{10}$-C_{21} hydrocarbon concentrations (4,200 and 760 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 2010 that sulphur and sediment fines content were elevated by drilling activity.

Sediment contamination did not extend beyond the zone of influence predicted by Seaconsult (1998). The model predicted that, after 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 2 km from drill centres; concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to low levels (near or below detection limit) at approximately 3 km from drill centres; and elevated levels of sulphur and fines occurred at a few stations within 1 to 2 km 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 greatest within 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.

There was no evidence of project effects on suspended solids or the metals frequently detected in water samples (arsenic, copper and iron) or phytoplankton pigments.

Sediment contamination and effects on benthic invertebrates were not coupled with biological effects on commercial fish. Scallop resources at Terra Nova were not tainted, although some contamination of scallop tissue was noted (median barium concentration in viscera of 14 mg/kg were noted in the Study Area versus levels below laboratory detection limit (1.5 mg/kg) in the Reference Area). Unlike previous years, no hydrocarbon contamination of scallop tissue was noted. 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 no 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 (2010) was led by Stantec Consulting Ltd. (St. John's, NL) under contract to Suncor Energy and under the direction of Roger Crowley and Greg Janes (Suncor Energy). Stantec Consulting Ltd. led data collection. Participants in the commercial fish survey included Barry Wicks and Rebecca Sheppard (Stantec Consulting Ltd.), and Raymond Soper and Wynnan Melvin (Oceans Ltd., St. John's, NL). Participants in the sediment and water survey included Barry Wicks, Doug Rimmer, Rebecca Sheppard, Kristian Greenham, Matt Steeves and Justin Bath (Stantec Consulting Ltd.) Fugro Jacques Geosurveys Inc. (Darren White and Melony Boutillier) 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, water and tissues were conducted by Maxxam Analytics (Halifax, NS and St. John's, NL). Chromatograms were interpreted by Dr. Joe Kiceniuk. Particle size analysis was conducted by Stantec Consulting Ltd. Sediment toxicity tests were supervised by Trudy Wells (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.). Water quality and body burden data were analyzed by Dr. Michael Paine (Paine, Ledge and Associates, North Vancouver, BC). Sediment chemistry and toxicity data were analyzed by Drs. Michael Paine and Bruce Kilgour (Kilgour & Associates, Ottawa, ON). Benthic community data were analyzed by Dr. Bruce Kilgour. Dr. Anthony Francis (Kilgour & Associates) and Will Gibson (Environment Resolution Services, Vancouver, B.C.) provided support services for analysis of sediment chemistry, toxicity and benthic community data. Drs. Elisabeth DeBlois, Mike Paine, 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.). Theresa Tobin and Amber Frickleton (Stantec Consulting Ltd.) provided administrative and graphics support, respectively. Sandra Whiteway (Stantec Consulting Ltd.) reviewed the report from Stantec Consulting Ltd.'s quality point of view. Roger Crowley and Greg Janes (Suncor Energy) and Dr. Joe Kiceniuk reviewed the document before final printing.

Acknowledgement - Dr. Mike Paine

Dr. Mike Paine, who passed away unexpectedly in June 2011, was involved in the design of the Terra Nova Baseline program, the design of the Terra Nova EEM program and has been performing analyses in support of the Terra Nova EEM program since its inception in 2000. The authors and reviewers of the Terra Nova EEM report will miss him for his dry sense of humour and his expert skills as a statistician, and want to acknowledge his contributions to the Terra Nova EEM Program.

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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., Exxon-Mobil Canada Properties, Husky Oil Operations Ltd., Statoil Canada Ltd., Murphy Oil Company Ltd., Mosbacher Operating Ltd. and Chevron Canada Ltd.).

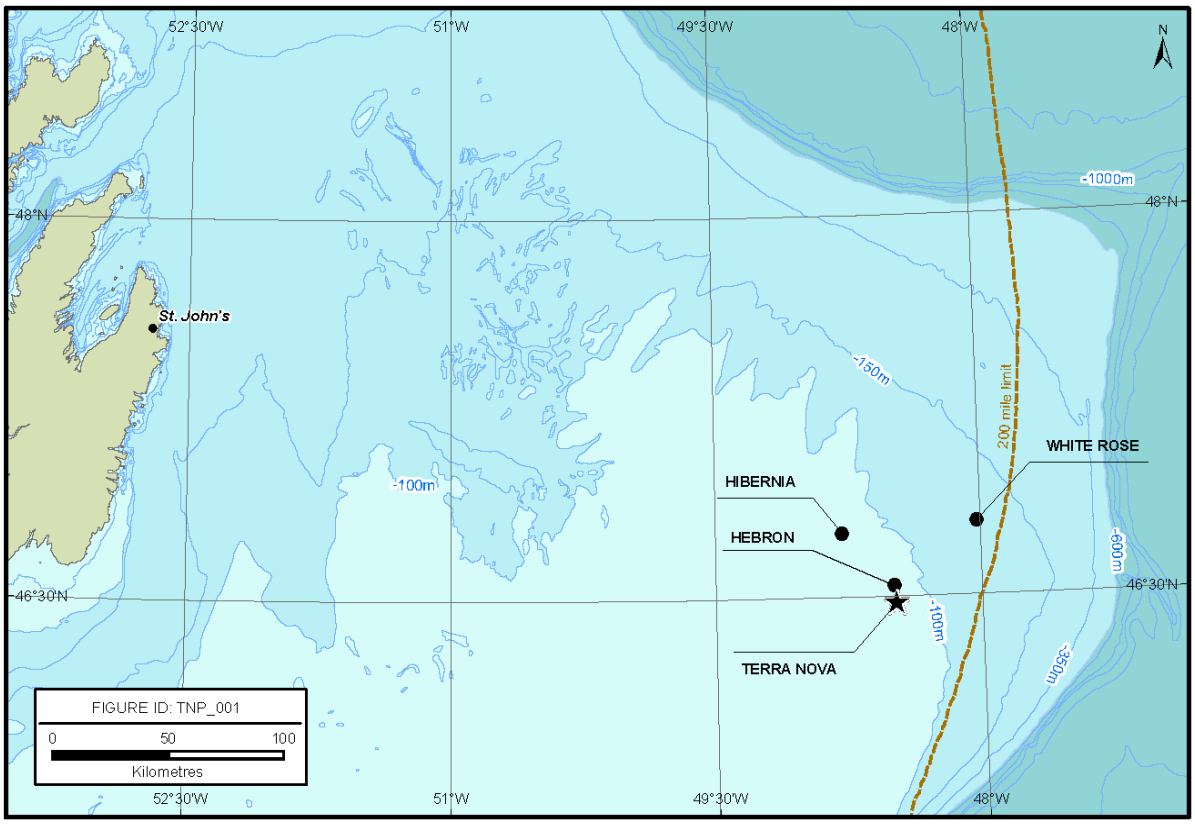


Figure 1-1 Terra Nova and Other Field Locations on the Grand Banks

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

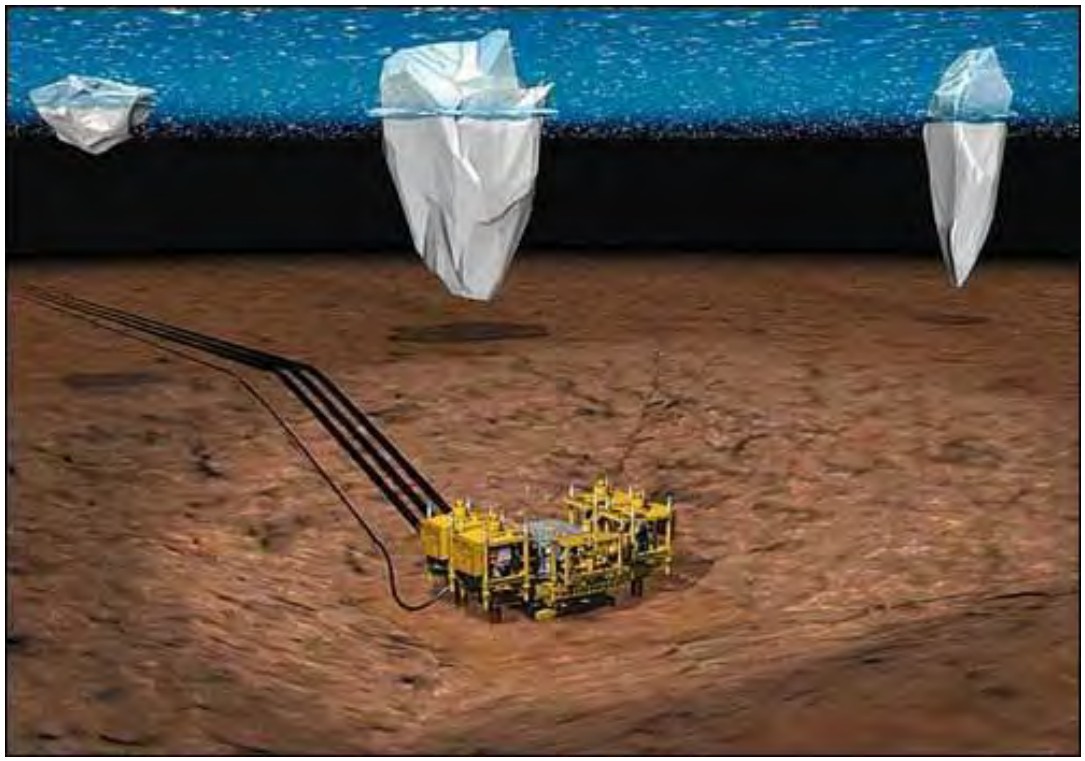


Figure 1-3 Typical Glory Hole Configuration

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[3]. 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 a number of 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 to discuss existing knowledge on EEM and develop a monitoring strategy. The design team consisted of Urban Williams (Suncor Energy, St. John's, NL), Kathy Penney (Stantec Consulting Ltd., St. John's, NL), Sandra Whiteway (Stantec Consulting Ltd., St. John's, NL), Ellen Tracy (Stantec Consulting Ltd., St. John's, NL), Mary Murdoch (Stantec Consulting Ltd., St. John's, NL), Dr. Michael Paine (Paine, Ledge and

[3] The name of this organization has since been changed to Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB).

Associates, North Vancouver, BC), Judith Bobbitt (Oceans Ltd., St. John's, NL), Dr. David Schneider (Memorial University, St. John's, NL), Don Hodgins (Seaconsult Marine Research Ltd., Salt Spring Island, BC) and Mrs. Lavina Massie (Marine Environmental Consultant, Scotland, UK).

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 final design document (Suncor Energy 1998b) was submitted to the Canada-Newfoundland Offshore Petroleum Board in October 1998. The EEM program has been implemented seven times, in 2000, 2001, 2002, 2004, 2006, 2008 and 2010.

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[4] 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

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

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.

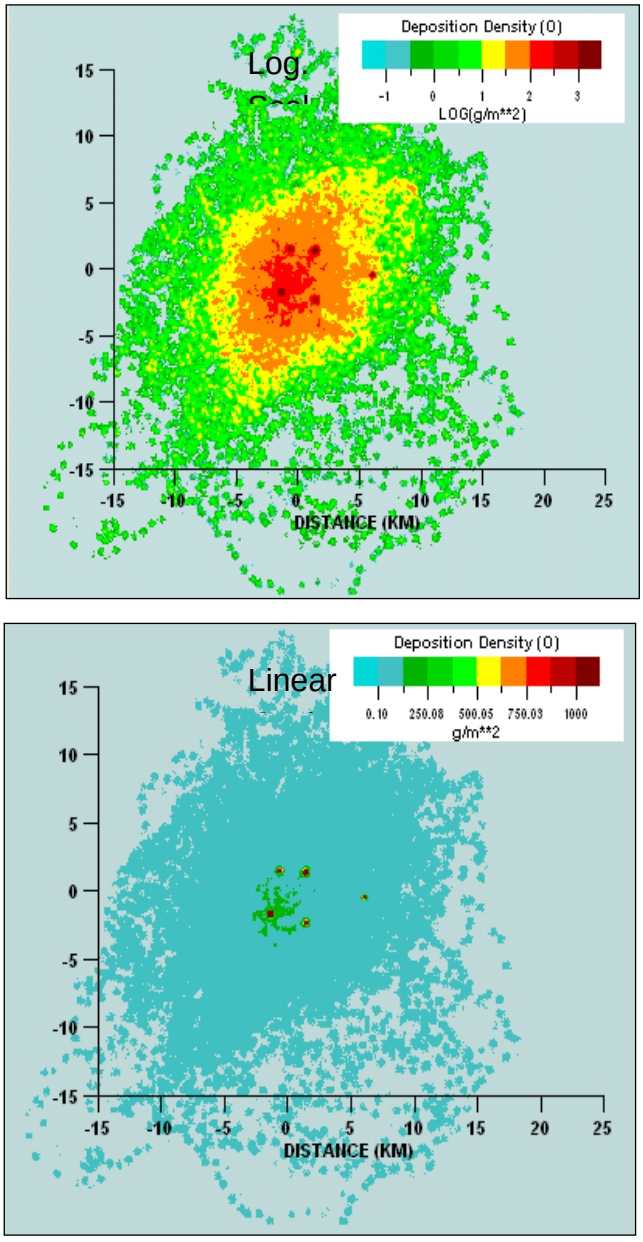


Figure 1-4 Zone of Influence for Drill Cuttings After Completion of Drilling (Seaconsult 1998)

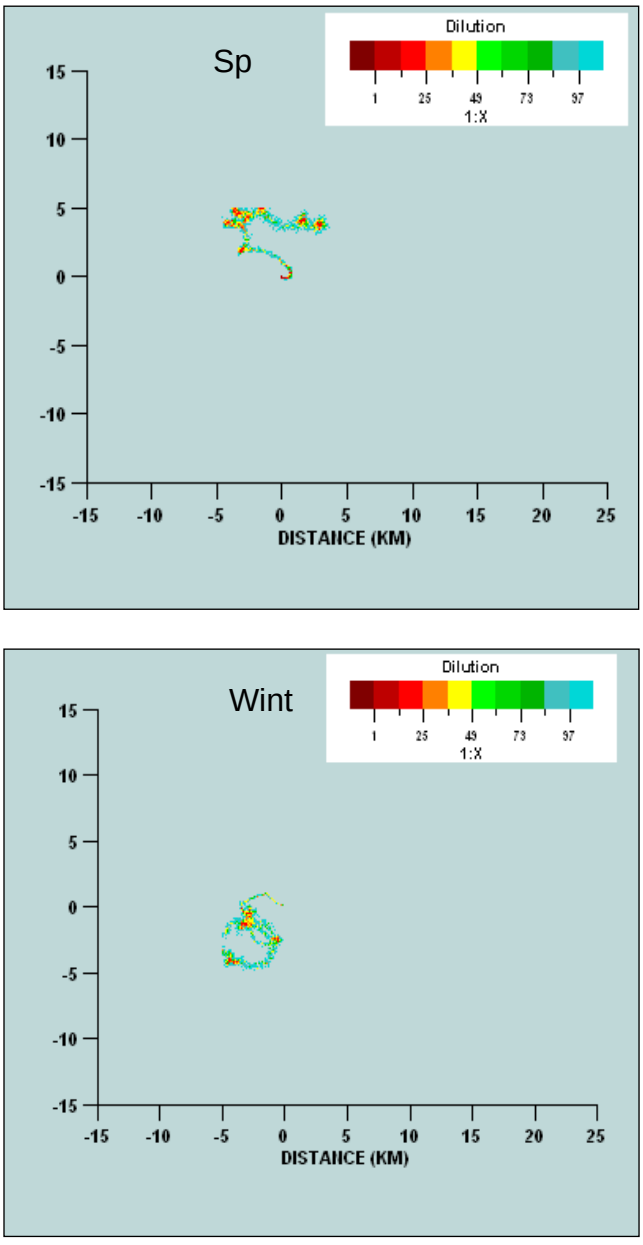


Figure 1-5 Snap-Shot of the Distribution of Produced Water (Seaconsult 1998)

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 1998b), as well as the Baseline program report (Suncor Energy 1998a).

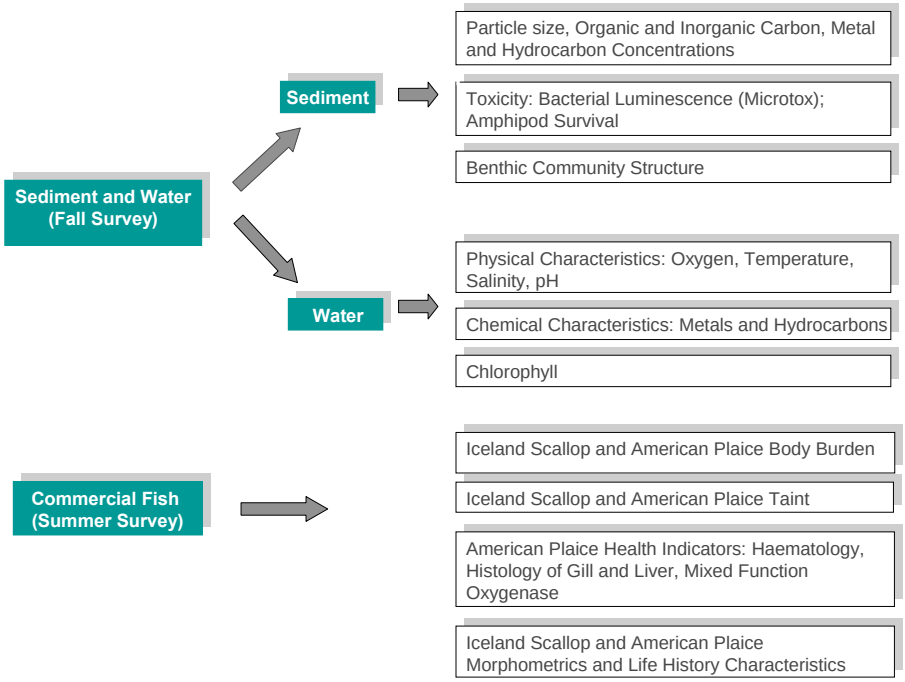


Figure 1-6 EEM Components

1.7 MONITORING HYPOTHESES

Monitoring, or null (H_0), hypotheses were developed in Suncor Energy (1998b) as 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[5] 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.

[5] 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 the drill centres (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 1998b for details).

The general spatial distribution of sampling sites was established during the design phase of the Terra Nova EEM program (Suncor Energy 1998b). 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. Details on sampling design modifications are provided in Suncor Energy (2000a, 2000b).

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. In 2002, 2004, 2006 and 2008, because of reduced construction at Terra Nova, sediment samples were collected at four stations inside the FEZ, but station 48(FEZ) could not be sampled in 2004 because of drilling activity. Station locations for sediment and water for the Baseline program are shown in Figure 1-7. Station locations for sediment and water for the EEM programs are shown in Figure 1-8. Transect locations for scallop and plaice for the Baseline program and the EEM programs are shown in Figures 1-9 to 1-20. Station name changes that have occurred since the Baseline program are identified in Table 1-2.

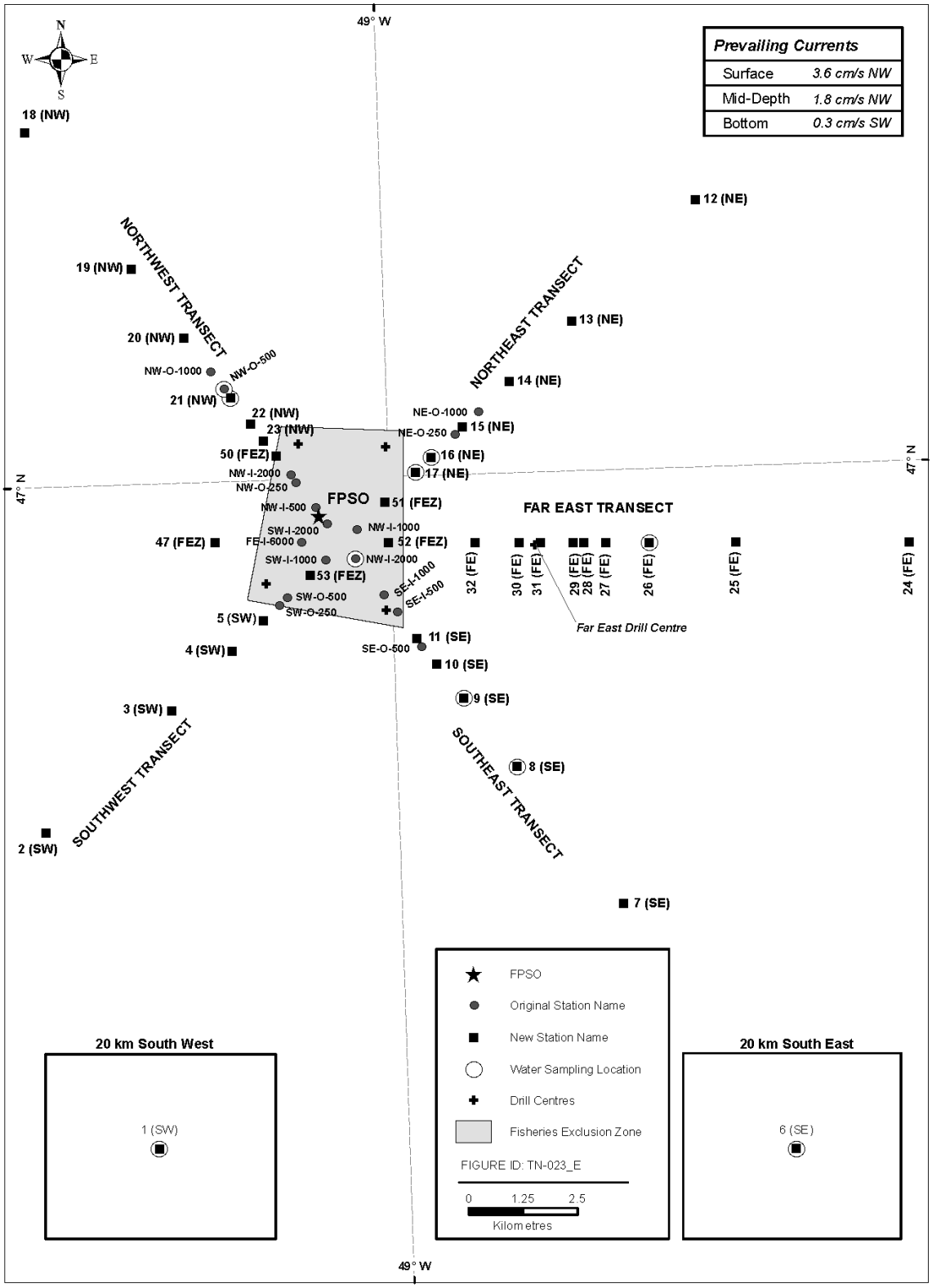


Figure 1-7 Station Locations for the Baseline Program (1997) Sediment and Water Collections

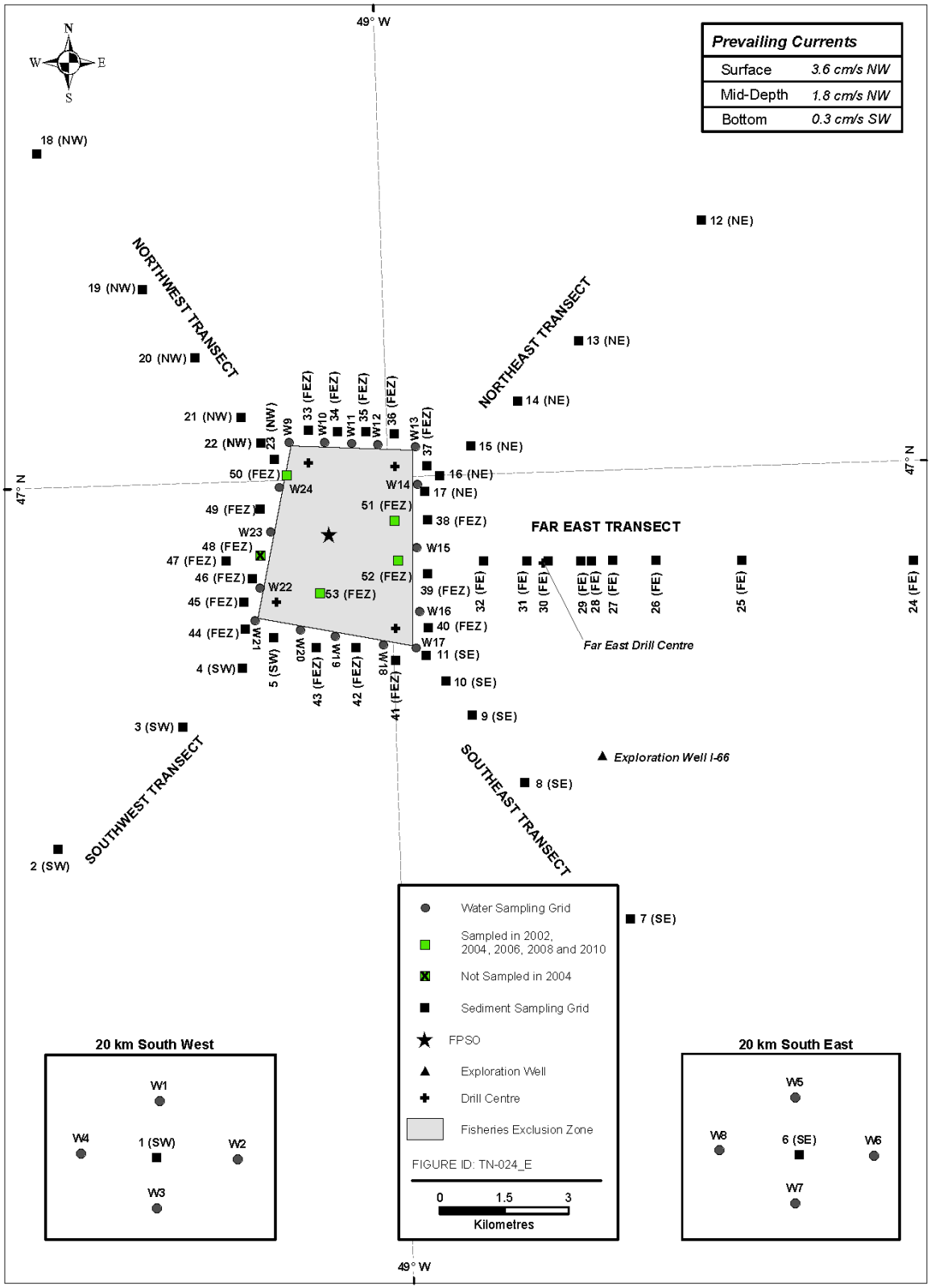


Figure 1-8 Station Locations for the EEM Program Sediment and Water Collections

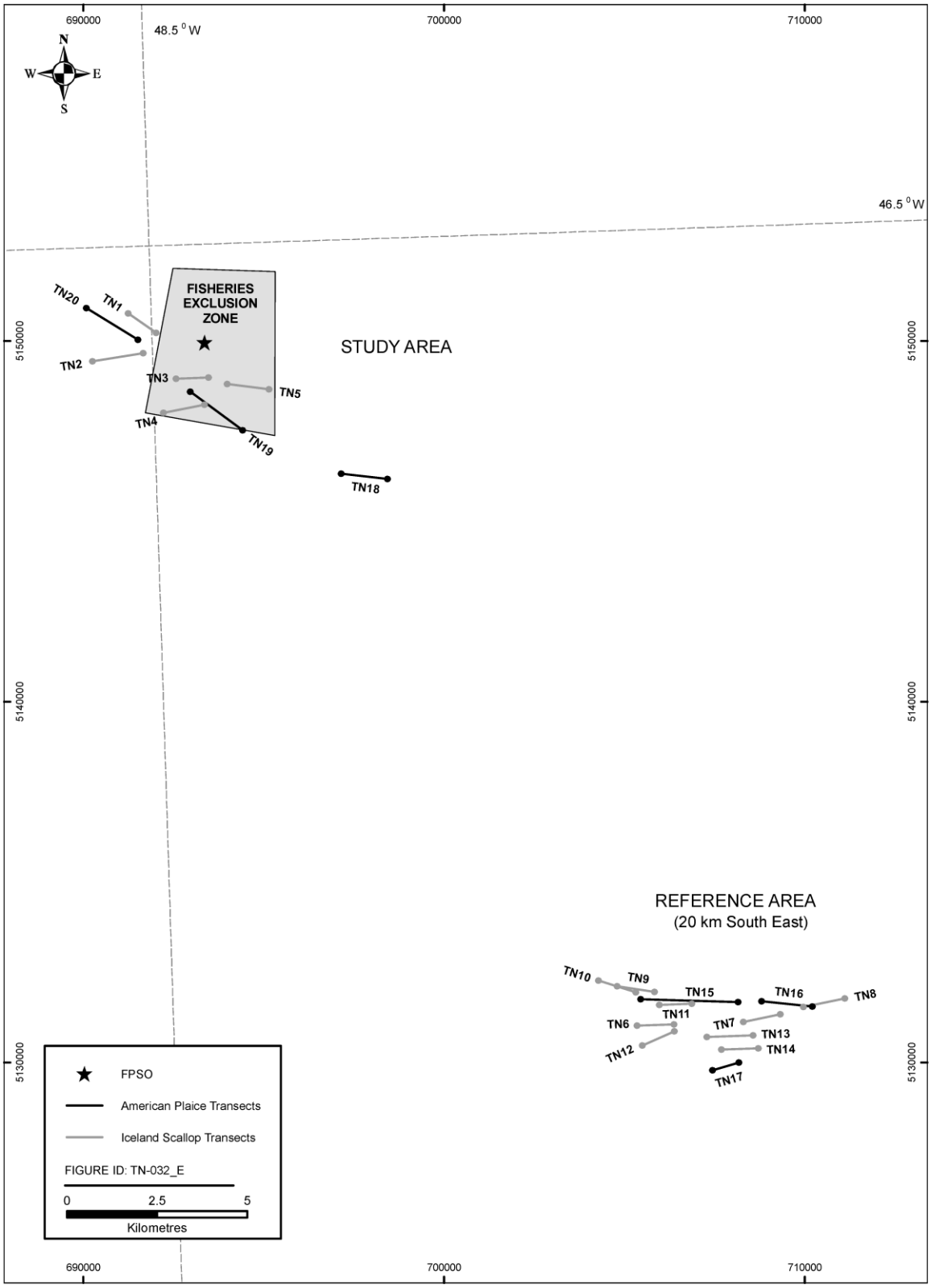


Figure 1-9 Transect Locations for Scallop and Plaice (1997)

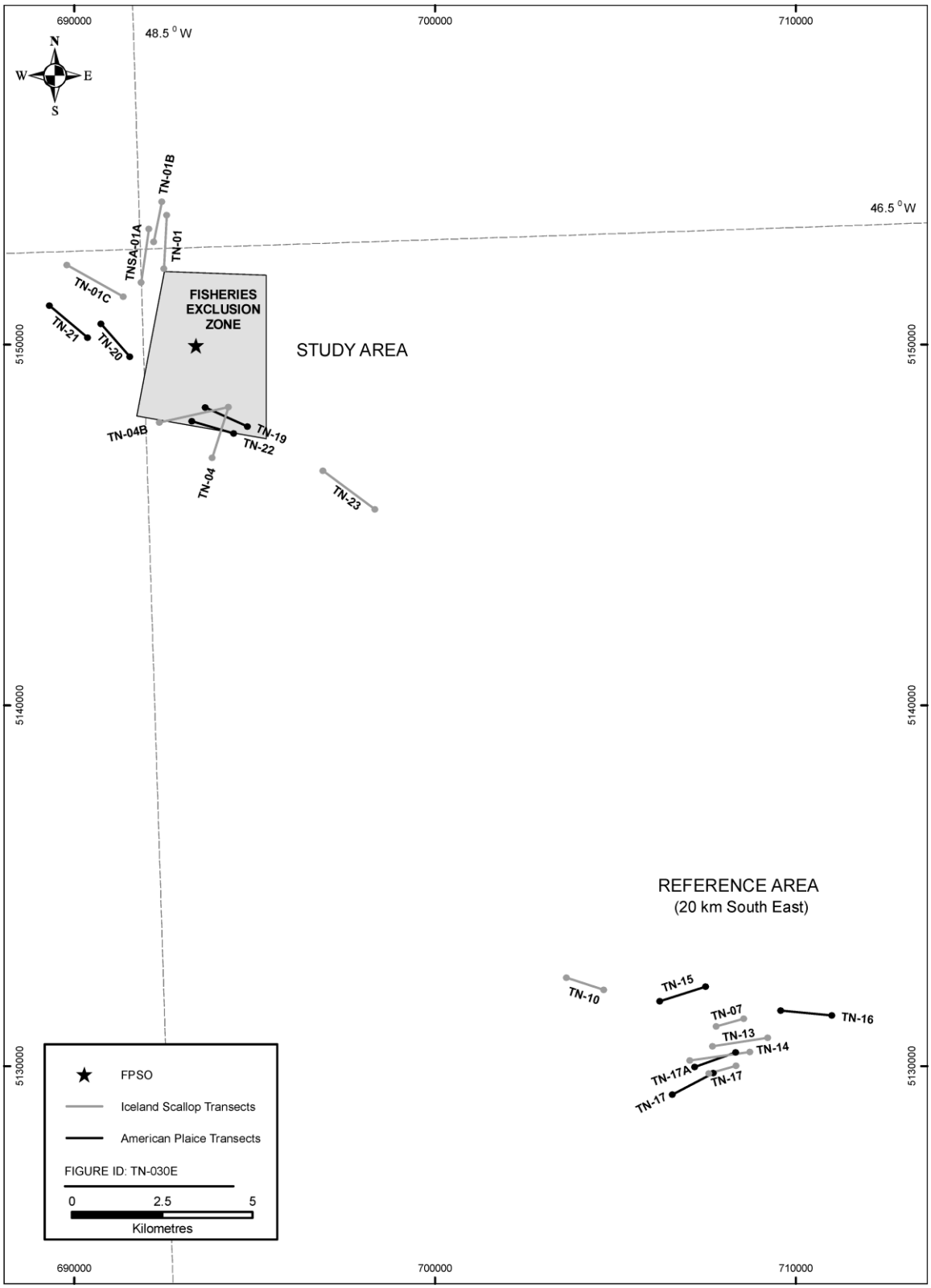


Figure 1-10 Transect Locations for Scallop and Plaice (2000)

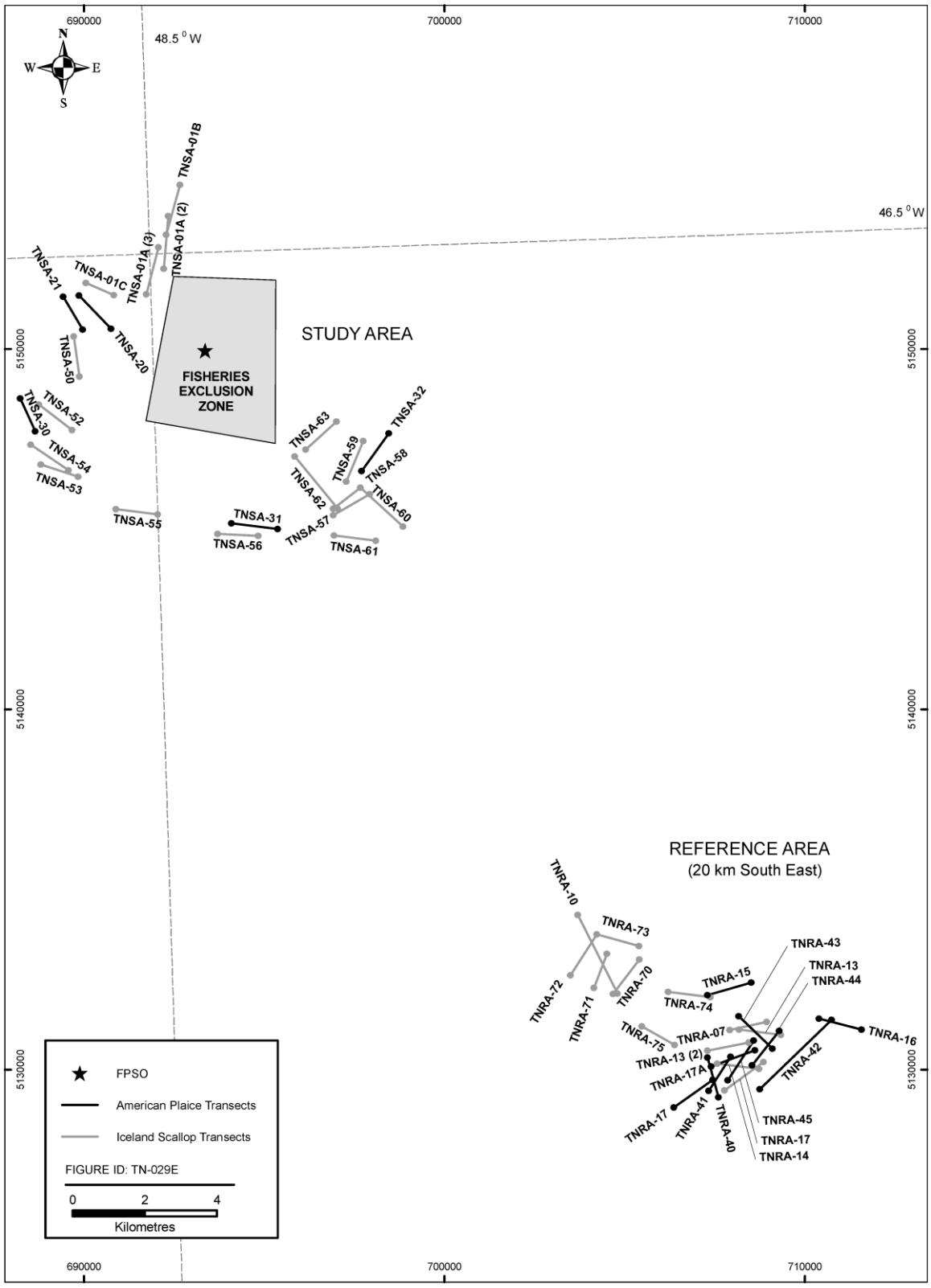


Figure 1-11 Transect Locations for Scallop and Plaice (2001)

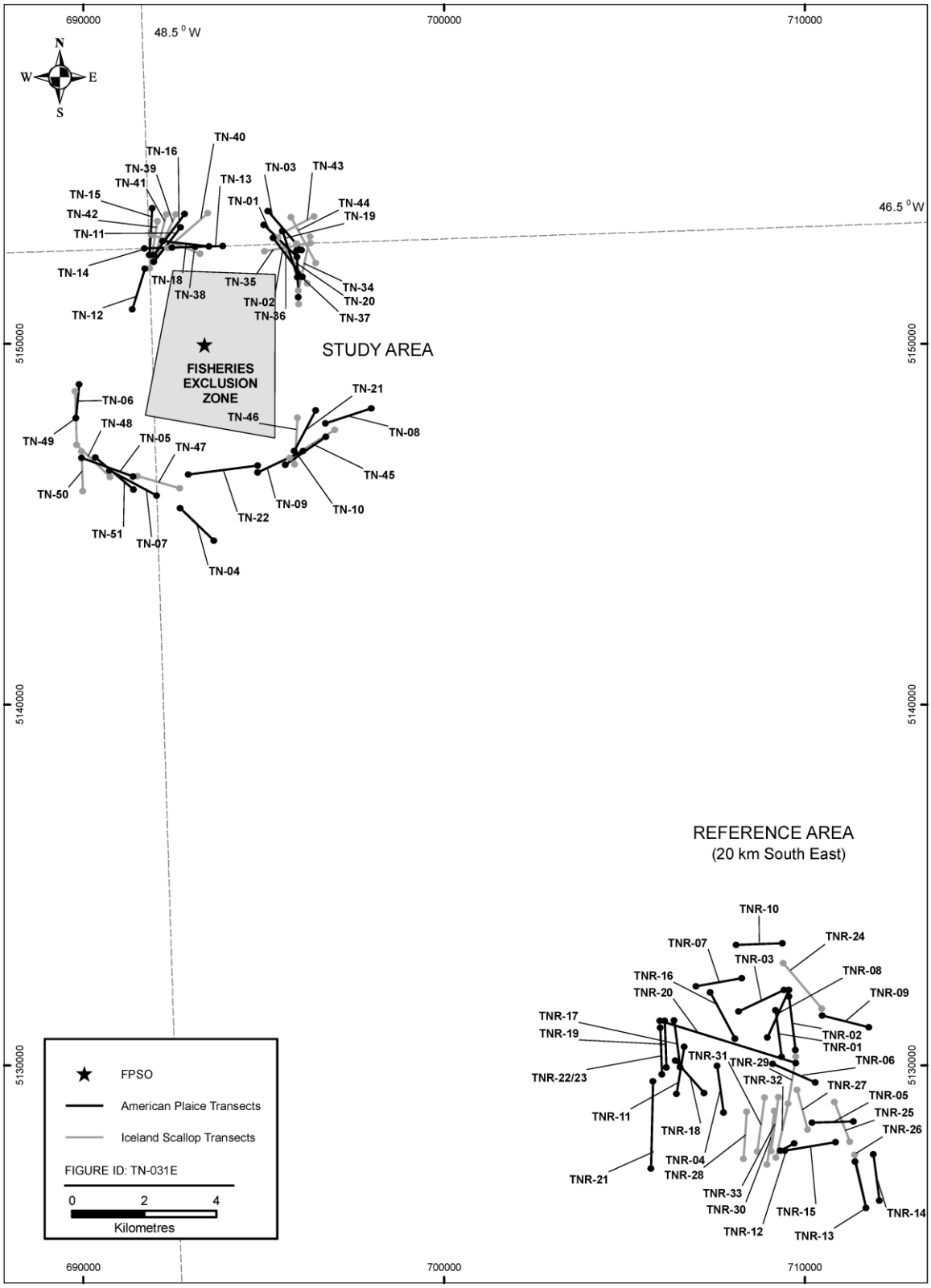


Figure 1-12 Transect Locations for Scallop and Plaice (2002)

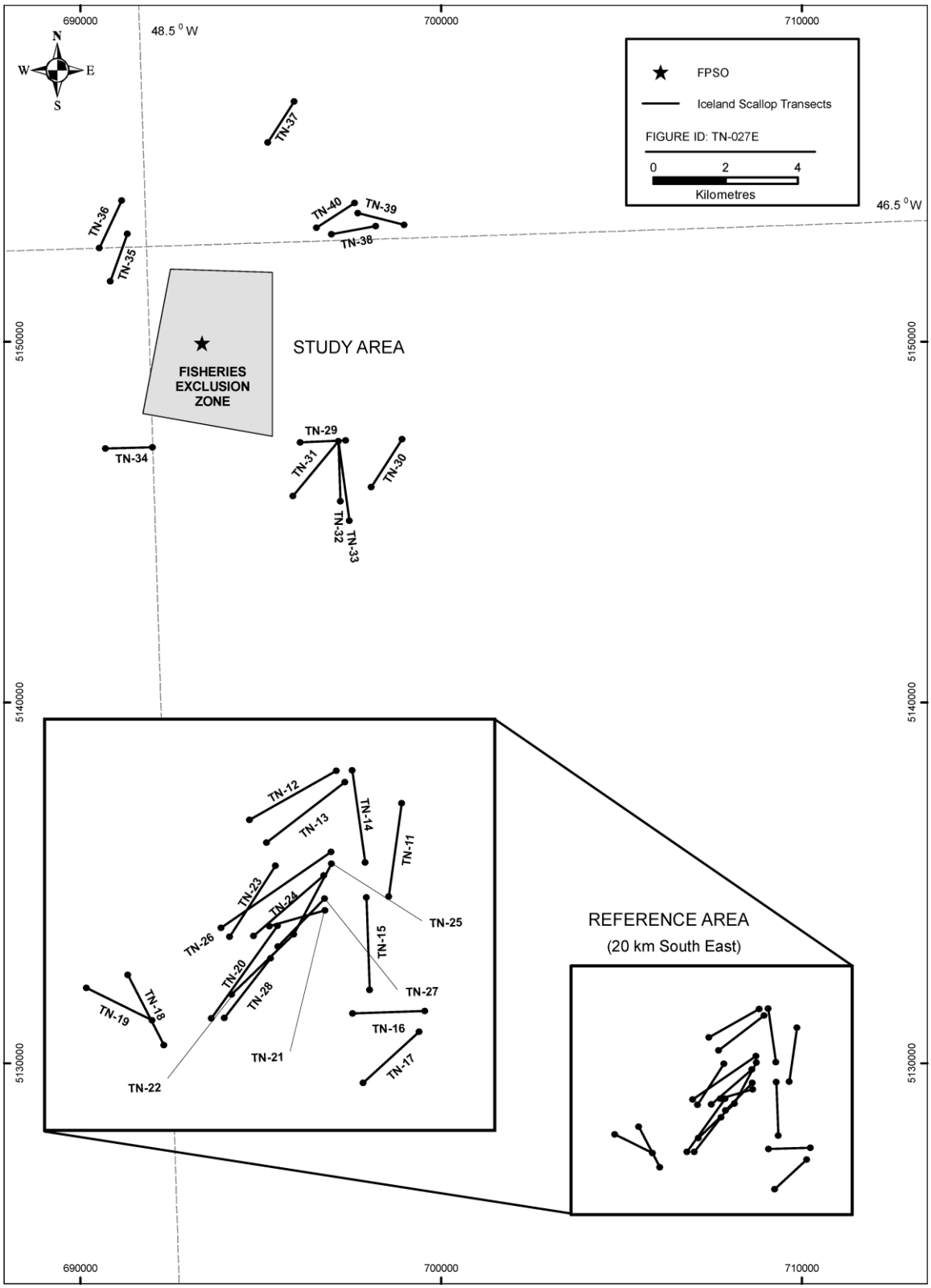


Figure 1-13 Transect Locations for Scallop (2004)

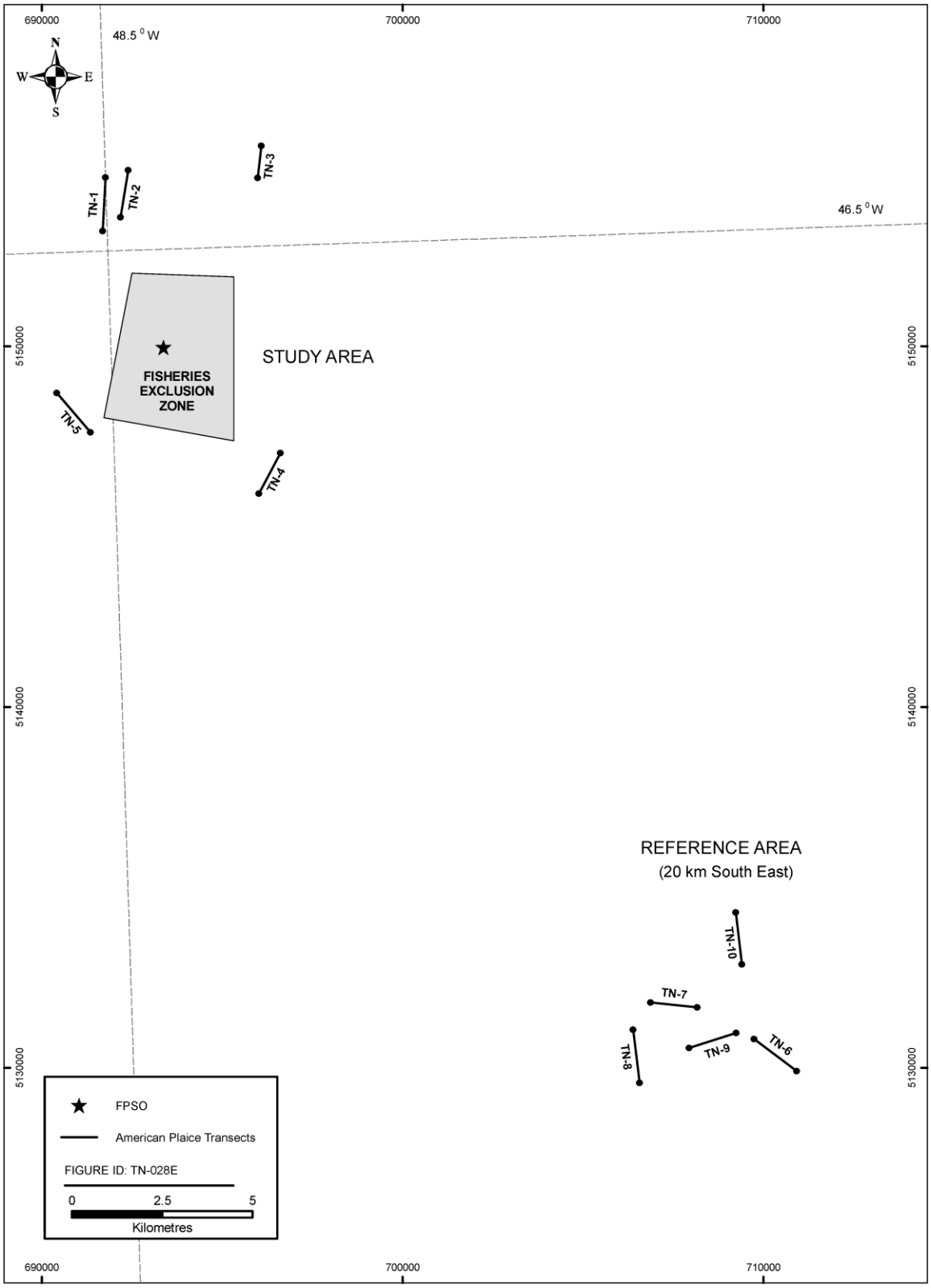


Figure 1-14 Transect Locations for Plaice (2004)

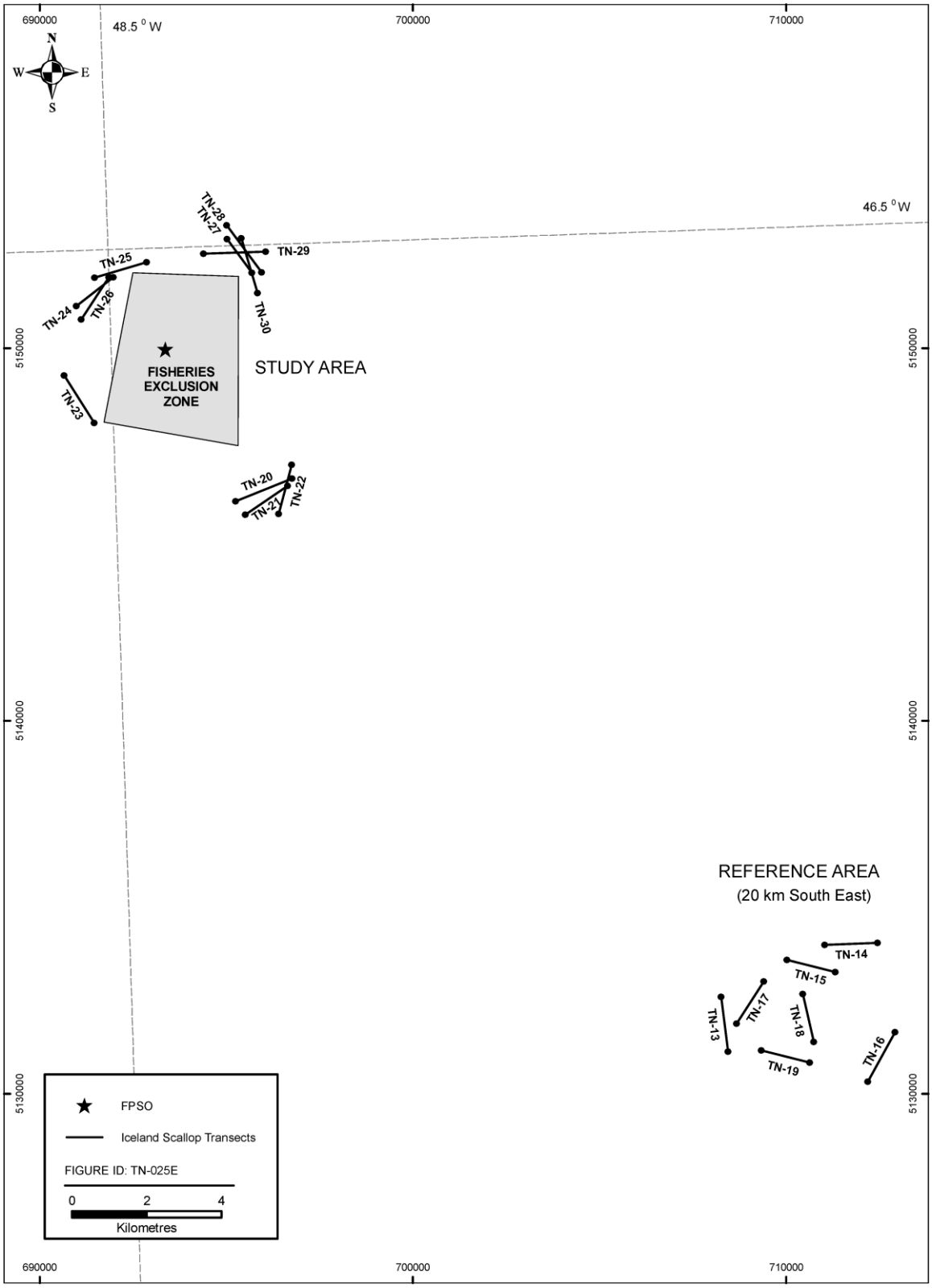


Figure 1-15 Transect Locations for Scallop (2006)

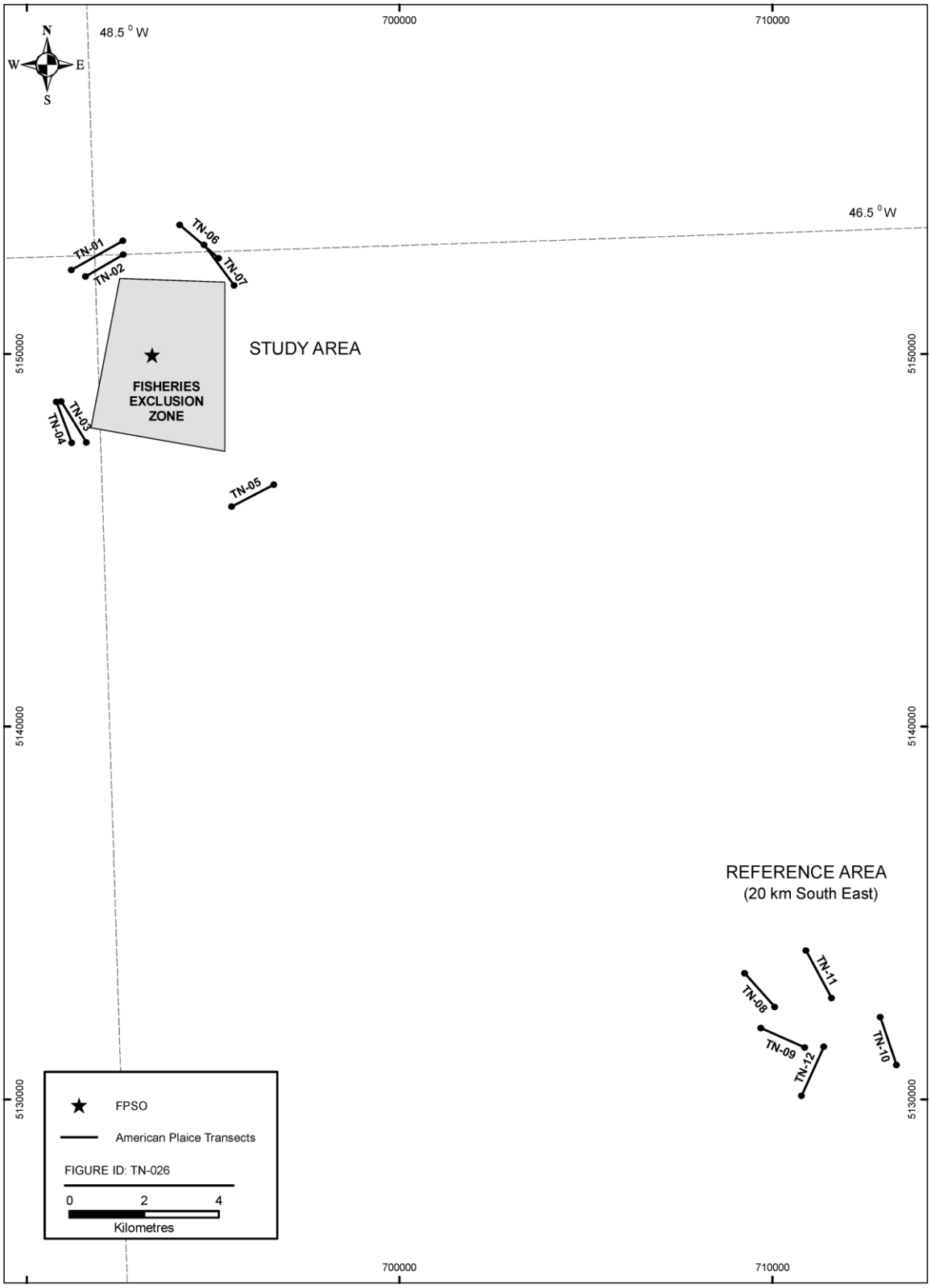


Figure 1-16 Transect Locations for Plaice (2006)

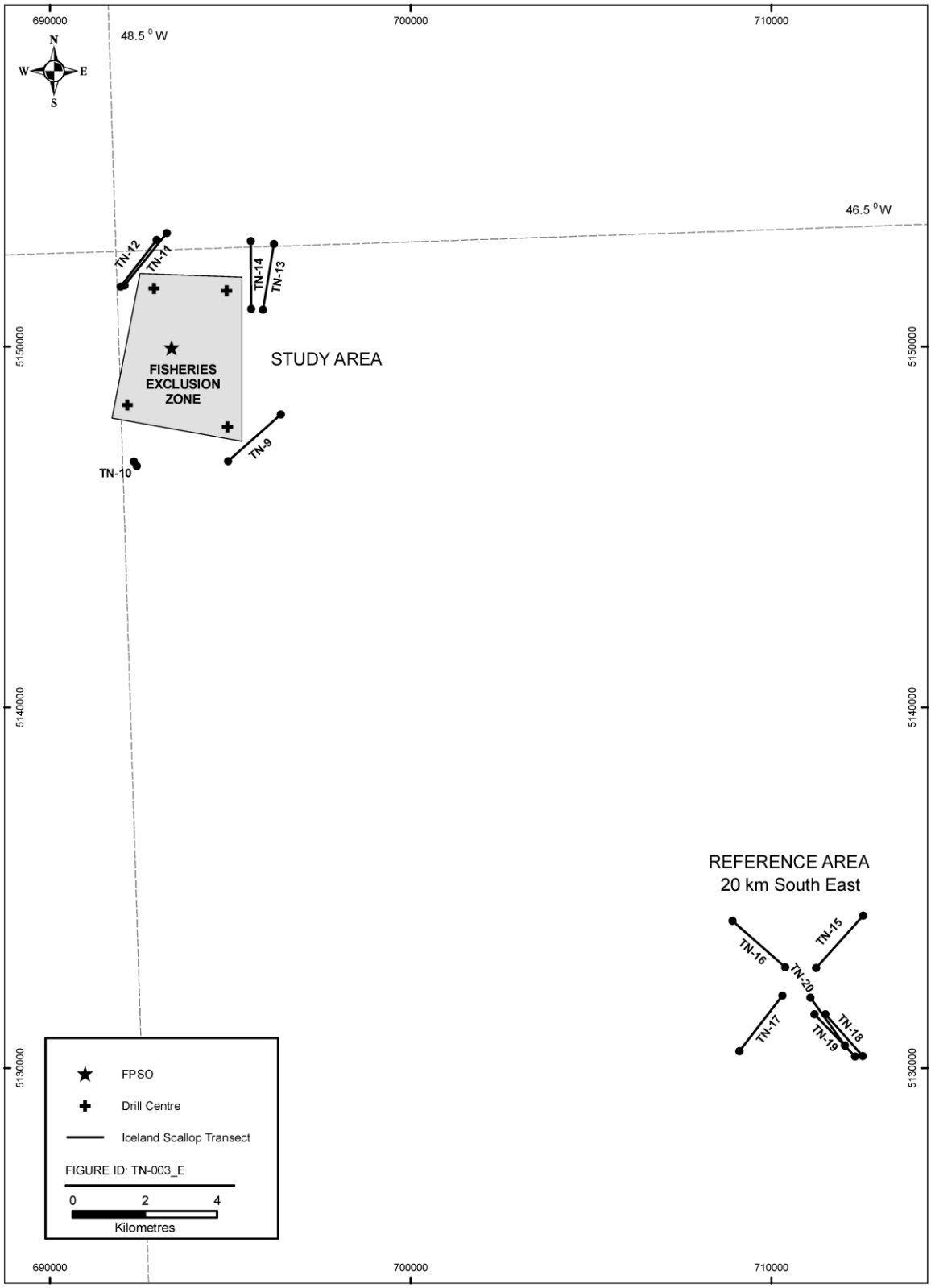


Figure 1-17 Transect Locations for Scallop (2008)

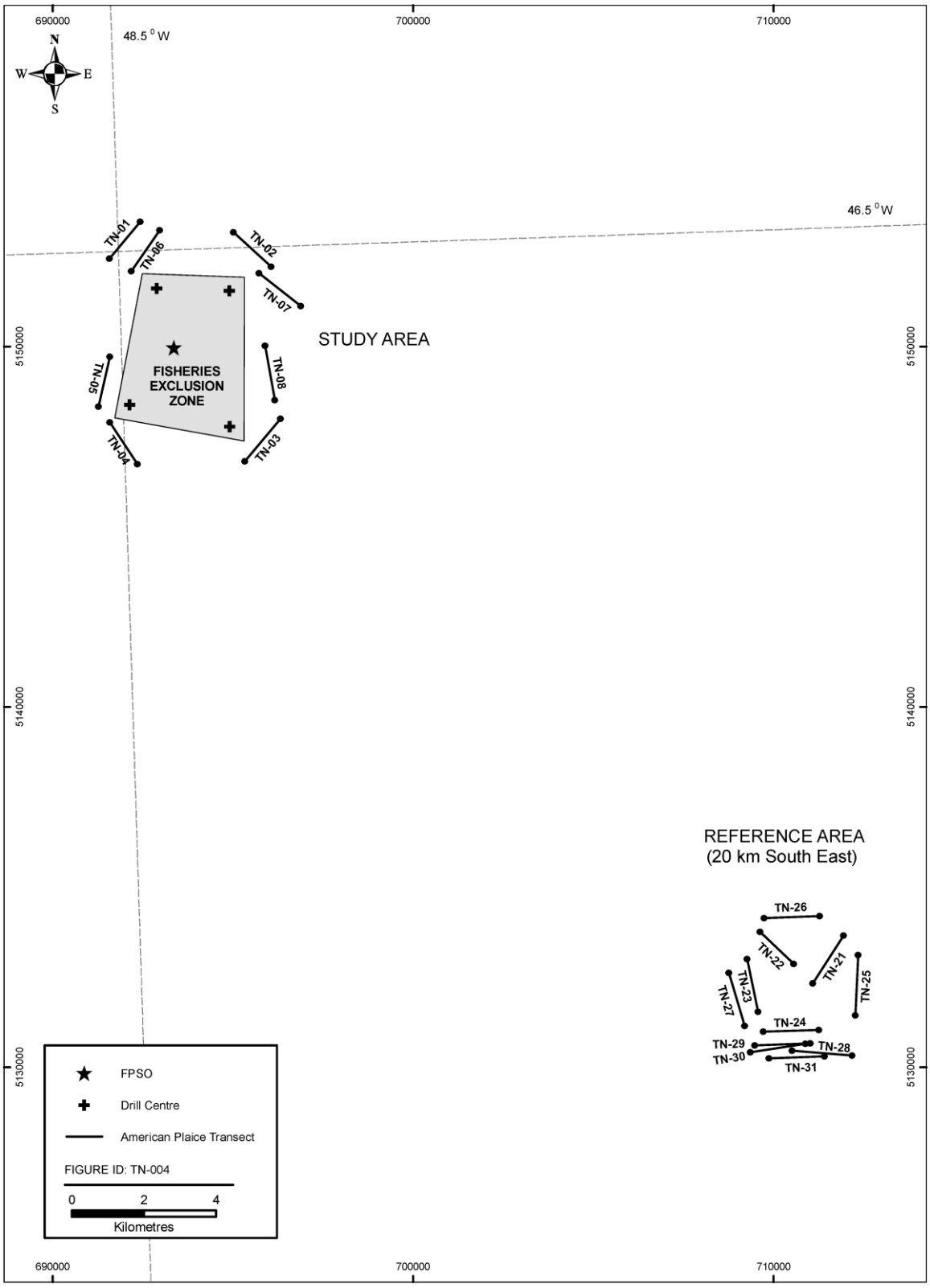


Figure 1-18 Transect Locations for Plaice (2008)

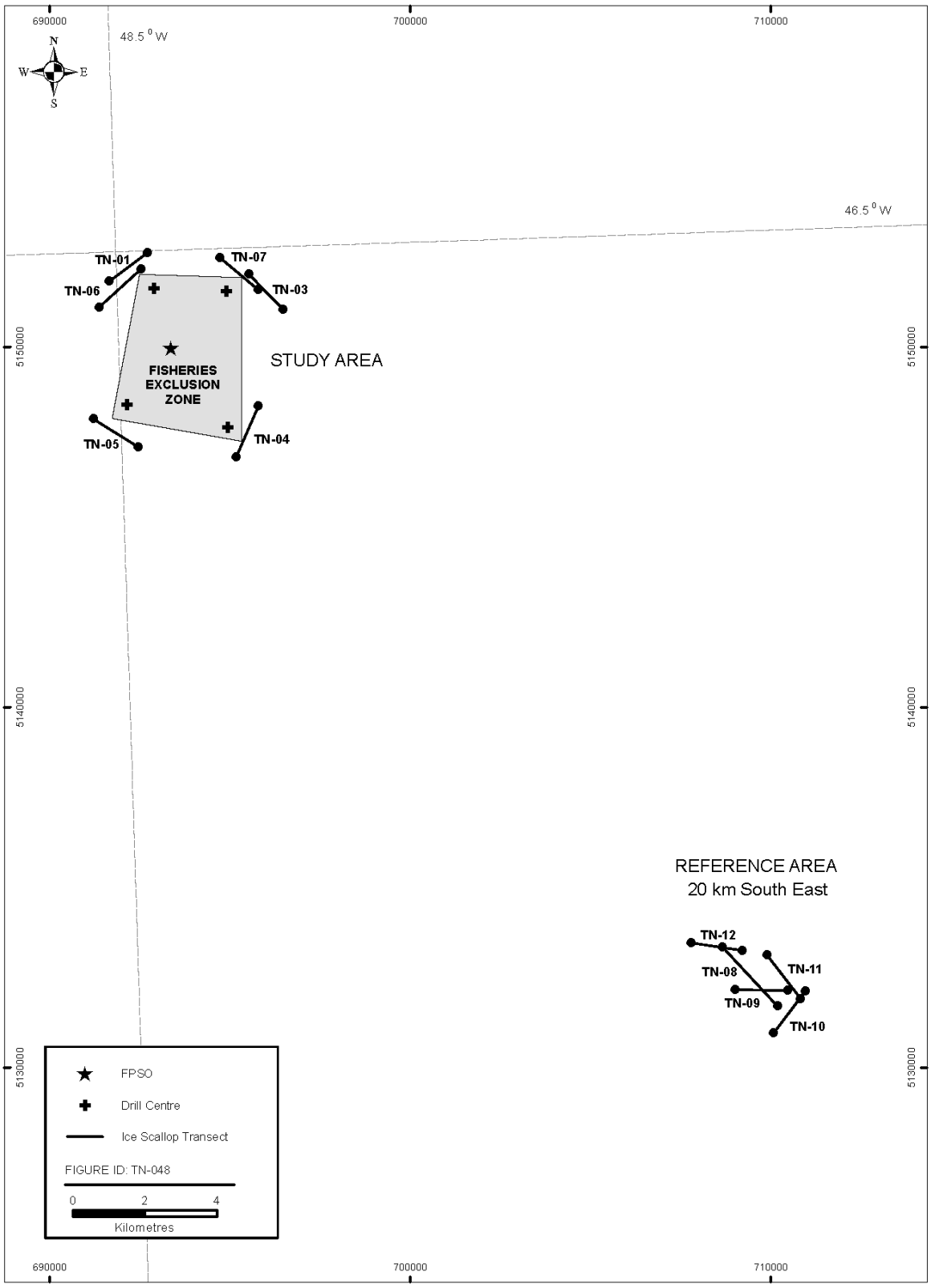


Figure 1-19 Transect Locations for Scallop (2010)

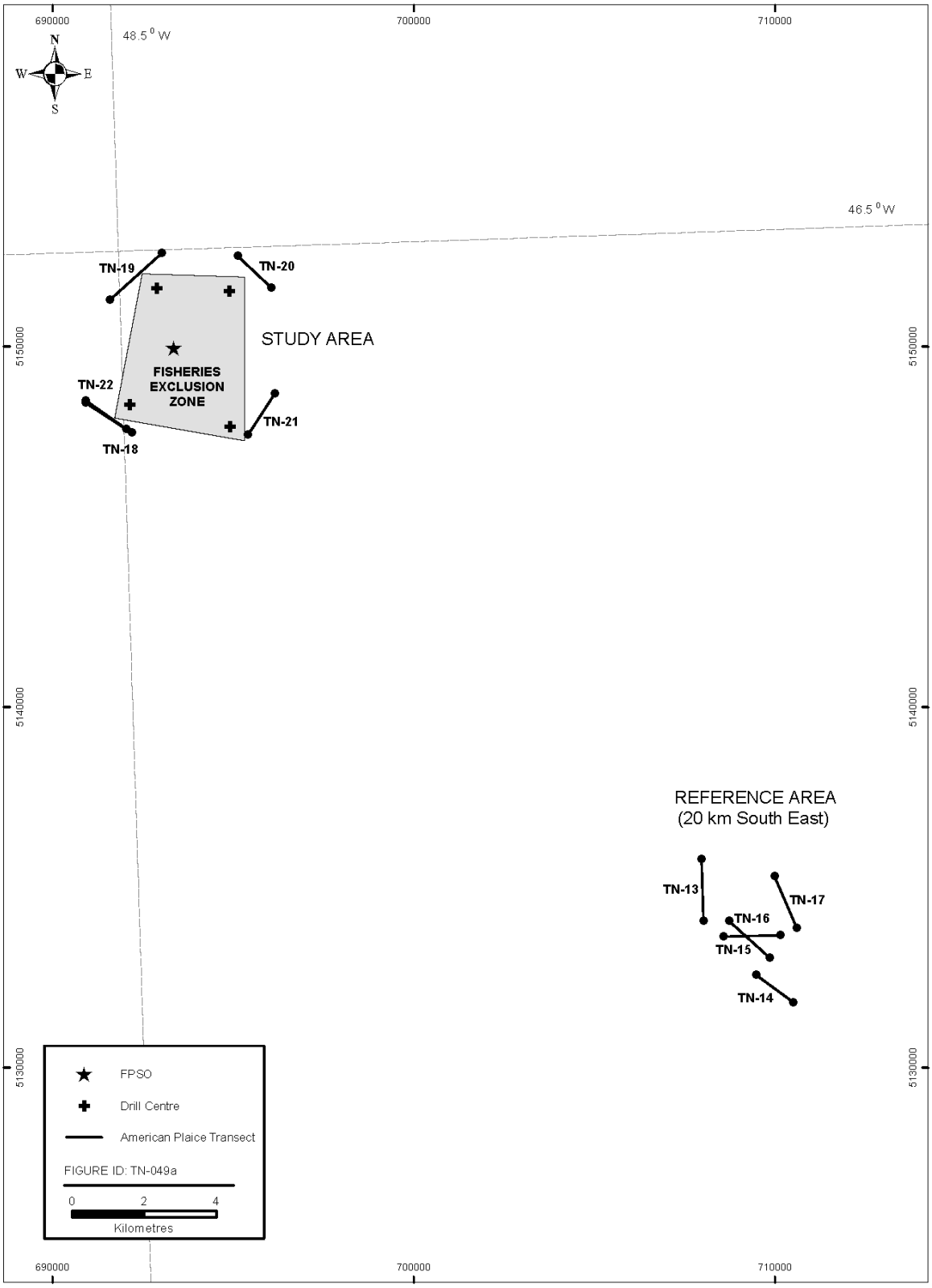


Figure 1-20 Transect Locations for Plaice (2010)

Table 1-2 Terra Nova Station Name Changes

Sample type	Station Name 2002	Station Name in Previous Programs	Latitude	Longitude
Sediment	1 (SW)	SW-O-20000	46° 20.32'N	48° 40.41'W
	2 (SW)	SW-O-8000	46° 24.69'N	48° 33.95'W
	3 (SW)	SW-O-4000	46° 26.17'N	48° 31.62'W
	4 (SW)	SW-O-2000	46° 26.88'N	48° 30.50'W
	5 (SW)	SW-O-1000	46° 27.25'N	48° 29.92'W
	6 (SE)	SE-O-20000	46° 18.34'N	48° 18.11'W
	7 (SE)	SE-O-8000	46° 23.58'N	48° 23.60'W
	8 (SE)	SE-O-4000	46° 25.33'N	48° 25.44'W
	9 (SE)	SE-O-2000	46° 26.21'N	48° 26.36'W
	10 (SE)	SE-O-1000	46° 26.64'N	48° 26.81'W
	11 (SE)	SE-O-250	46° 26.97'N	48° 27.16'W
	12 (NE)	NE-O-8000	46° 32.31'N	48° 21.89'W
	13 (NE)	NE-O-4000	46° 30.85'N	48° 24.20'W
	14 (NE)	NE-O-2000	46° 30.12'N	48° 25.35'W
	15 (NE)	NE-O-500	46° 29.57'N	48° 26.22'W
	16 (NE)	NE-I-500	46° 29.21'N	48° 26.80'W
	17 (NE)	NE-I-1000	46° 29.03'N	48° 27.09'W
	18 (NW)	NW-O-8000	46° 33.41'N	48° 33.95'W
	19 (NW)	NW-O-4000	46° 31.66'N	48° 32.11'W
	20 (NW)	NW-O-2000	46° 30.79'N	48° 31.19'W
	21 (NW)	NW-O-250	46° 30.03'N	48° 30.38'W
	22 (NW)	NW-I-500	46° 29.70'N	48° 30.04'W
	23 (NW)	NW-I-1000	46° 29.48'N	48° 29.81'W
	24 (FE)	FE-O-8000	46° 27.95'N	48° 18.24'W
	25 (FE)	FE-O-4000	46° 28.03'N	48° 21.37'W
	26 (FE)	FE-O-2000	46° 28.06'N	48° 22.93'W
	27 (FE)	FE-O-1000	46° 28.08'N	48° 23.71'W
	28 (FE)	FE-O-500	46° 28.09'N	48° 24.10'W
	29 (FE)	FE-O-250	46° 28.10'N	48° 24.30'W
	30 (FE)	FE-I-500	46° 28.11'N	48° 24.88'W
	31 (FE)	FE-I-1000	46° 28.12'N	48° 25.27'W
	32 (FE)	FE-I-2000	46° 28.13'N	48° 26.05'W
	33 (FEZ)	NW-N-750	46° 29.83'N	48° 29.17'W
	34 (FEZ)	NW-NE-1	46° 29.80'N	48° 28.65'W
	35 (FEZ)	NW-NE-2	46° 29.79'N	48° 28.12'W
	36 (FEZ)	NE-N-750	46° 29.76'N	48° 27.60'W
	37 (FEZ)	NE-E-750	46° 29.34'N	48° 27.03'W
	38 (FEZ)	NE-SE-1	46° 28.66'N	48° 27.05'W
	39 (FEZ)	NE-SE-2	46° 27.99'N	48° 27.08'W
	40 (FEZ)	SE-E-750	46° 27.31'N	48° 27.10'W
	41 (FEZ)	SE-S-750	46° 26.92'N	48° 27.71'W
	42 (FEZ)	SW-SE-2	46° 27.10'N	48° 28.42'W
	43 (FEZ)	SW-SE-1	46° 27.11'N	48° 29.15'W
	44 (FEZ)	SW-SW-1	46° 27.37'N	48° 30.42'W
	45 (FEZ)	SW-W-750	46° 27.71'N	48° 30.43'W
	46 (FEZ)	NW-SW-3	46° 28.00'N	48° 30.27'W
	47 (FEZ)	FE-I-8000	46° 28.23'N	48° 30.74'W
	48 (FEZ)	NW-SW-2	46° 28.28'N	48° 30.12'W
	49 (FEZ)	NW-SW-1	46° 28.87'N	48° 30.09'W
	50 (FEZ)	NW-O-1000	46° 29.29'N	48° 29.60'W
	51 (FEZ)	NE-I-2000	46° 28.66'N	48° 27.66'W
	52 (FEZ)	FE-I-4000	46° 28.17'N	48° 27.62'W
	53 (FEZ)	SW-I-500	46° 27.79'N	48° 29.05'W

Sample type	Station Name 2002	Station Name in Previous Programs	Latitude	Longitude
Water	W1	SW-20000-1	46° 20.60'N	48° 40.39'W
	W2	SW-20000-2	46° 20.30'N	48° 40.00'W
	W3	SW-20000-3	46° 20.06'N	48° 40.41'W
	W4	SW-20000-4	46° 20.33'N	48° 40.79'W
	W5	SE-20000-1	46° 18.62'N	48° 18.13'W
	W6	SE-20000-2	46° 18.33'N	48° 17.74'W
	W7	SE-20000-3	46° 18.09'N	48° 18.13'W
	W8	SE-20000-4	46° 18.35'N	48° 18.52'W
	W9	NW-2	46° 29.69'N	48° 29.54'W
	W10	NW-3	46° 29.68'N	48° 28.89'W
	W11	NW-4	46° 29.65'N	48° 28.39'W
	W12	NE-1	46° 29.63'N	48° 27.92'W
	W13	NE-2	46° 29.59'N	48° 27.24'W
	W14	NE-3	46° 29.12'N	48° 27.22'W
	W15	NE-4	46° 28.32'N	48° 27.26'W
	W16	SE-1	46° 27.52'N	48° 27.26'W
	W17	SE-2	46° 27.06'N	48° 27.34'W
	W18	SE-3	46° 27.12'N	48° 27.93'W
	W19	SE-4	46° 27.25'N	48° 28.81'W
	W20	SW-1	46° 27.34'N	48° 29.43'W
	W21	SW-2	46° 27.47'N	48° 30.25'W
	W22	SW-3	46° 27.88'N	48° 30.15'W
	W23	SW-4	46° 28.58'N	48° 29.92'W
	W24	NW-1	46° 29.13'N	48° 29.74'W

2.0 SCOPE AND REPORT STRUCTURE

This document, *Terra Nova Environmental Effects Monitoring Program 2010 (Volume 1)*, provides summary results, analysis and interpretation for the Terra Nova 2010 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 2010.

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 2010 (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
B-C	Bray-Curtis
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCME	Canadian Council of Ministers of the Environment
CI	Confidence Interval
C-NLOPB	Canada Newfoundland and Labrador Offshore Petroleum Board
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
GSI	Gonado-somatic Index
HSI	Hepato-somatic Index
IC50	(50% inhibitory concentration); molar concentration of an agonist which produces 50% of the maximum possible inhibitory response to that agonist
MFO	Mixed Function Oxygenase
MODU	Mobile Offshore Drilling Unit
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

Acronym	Meaning
RM	Repeated-measures
SD	Significant Differencd
SE	South East
SW	South West
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
UCM	Unresolved Complex Mixture
USEPA	United States Environmental Protection Agency

4.0 PROJECT-RELATED ACTIVITIES AND DISCHARGES

A number of site development activities occurred between 1997, when baseline field collection took place, and October 2010, when the collections for the seventh sampling year of the EEM program were performed. These activities were related to site development and operation, as described in the following sections[6].

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 (MODUs) *Glomar Grand Banks* and *Henry Goodrich*. Each template was piled into the seabed using a drilled piling technique.

[6] Please note that the statistics present within this section pertain only to those operational activities that occurred prior to and including October 2010, when EEM sampling was performed. The discharge statistics do not reflect the production and drilling activities conducted beyond this period.

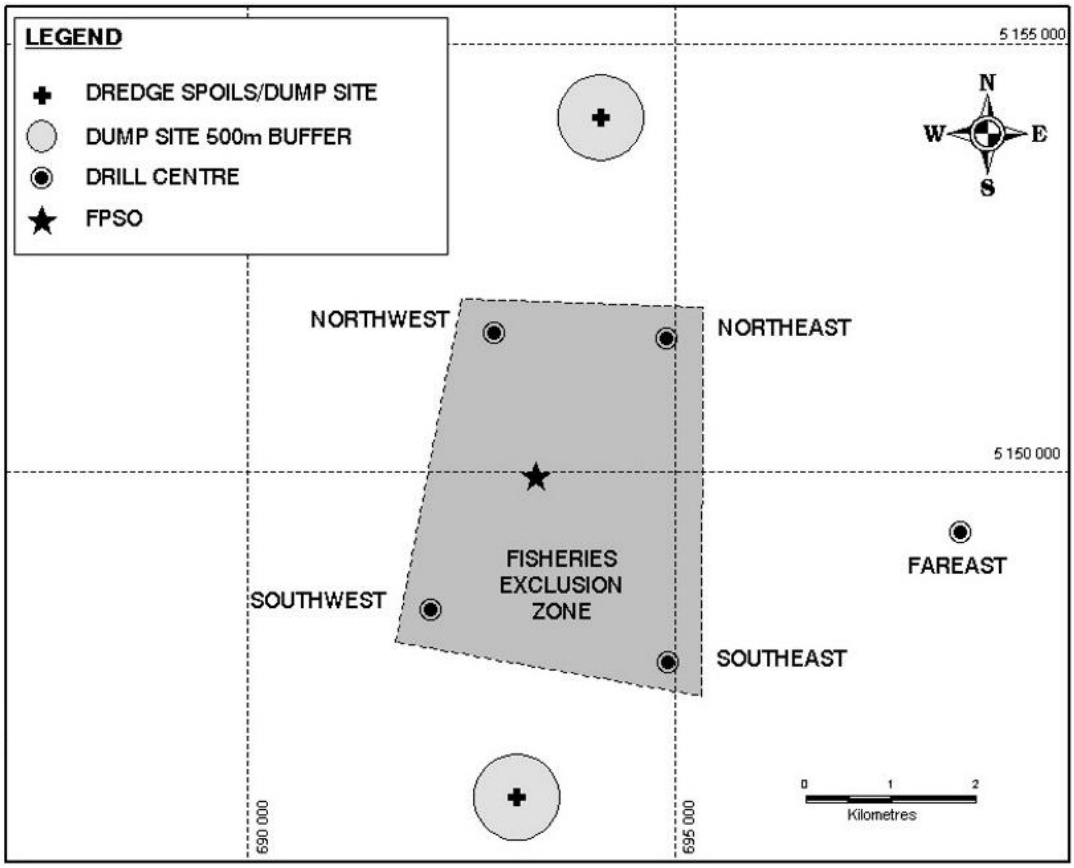


Figure 4-1 Drill Centre Locations and Dump Sites for Dredge Spoils

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 since 2008 have been 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.

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 November 2009, 35 distinct wellbores and sidetracks have been drilled within the field. Since first oil in 2002, 29 wells in the NW, NE, SW and SE drill centres have been used for production activities. Of these 29 wells, 15 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 muds;
2. synthetic-based muds; and
3. water-based completion fluid.

Water-based muds are used during the first two hole sections (conductor and surface) of each well. Synthetic-based 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 MUD DISCHARGES

Water-based muds are 90% water, the remaining 10% is comprised of barite, gel, caustic soda and lime. Cuttings generated using water-based muds are returned to the seafloor and then transferred out of the drill centre using the cuttings transfer

system. No drilling activities were conducted using water-based muds during the period of September 2008 to October 2010.

From the beginning of drilling to October 2010, Suncor reported cumulative water-based discharges of 54,622 m^3. Of these, 18,471 m^3 were discharged at the SW drill centre, 10,511 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 MUD DISCHARGES

Synthetic-based muds were used to facilitate the drilling of a single well during May and June of 2009. The composition of synthetic-based 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 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 2009 with synthetic-based muds was drilling out of the NE drill centre (see Table 4-1 for details). No other synthetic-based mud drilling activities were conducted in the Terra Nova field during the period of September 2008 to October 2010.

Table 4-1 PureDrill IA35-LV on Cuttings Discharged from September 2008 to October 2010

Year	Month	Well	Drill Centre	Discharge to Sea		
				PureDrill Volume (m^3)	PureDrill Weight (tonne)	Cuttings Weight (tonne)
2009	May	G-90 4z (F5)	NE	58.58	48.33	720.09
2009	June	G-90 4z (F5)	NE	49.36	40.72	456.89
September 2008 to October 2010 Total				108	89	1,177

Drill cuttings from the synthetic-based 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 April to June 2009, Suncor reported cumulative synthetic-based mud-on-cuttings discharges of 89 tonnes, all of which were discharged at the NE drill centre. Since the beginning of drilling to October 2010, Suncor reported cumulative synthetic-based mud-on-cuttings discharges of 5,515 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, 469 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.

A single well was completed with water-based completion fluids in June and July of 2009. Re-completion operations were conducted on the same well during October and November of the same year. No other completion operations were conducted in the Terra Nova field during the period of September 2008 to October 2010.

The single well completed during 2009 was located in the NE drill centre (see Table 4-2 for details).

Table 4-2 Discharges of Water-based Completion Fluid from September 2008 to October 2010

Year	Period	Well	Drill Centre	Discharges To Sea Fluid Volume (m^3)
2009	July	G-90 4Z (F5)	NE	862.0
2009	November	G-90 4Z (F5)	NE	569.5
September 2008 to October 2010 Total				1,431.5

From April to November 2009, Suncor reported cumulative water-based completion fluid discharges of 1,432 m3, all of which were discharged at the NE drill centre. From the beginning of drilling to October 2010, Suncor reported cumulative water-based completion fluid discharges of 43,485 m3: 11,844 m3 were discharged at the SW drill centre, 24,280 m3 were discharged at the NE drill centre, 2,636 m3 were discharged at the SE drill centre and 4,725 m3 were discharged at the NW drill centre.

4.3 PRODUCED WATER

The FPSO arrived at the Terra Nova oil field on August 4, 2001. Start-up of oil production occurred on January 20, 2002, with the opening of the HPE5 well from the SW drill centre at 1720 hours. Production was shut-down six times between September 2008 and October 2010. Shut-down periods are listed in Table 4-3.

Table 4-3 Production Shut-Down Periods from September 2008 to October 2010

Year	Shut-Down Interval
2008	September 19-20
	October 15 -17
2009	June 22 - 29
	August 2-4
	September 18 – October 5
2010	July 11 – August 1

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 September 2008 to October 2010 are provided in Table 4-4.

The compliance limits associated with the discharge of produced water from the Terra Nova FPSO were:

- A 30-day volume weighted average not to exceed 30 mg/L of oil–in-water; and
- A 24-hour arithmetic average not to exceed 60 mg/L of oil–in-water.

Suncor did not exceed its produced water compliance limits during the period from September 2008 to October 2010.

Table 4-4 Produced Water Discharges from September 2008 to October 2010

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
September 2008	24.6	190,616
October 2008	24.2	368,275
November 2008	24.2	190,616
December 2008	18.7	226,692
January 2009	17.7	306,042
February 2009	17.3	426,962
March 2009	16.7	406,057
April 2009	12.9	413,601
May 2009	10.7	494,897
June 2009	15.5	431,056
July 2009	12.7	488,811
August 2009	12.4	340,240
September 2009	11.7	492,087
October 2009	14.8	390,051
November 2009	12.5	286,019
December 2009	18.5	316,056
January 2010	21.1	564,074
February 2010	19.0	534,730
March 2010	19.3	588,071
April 2010	20.6	479,293
May 2010	18.0	561,223
June 2010	16.6	539,074
July 2010	15.2	595,766
August 2010	15.7	577,567
September 2010	16.2	175,649
October 2010	18.6	502,016

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 C-NLOPB separately for the drilling program on the *Henry Goodrich* and the production on the FPSO.

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

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

Bilge water for the *Henry Goodrich* passes through the oily water separator system before discharge to the marine environment. The total volume of bilge water discharged for the *Henry Goodrich* in the Terra Nova field from April to July and October to November 2009 was 206 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 September 2008 to October 2010.

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 between September 2008 and October 2010 was 18,995 m^3. During this period, there was a single exceedance of the 15 ppm oil-in-water compliance limit on April 11, 2010.

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 FIELD COLLECTION

The sediment component of the 2010 EEM program was conducted from October 14 to 23, 2010, using the offshore supply vessel *Maersk Gabarus*. 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). Sediment collection stations for the 2010 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 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

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 samples collected for physical and chemical analysis, as well as for archive, were a composite from the top 3 cm of all three cores (Figure 5-3). These were stored in pre-labelled 250-mL glass jars at -20°C. Sediment samples collected for toxicity were collected from the top 7.5 cm of one core and stored in the dark at 4°C in a 4-L high-density food-grade polyethylene bucket with an O-ring seal (amphipod toxicity) and a sterile 200 mL Whirl-Pak (bacterial luminescence; Microtox). Sediment samples for benthic community structure analysis were collected from the top 15 cm of two cores and stored in two separate 11-L pails. These samples were preserved with approximately 1 L of 10% buffered formalin.

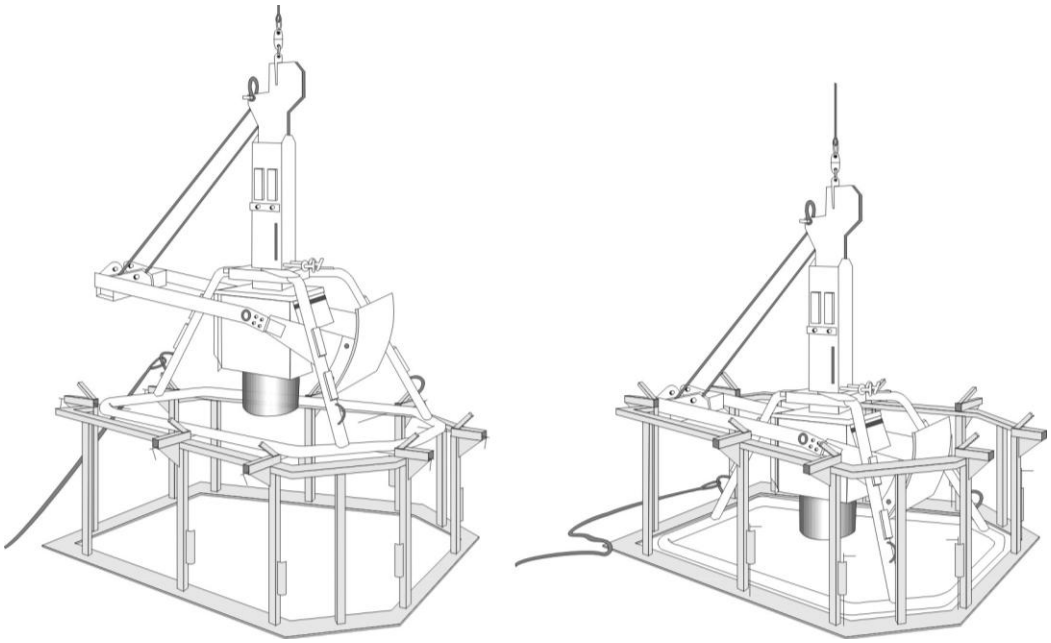
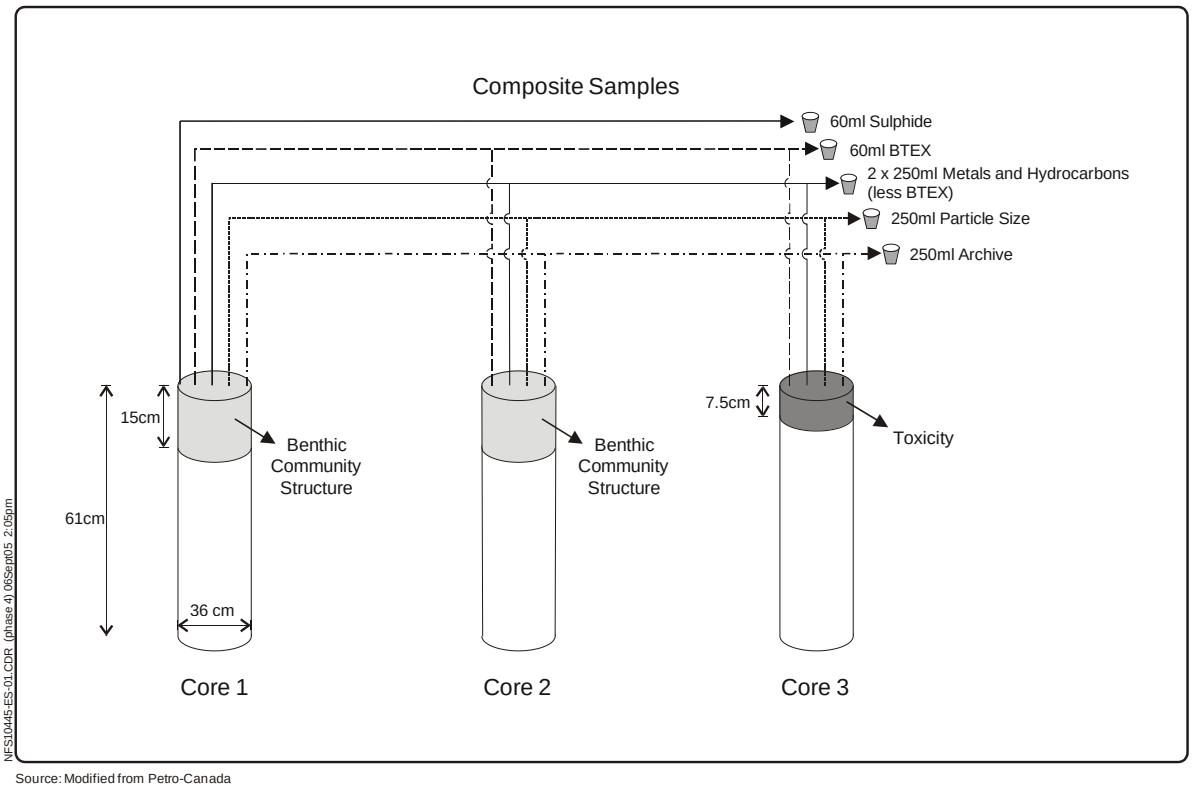


Figure 5-1 Sediment Corer Diagram

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 Maxxam Analytics were collected for stations 3(SW), 21(NW) and 24(FE). 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 6(SE), 11(SE), 21(NW), 41(FEZ) and 51(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.

5.2 LABORATORY ANALYSIS

5.2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Sediment samples were processed for particle size, hydrocarbons and metals (Tables 5-2 and 5-3). Particle size analysis was conducted by Stantec Consulting Ltd. in St. John's, Newfoundland and Labrador. Hydrocarbons and metals 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 Analytes (1997 to 2010)

Variable	Method	Laboratory Detection Limit							Units
		1997	2000 &2001	2002	2004	2006	2008	2010	
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[*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

Variable	Method	Laboratory Detection Limit							Units
		1997	2000 &2001	2002	2004	2006	2008	2010	
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
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	CVAA	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
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
Sulphur	LECO	NA	NA	0.03	0.02	0.002	0.01	0.03	%(w)
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 by Maxxam Analytics 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.

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 like diesel will be detected. The >C_{21}-C_{32} range is where lubricating oils (i.e., motor oil and grease), crude oil and, in some cases, bunker C oil, would be detected. Total petroleum hydrocarbons (TPHs) 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 (UCM). 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 UCM 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.

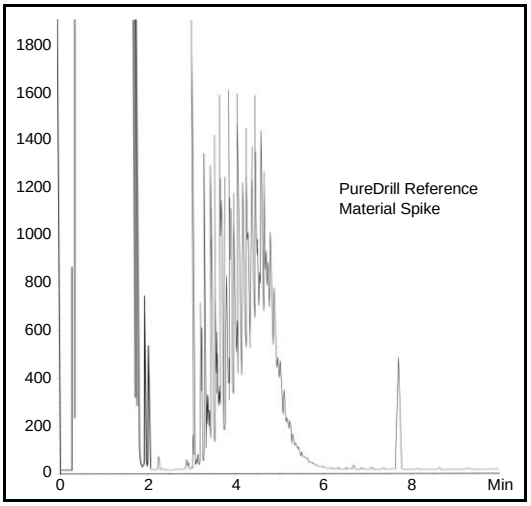


Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.2.2 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 2002, 2004, 2006, 2008 and 2010 was conducted as outlined in Environment Canada's 2002 Reference Method. Data from the 1997, 2000 and 2001 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). All samples for the amphipod test were initially tested within six weeks of sample collection. However, due to a failure during the quality control check, three samples (36(FEZ), 48(FEZ) and 50(FEZ)) needed to be retested outside the recommended six week storage time.

5.2.2.1 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 TOXCALC computer program (Tidepool Scientific Software 1994). 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[7] 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

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

2. the IC50s for the test sediment and reference sediment or negative control sediment differ significantly.

There are some limitations for calculations of dry weights using the Microtox computer program (Microbics Corporation 1997). 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 dose-response relationship (hormetic response[8]). When this occurs, wet weights IC50s are calculated by hand using probit graphs.

5.2.3 BENTHIC COMMUNITY STRUCTURE

All 2010 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 ranging from 97 to 99% were achieved (i.e., the first sorter recovered 97 to 99% of the organisms recovered by both sorters combined). Wet weight biomass (g/sample) was estimated

[8] 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).

by weighing animals to the nearest milligram at the time of sorting after blotting to remove surface water. None of the samples were sub-sampled.

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

Benthic invertebrate samples collected in 2001 and 2002 were processed (sieved and identified) by Pat Stewart of Envirosphere Ltd. Identification of invertebrates was performed by Pat Stewart of Envirosphere Ltd in 2000. Arenicola Marine Limited identified invertebrates in 1997 and sieved and identified samples in 2004, 2006, 2008 and 2010. 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).

5.3 DATA ANALYSIS

5.3.1 GENERAL APPROACH

Data analyses addressed two general questions:

1. Were spatial distributions and temporal changes in sediment quality variables indicative of effects from project activities?

This is the attenuation with distance from the drill centres hypothesis, a regression approach. The *Y* (predictor) variables analyzed were analyte concentrations, while the *X* (response) variables were distances from the drill centres.

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

This is the traditional Sediment Quality Triad correlation approach (Green et al. 1993; also see Section 1). However, it could also be considered a regression approach if major constituents of drill muds rather than distance were used as *X*.

Statistical significance was defined using the standard α level ($p \leq 0.05$). However, results emphasized in tables and interpretation were:

1. results significant at $p \leq 0.01$ and especially $p \leq 0.001$;
2. "strong" correlations (i.e., $|r$ or $r_s| \geq 0.5$) with some predictive or explanatory value; and
3. "large" (typically more than 2-fold) differences over space or time.

5.3.1.1 Analysis of 2010 Data

For the 2010 data, bivariate Spearman rank correlations (r_s) were calculated among *Y* variables within each Triad "leg" (physical/chemical characteristics, toxicity test responses, benthic community variables). Second, correlations between *Y* variables and major constituents of drill muds were calculated and tested. Primary constituents tested were $>C_{10}$-C_{21} hydrocarbons (major constituents of synthetic-based drill muds) and barium (a major constituent of water-based and synthetic-based drill muds). Third, regression relationships between *Y* variables and distances from drill centres were tested. Three distance measures (*X*) were used:

- distance from the nearest active drill centre (Min *d*);
- distance from the nearest of the four drill centres (NE, NW, SE, SW) surrounding the FEZ (FEZ *d*); and
- distance from the FE drill centre (FE *d*).

The distance regressions were based on rank-transformed *Y* and *X* values, since parametric models based on log-transformed values were not always appropriate. Parametric log-log bivariate and threshold ("hockey-stick") distance regression models with Min *d* as the distance (*X*) variable were then tested on variables strongly correlated with distance. Appendix B-4 describes the hockey-stick models and other basic analyses in more detail. Modifications addressing specific issues are provided in Sections 5.3.2 to 5.3.5.

5.3.1.2 Comparison Among Years

Comparisons among years were divided into two broad components. The first component involved non-parametric comparison of distance gradients and qualitative comparison of overall *Y* variable values among years. These comparisons were based on all stations sampled in each year.

For each sample year, Spearman rank correlations (r_s) were calculated between sediment quality variables and distance from the nearest active drill centre (Min *d*).

In 2000, the NE and SW drill centres were active. In 2001, all four FEZ drill centres were active. From 2002 to 2010, all four FEZ drill centres and the FE drill centre were active[9]. The NE and SW drill centres were considered "active" in 1997 (baseline) to allow calculation of natural distance gradients for comparison to gradients.

Annual distributions of individual *Y* variable values and summary statistics (median, 20th and 80th percentiles) were plotted against year to assess temporal changes over the entire study area. Percentiles were calculated using the non-parametric method provided in Gilbert (1987, p. 141) because distributions of many *Y* variables were not normal or log-normal.

The second component of the analysis consisted of parametric comparisons of distance gradients among EEM years using the repeated-measures regression model described in Appendix B-4 and the subset of 48 stations (repeated-measures stations) sampled in each EEM year. The repeated-measures regression model described in Appendix B-4 requires that the same stations be re-sampled over time. Therefore, repeated-measures analyses were restricted to comparisons among EEM years based on the 48 stations sampled every EEM year[10]. This approach did not allow parametric comparisons of EEM distance gradients to baseline gradients, but that issue was addressed by comparisons of non-parametric distance correlations among years.

EEM stations 30(FE) and 31(FE), located at 0.14 and 0.37 km from the FE drill centre, respectively, were excluded from parametric repeated-measures regression analyses, providing n = 46 stations for those analyses. The two excluded stations were closer to a drill centre than other stations and represented extreme (minimum) distance (*X*) values with a potentially large influence on regression results. After drilling began at the FE drill centre, values for some *Y* variables at one or both of these stations were also extreme and statistical outliers. *Y* variable values at the two stations were included in non-parametric distance correlations and also compared to values at other stations. Appendix B-4 provides further discussion of

[9] For EEM years, a drill centre was considered active if drilling had occurred at any time in the past at that drill centre, even though drilling may not have occurred there in recent years.

[10] Repeated-measures analyses for the 2000, 2001, 2002 2004 and 2006 EEM programs (Suncor Energy 2001, 2002, 2003, 2005 2007) focused on the 33 stations sampled in all years, including 1997. However, those analyses excluded 15 stations sampled in every EEM year but not sampled in 1997, and could not be conducted on variables that were not comparable between 1997 and EEM years.

the effects of including versus excluding the two stations from repeated-measures regression analyses.

Multiple regression slopes for *Y* variables versus FEZ *d* and FE *d* were calculated for each EEM year based on the stations included in repeated-measures analyses to summarize changes in distance gradients over time. These slopes adjusted the effects of each distance variable for the effects of the other distance variable (see Appendix B-4 for further details).

5.3.2 PHYSICAL AND CHEMICAL CHARACTERISTICS

5.3.2.1 Variables

Sediment physical and chemical characteristics were divided into four subgroups of variables:

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

As noted in Section 5.3.1, >C_{10}-C_{21} hydrocarbons are major constituents of synthetic-based drilling muds and barium is a major constituent of water-based drilling muds and synthetic-based 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.

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 potentials in sediments.

5.3.2.2 Statistical Analysis of Physical and Chemical Variables

Statistical analysis of sediment physical and chemical variables generally followed the basic analyses outlined in Section 5.3.1. Additions and modifications are detailed in the Section that follows.

Analysis of 2010 Data

Bivariate rank correlations within and among the subgroups of variables were calculated primarily to determine if these subgroups represented subsets of related variables. Principal Components Analysis (PCA[11]) was used to develop multivariate summary measures of metals concentrations (Metals PC).

In 2010 and past years, seven metals were included in the metals PCA. Aluminum, iron, lead, manganese, strontium and vanadium were detected in all samples in every year. Chromium was detected in all samples in every year except 2006, when it was detected in 51 of 53 samples. PCA was used to assess relationships among concentrations of these seven metals and to derive two summary measures (Metals PC1 and PC2). The two chromium concentrations less than laboratory detection limit were set to ½ the detection limit. The metals PCA was based on $\log_{10}$-transformed concentrations. All 416 samples collected from 1997 to 2010 were included, so that the Metals PCs could be used for a broad range of analyses of various subsets of the data.

For 2010, bivariate rank correlations were calculated between values (scores) for the Metals PCs and concentrations of zinc and uranium. The objective was to determine if those two metals “behaved” in the same manner as the seven metals included in

[11] PCA identifies the major axis of covariance (PC1) among the original variables, which is also the major axis of variance among samples. The minor axis (PC2) is the axis accounting for the largest amount of remaining covariance among variables and variance among samples that is independent of (uncorrelated with) PC1. Positions of samples along the PC axes can be expressed as scores (weighted averages of original variable values), and the scores used for further analyses. The scores are standardized, so that the overall mean is 0 with SD = 1. The metals and other PCAs in this report were based on correlation rather than covariance matrices.

the PCA. Uranium was detected in all samples collected from 1997 to 2010, but at concentrations at or barely above the laboratory detection limit (i.e., variance was minimal). Zinc was detected in all samples prior to 2004, when a lower detection limit (2 mg/kg) was used, but was only detected in 131 of 211 samples from 2004 to 2010, when a higher detection limit (5 mg/kg) was used.

Rank-transformed sediment physical and chemical variable (*Y*) values were regressed on rank-transformed distances from drill centres following methods in Appendix B-4. Parametric log-log bivariate and hockey-stick distance models were tested for $>C_{10}$-C_{21} hydrocarbons and barium. Distances and $>C_{10}$-C_{21} hydrocarbon and barium concentrations were log-transformed for the parametric regressions.

Comparison Among Years

$>C_{10}$-C_{21} hydrocarbons, barium, fines, gravel, total organic carbon, Metals PC1 and PC2, sulphur, sulphide, ammonia and redox were compared among years following general methods provided in Section 5.3.1.2 (i.e., qualitative/non-parametric analyses of all years followed by quantitative parametric repeated-measures regression analyses of EEM years). Repeated-measures regression analyses excluded stations 30(FE) and 31(FE), located 0.14 km and 0.37 km from the FE drill centre, respectively, which were sample in every EEM year but were often outliers that did not fit the distance regressions for other stations. Multiple regression distance slopes for 1997 were also calculated based on the 31 EEM repeated-measures stations (again, with stations 30(FE) and 31(FE) excluded) sampled in that year for qualitative comparison to regression slopes for EEM years. Parametric threshold hockey-stick distance models for $>C_{10}$-C_{21} hydrocarbons and barium were also compared among years using all stations sampled in each year. Distances, barium, $>C_{10}$-C_{21} hydrocarbons, fines, gravel, total organic carbon (TOC), ammonia and redox were log-transformed for repeated-measures and hockey-stick regression analyses.

$>C_{10}$-C_{21} hydrocarbons were not detected in 1997 when a higher detection limit (15 mg/kg) was used than in EEM years (0.3 mg/kg). Therefore, only data from EEM years were used for analyses of these hydrocarbons. Prior to 2006, detection limits for $>C_{10}$-C_{21} hydrocarbons were reported as 0.25 mg/kg. From 2006 to 2010, detection limits were changed to 0.3 mg/kg to better reflect the precision of the analytical methods (which did not change). Therefore, all $>C_{10}$-C_{21} hydrocarbon concentrations less than detection limit in EEM years were set at 0.15 mg/kg

(½ the recent detection limit). The one detectable concentration between 0.25 and 0.3 mg/kg (0.298 mg/kg in 2001) was also set at 0.15 mg/kg.

Sulphur has been measured since 2001, but laboratory detection limits have varied over time (Table 5-3). Therefore, parametric repeated-measures analyses of sulphur were not conducted. Rank correlations between sulphur and distance from the nearest active drill centre were based on the actual values reported in each year, with values less than detection limit for that year treated as tied for the lowest rank. For plotting of annual distributions and calculation of summary statistics, all sulphur concentrations less than the highest detection limit of 0.03% (from 2001 and 2002) were set at ½ of that detection limit, even if they were greater than lower detection limits achieved from 2004 to 2010 (0.002 to 0.02%).

Sulphide has been measured since 2001. However, prior to 2006, detection limits varied among years and were higher than in more recent years. Therefore, analyses were restricted to 2006, 2008 and 2010, when detection limits were consistently 0.2 mg/kg. Repeated-measures regression analyses were not conducted on sulphide because of the high frequency of values less than detection limit in 2010. Values less than the detection limit were set at ½ the detection limit for plotting purposes.

Ammonia was not measured in 1997 and 2000, so analyses were restricted to 2001 and subsequent years. Two ammonia concentrations less than the laboratory detection limit in 2001 were set at ½ the laboratory detection limit. Redox was only measured at a subset of 29 stations in 1997, so analyses were restricted to EEM years.

5.3.3 TOXICITY

Amphipod survival and Microtox IC50s were analyzed using the basic methods provided in Section 5.3.1. Distance regressions were calculated based on rank-transformed amphipod survival, IC50s and distance values.

Amphipod survival was not compared among years because survival has been uniformly high and most samples were non-toxic.

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 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 ½ the highest concentration tested (197,000 mg wet/L) from 2004 to 2010[12]. Samples with IC50s less than 50,000 mg wet/L were considered "toxic" in this report, since most samples with IC50s less than 50,000 mg wet/L would be 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 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.

5.3.4 BENTHIC COMMUNITY STRUCTURE

Invertebrates in samples from the 54 stations sampled in 1997 (baseline) and from 11 of 49 stations sampled in 2000 were recovered using the Wash method. Invertebrates from 38 stations sampled in 2000 and all stations sampled from 2001 to 2010 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, most analyses were restricted to Elutriate samples.

Analyses of invertebrate community data followed procedures used in past Terra Nova EEM program reports. Taxon abundances from the two replicates within each station were summed to provide station totals. Lower-level taxa (genera or species) were pooled within families to maintain consistency over time and between the two taxonomists used in the monitoring programs. Lower-level taxa were first

[12] 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).

assigned to families by the taxonomists based primarily on Gosner (1971), a general East Coast of Canada reference, and occasionally more recent online sources (e.g., MarBEF (2004) and WoRMS (2009)). Family assignments were then updated by the data analyst using Kozloff (1987), a general West Coast of Canada reference**,** to reflect more recent taxonomy. Kozloff (1987) includes most genera, if not species, collected in Terra Nova samples, and family assignments from Kozloff (1987) and Gosner (1971) usually agreed.

Meiofauna, including nematodes, nemerteans, oligochaetes, archiannelid polychaetes (mostly Family Protodrilidae), ostracods and copepods, were excluded from calculation of all variables except biomass. These small organisms are poorly recovered with the 0.5-mm sieve used but were not removed before all recovered invertebrates in samples were weighed to estimate biomass. The contribution to overall biomass from these organisms is expected to be small.

5.3.4.1 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:

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

Adjusted richness values were residuals (deviations) from regressions of log *S* on log *N* for all 348 Elutriate samples from the seven EEM years. 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 2010 (*n* = 348 stations). 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 (B-C) distances were then calculated between all possible pairs of stations. The B-C distances are % differences in overall community composition since they were based on relative (%) abundances of individual taxa. The B-C distance matrix was used in NMDS to generate multivariate community composition measures (i.e., scores or positions along NMDS axes).

Abundances of the following taxa were analyzed:

1. the dominant polychaete (Polychaeta) families (Spionidae, Cirratulidae and Syllidae);
2. selected sub-dominant polychaete families (Orbiinidae, Paraonidae and Phyllodocidae);
3. the most abundant bivalve (Bivalvia) family, Tellinidae;
4. amphipods (Amphipoda), the most abundant crustaceans (Crustacea); and
5. echinoderms (Echinodermata).

These taxon abundances were examined to provide better resolution of natural and project-related effects. In other words: when natural or project-related effects on summary measures occurred, which taxa were affected? For example, changes in total abundance or community composition based on relative abundances could involve changes in abundances of one or a few dominants, or changes in abundances (often in opposite directions) of many taxa. Amphipods and echinoderms are also considered sensitive, but were too rare to have much influence on summary measures such as total abundance or NMDS community composition measures. The list of sub-dominant taxa analyzed was biased towards taxa showing the strongest responses to natural and project-related factors.

5.3.4.2 Statistical Analysis

Analysis of 2010 Data

Summary statistics for, and rank correlations among, benthic community variables were calculated. Correlations between the community variables and other sediment variables (physical and chemical characteristics, amphipod survival, Microtox IC50s) were also calculated. Rank-rank regressions were calculated between community variables and distance variables (see Appendix B-4 for details).

Comparison Among Years

Comparisons of community variables among years followed the general approach in Section 5.3.1.2 (i.e., non-parametric/qualitative summary of annual distance correlations, distributions of individual values, medians, and 20th and 80th percentiles followed by parametric repeated-measures regression analyses). Only the first step was conducted for dominant and sub-dominant taxon abundances. Analyses of all variables were generally restricted to EEM samples processed using the Elutriate recovery method.

Repeated-measures regression analyses were restricted to stations sampled in every year from 2001 to 2010 and processed using the Elutriate recovery method. The repeated-measures regression analyses was conducted with stations 30(FE) and 31(FE) excluded for reasons discussed in Section 5.3.2.2. Past analyses have included the Elutriate samples from 2000, but that restricted analyses to 37 rather than 46 stations. Suncor Energy (2002) summarizes differences between 2000 and 2001, which were not tested in this report. However, this report provides multiple regression slopes for distances from the FEZ and FE drill centres for 2000 for qualitative comparison to distance slopes from 2001 to 2010.

For the repeated-measures analyses, distances and total abundance, biomass and richness were log-transformed. The original adjusted richness values, or residuals from the log-log S-N regression, were analyzed. The original NMDS axis scores (i.e., NMDS1, NMDS2) were also analyzed in the repeated-measures analysis.

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 identify a further subset of variables that included only those 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.

5.4 RESULTS

5.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

5.4.1.1 Overview

Summary statistics for sediment physical and chemical characteristics from 1997 to 2010 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 5-3 reports all measured metals and organic compounds in each year. Raw data for 2010 are also provided in Appendix B-2.

$>C_{10}$-C_{21} hydrocarbon concentrations have generally increased since 2000 but have decreased in recent years from levels observed in 2004 and 2006. Baseline (1997) data cannot be compared to subsequent years because detection limits in 1997 (15 mg/kg) were higher than detection limits in other years (0.3 mg/kg). Median $>C_{10}$-C_{21} hydrocarbon concentrations across all stations 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 (Appendix B-2). The maximum $>C_{10}$-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 2010, as in previous years, concentrations decreased rapidly with distance from drill centres (Figure 5-6). All chromatograms for stations with hydrocarbon concentrations at or above laboratory detection limit (46 of 53 stations in 2010) showed a UCM in the range of PureDrill IA35-LV (Appendix B-2).

In 2010 and previous years, concentrations of $>C_{21}$-C_{32} hydrocarbons above detection limit were recorded at many stations where $>C_{10}$-C_{21} hydrocarbon concentrations were high, but it has been established previously that this is because of 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, 2005 pers. comm.; Maxxam Analytics, 2005 pers. comm.). Based on interpretation of chromatograms for 2011, $>C_{21}$-C_{32} hydrocarbons were present only in trace amounts (Appendix B-2; J. Kiceniuk, 2011 pers. comm.).

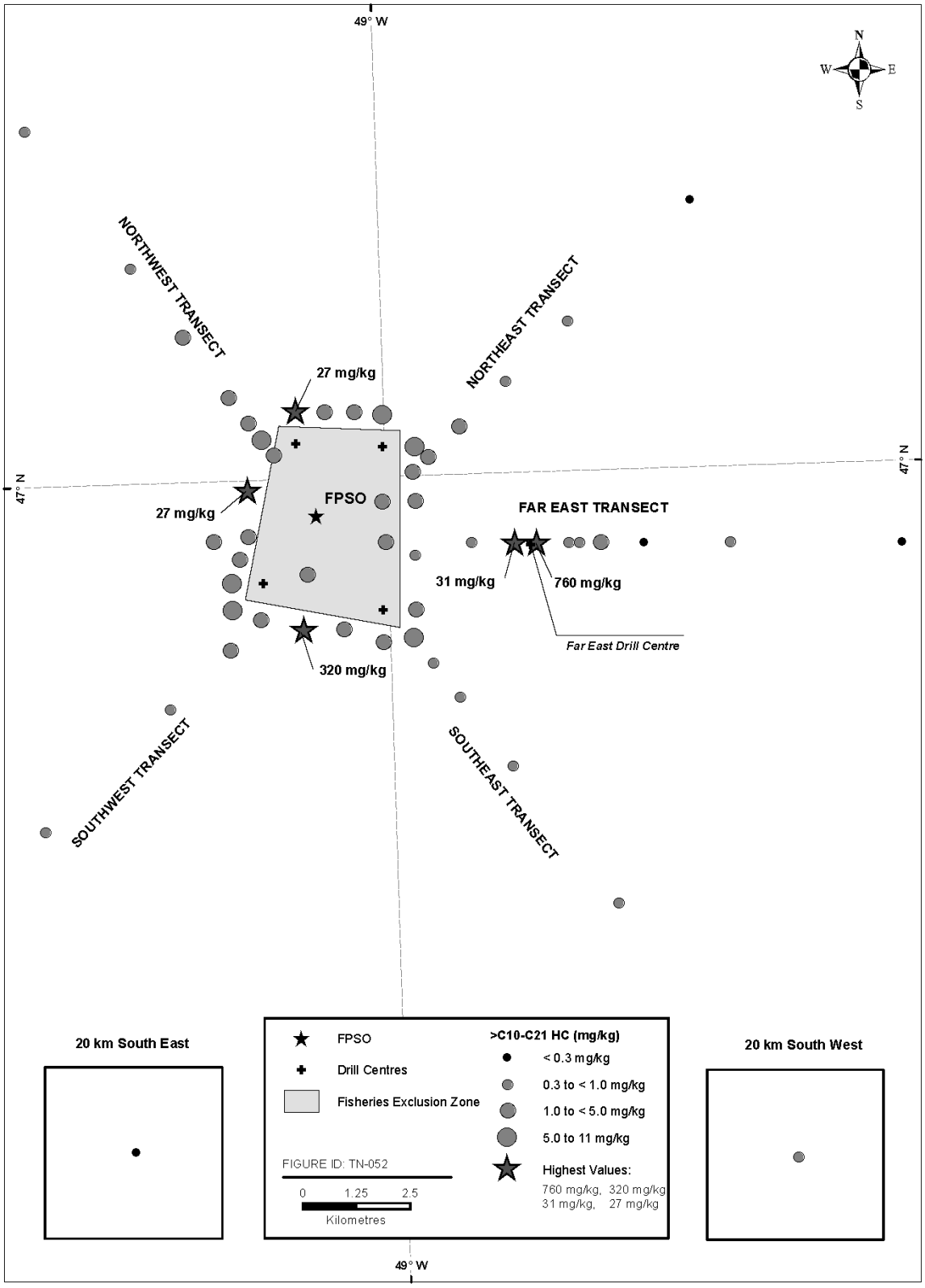


Figure 5-6 Spatial Distribution of >C_{10}-C_{21} Hydrocarbons (2010)

Median barium concentrations increased from 120 mg/kg in baseline (1997) to median levels ranging from 130 to 170 mg/kg from 2000 to 2010 (Appendix B-2). Maximum levels from 2002 to 2010 (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 5-7). For interpretation of Figure 5-7 and other results for barium, concentrations less than 190 mg/kg can be considered within the background range and below the 90th percentile of baseline concentrations. Concentrations between 190 and 280 mg/kg can be considered elevated above background, although still below the maximum concentration (280 mg/kg) observed in 1997. Concentrations above 280 mg/kg can be considered outside the background range and clear evidence of contamination from drill cuttings discharges.

In 2010, and for both barium and $>C_{10}$-C_{21} hydrocarbons, directional gradients, with concentrations higher in one or more directions from sources, were not strong relative to distance gradients (Figures 5-6 and 5-7).

In 2010, PAHs were detected at low levels at six stations: 10(SE), 16(NE), 19(NW), 20(NW), 28(FE) and 44(FEZ). Dibenz[*a,h*]anthracene was detected at all six stations; indeno[1,2,3-*cd*]pyrene was detected at three stations; phenanthrene was detected at two stations; benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*g,h,i*]perylene, chrysene and perylene were detected at one station. All nine PAHs were detected at station 19(NW); dibenzo[*a,h*]anthracene was the only PAH detected at stations 16(NE), 28(FE) and 44(FEZ).

A more detailed analysis of physical and chemical characteristics follows.

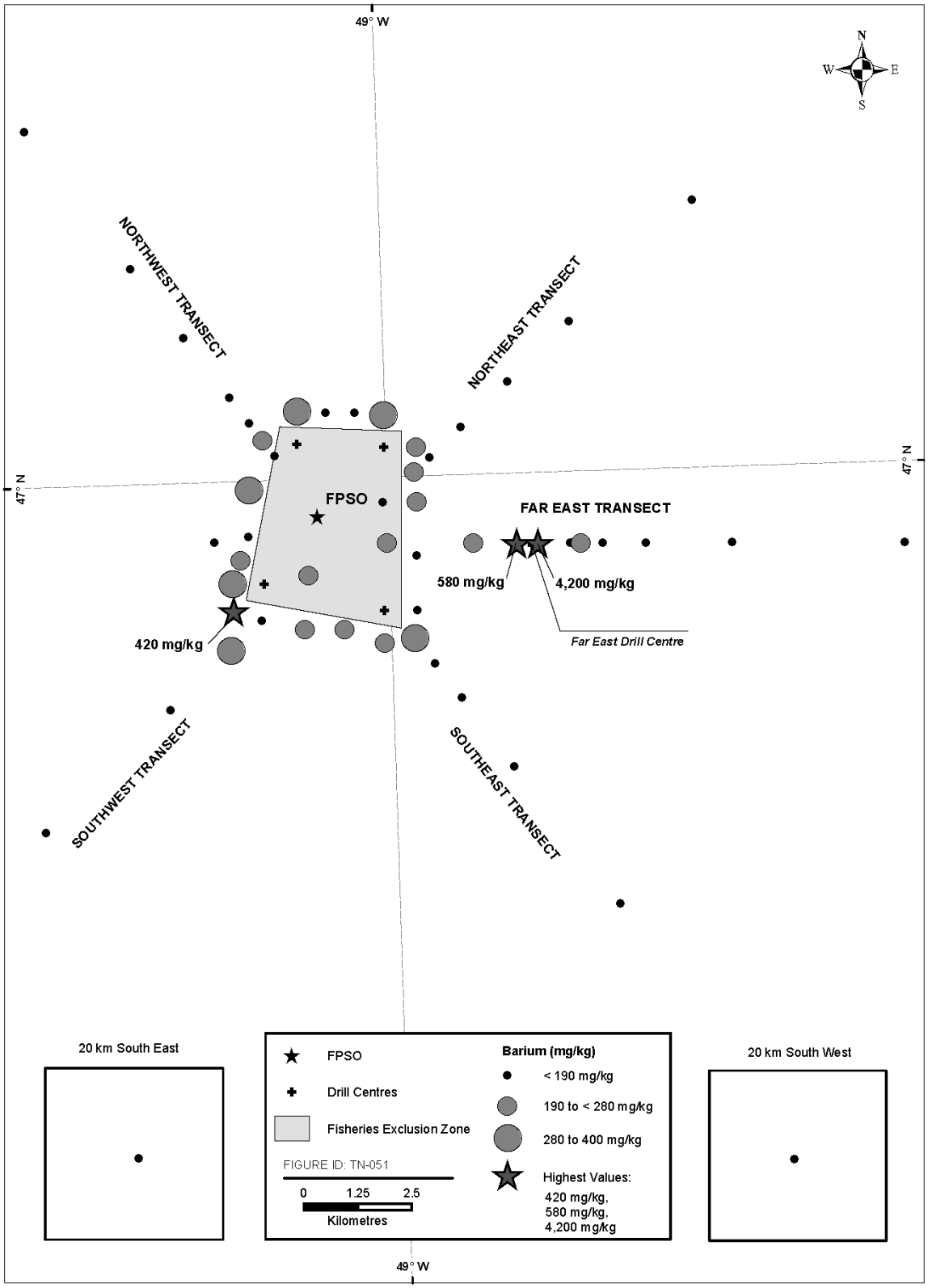


Figure 5-7 Spatial Distribution of Barium (2010)

5.4.1.2 Analysis of 2010 Data

Hydrocarbons and Barium

Concentrations of $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons and barium in 2010 sediment samples were positively correlated, with all bivariate rank correlations (r_s) significant at $p < 0.001$ (Table 5-4). The strong correlation between $>C_{21}$-C_{32} hydrocarbons and $>C_{10}$-C_{21} hydrocarbons supports the argument that $>C_{21}$-C_{32} hydrocarbon concentrations resulted from a laboratory artefact (see Section 5.4.1). Because the $>C_{21}$-C_{32} hydrocarbon variable was largely redundant with the $>C_{10}$-C_{21} hydrocarbon variable, $>C_{21}$-C_{32} hydrocarbons were not considered in further analyses.

Table 5-4 Spearman Rank Correlations (r_s) Between $>C_{10}$-C_{21} Hydrocarbons, $>C_{21}$-C_{32} Hydrocarbons and Barium (2010)

	$>C_{10}$-C_{21} hydrocarbons	**$>C_{21}$-C_{32} hydrocarbons**
$>C_{21}$-C_{32} hydrocarbons	0.728***	
Barium	0.816***	0.613***

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

Other Sediment Physical and Chemical Characteristics

Sediments were predominantly sand, with mean and median sand content approximately 90% for the 53 samples collected in 2010 (Appendix B-2; Figure 5-8). Fines content was low (0.5 to 2.7%; median = 1.0%). Gravel content varied widely, from 0% to approximately 40% (Appendix B-2; Figure 5-8)[13].

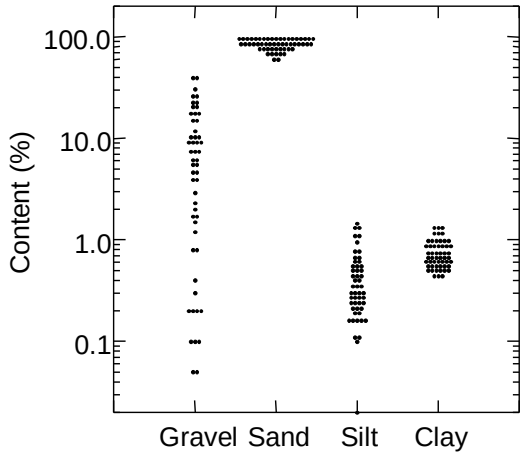


Figure 5-8 Distribution of Values for Four Particle Size Categories (2010)

[13] The two gravel content values of 0% were set at 0.05% (½ the next lowest value of 0.1%) in Figure 5-8 and other figures so they could be plotted on a logarithmic scale.

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

Table 5-5 Spearman Rank Correlations (r_s) Among Sediment Particle Size Categories and Total Organic Carbon Content (2010)

	% fines	% sand	% gravel
% sand	–0.295*		
% gravel	0.237	–0.994***	
Total organic carbon	0.396**	–0.422**	0.391**

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

In 2010, fines content and gravel content were positively but not significantly correlated. Sediment organic carbon content was low, ranging from 0.4 to 3.1 g/kg (0.04 to 0.31%) (Appendix B-2). Organic carbon content was significantly positively correlated with fines and gravel content and significantly negatively correlated with sand content (Table 5-5).

Concentrations of aluminum, chromium, iron, lead, manganese, strontium and vanadium from sediment samples collected from 1997 to 2010 were positively correlated with each other and with the first Principal Component (Metals PC1) derived from those concentrations (Table 5-6). Metals PC1 accounted for 64% of the total variance and served as a summary "total metals" measure. Metals PC2 accounted for 18% of the total variance, and was positively correlated with strontium, aluminum and lead concentrations and negatively correlated with manganese and iron concentrations. Metals PC2 scores reflect differences independent of the general positive correlation among concentrations of all metals. Higher PC2 scores indicate higher strontium (and to a lesser extent, aluminum and lead) levels relative to manganese and iron levels.

Table 5-6 Correlations (r_p) Between Metal Concentrations and Principal Components Derived from those Concentrations (1997 to 2010)

Metal	Correlation (r_p) with:	
	Metals PC1	Metals PC2
Aluminum	0.81	0.38
Chromium	0.78	–0.18
Iron	0.87	–0.42
Lead	0.81	0.40
Manganese	0.75	–0.60
Strontium	0.62	0.60
Vanadium	0.93	–0.045
% variance	64.0	17.6

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, 53 in 2006, 53 in 2008, and 53 in 2010.
- PC's were retained if they explained >10% of the total variation in the data.

Concentrations of uranium and zinc, the only other metals relatively frequently detected in 2010 samples, were positively correlated with Metals PC1 (Table 5-7), despite the limited variance and presence of many values near or below laboratory detection limits. Therefore, the general tendency for metal concentrations to co-vary extended beyond the seven metals used to derive Metals PC1. Zinc concentrations were also negatively correlated with Metals PC2, suggesting that zinc concentrations were higher where manganese and iron concentrations (negatively correlated with PC2) were higher.

Table 5-7 Spearman Rank Correlations (r_s) Between Metals Principal Components and Concentrations of Uranium and Zinc (2010)

Metal	No. Values < Laboratory Detection Limit (of 53)	Correlation (r_s) with:	
		Metals PC1	Metals PC2
Uranium	0	0.673***	0.120
Zinc	8	0.599***	–0.425**

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

In 2010, all bivariate rank correlations among fines and gravel content, organic carbon, Metals PC1 and PC2, sulphur, sulphide and ammonia were positive, with 24 of the 28 correlations significant at $p \leq 0.05$ (Appendix B-4). Redox was not significantly correlated with any other variable except sulphide (r_s = –0.483).

Table 5-8 provides correlations between >C_{10}-C_{21} hydrocarbons and barium and other sediment physical and chemical characteristics for the 53 stations sampled in 2010. Except for redox, variables were positively correlated with >C_{10}-C_{21} hydrocarbons and barium.

Table 5-8 Spearman Rank Correlations (r_s) Between C_{10}-C_{21} Hydrocarbons and Barium and Other Sediment Physical and Chemical Characteristics (2010)

Variable	>C_{10}-C_{21} hydrocarbons	Barium
% fines	0.503***	0.550***
% gravel	0.246	0.428**
TOC	0.541***	0.631***
Metals PC1	0.402**	0.668***
Metals PC2	0.324*	0.465***
Sulphur	0.638***	0.592***
Sulphide	0.399**	0.515***
Ammonia	0.463***	0.517***
Redox	–0.288*	–0.276*

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

The positive and often significant correlations between other sediment variables and >C_{10}-C_{21} hydrocarbons and barium in Table 5-8 should be considered partly natural, reflecting the general tendency, also observed in baseline, for most sediment variables values to be higher near the centre of the Terra Nova development (Section 5.4.1.2).

Distance Relationships

Based on rank-rank regressions (Table 5-9), >C_{10}-C_{21} hydrocarbon and barium concentrations decreased significantly with distance from drill centres. Rank transformation reduced the influence of stations 30(FE) and 31(FE), which represent extreme values. For >C_{10}-C_{21} hydrocarbons and barium, r_s for regressions on distance from the nearest drill centre (Min *d*) were stronger than *R* for multiple regressions on distances from the FEZ and FE drill centres. Therefore, a single distance measure (Min *d*) was the best predictor of >C_{10}-C_{21} hydrocarbons and barium concentrations.

Table 5-9 Results of Rank-Rank Regressions of Selected Sediment Physical and Chemical Variables (Y) on Distance (X) Variables (2010)

***Y* variable**	**Regression on distance from nearest FEZ drill centre (FEZ *d*), and distance from FE drill centre (FE *d*)**			**Regression on distance from nearest drill centre *r* (=r_s)**
	Multiple *R*	**Partial *r***		
		***Y*-FEZ *d*/ FE *d* constant**	***Y*-FE *d*/ FEZ *d* constant**	
>C_{10}-C_{21} hydrocarbons	0.726***	–0.705***	–0.154	–0.784***
Barium	0.579***	–0.514***	–0.245	–0.686***
Fines	0.476**	–0.357**	–0.287*	–0.453***
Gravel	0.081	–0.039	–0.062	–0.055
TOC	0.477**	–0.438**	0.315*	–0.250
Metals PC1	0.307	–0.179	–0.220	–0.340*
Metals PC2	0.229	–0.109	–0.179	–0.208
Sulphur	0.451**	–0.451***	0.067	–0.418**
Sulphide	0.153	–0.120	–0.069	–0.157
Ammonia	0.278	–0.271	0.121	–0.373**
Redox	0.172	0.141	0.071	0.219

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

In parametric regression (Table 5-10), adding a threshold in a hockey-stick model of >C_{10}-C_{21} hydrocarbon concentrations versus distance to the nearest drill centre significantly (p = 0.013) reduced error variance relative to a bivariate regression (Table 5-10; the fitted line in Figure 5-9 is the hockey-stick model). The estimated threshold distance (zone of influence) for >C_{10}-C_{21} hydrocarbons was 2.8 km, with a 95% CI of 1.7 to 4.6 km. Adding a threshold also significantly (p < 0.001) reduced error variance for barium distance relationships. The estimated threshold distance for barium was 2 km, with a 95% CI of 1.5 to 2.6 km.

For both $>C_{10}$-C_{21} hydrocarbons and barium, adding a threshold distance significantly reduced error variances primarily because values for stations 30(FE) and 31(FE) were extreme outliers for bivariate linear regressions but not hockey-stick models. With stations 30(FE) and 31(FE) excluded, adding a threshold to distance models did not significantly reduce error variance for $>C_{10}$-C_{21} hydrocarbons and barium (Table 5-10). With the two stations excluded, relationships for both drilling indicators were weaker.

Table 5-10 Results of Parametric Distance Regressions for $>C_{10}$-C_{21} Hydrocarbons and Barium (2010)

Result/Estimate	$>C_{10}$-C_{21} hydrocarbons		Barium	
	All stations	**30(FE), 31(FE) excluded**	**All stations**	**30(FE), 31(FE) excluded**
r for bivariate regression	-0.714***	-0.639***	-0.686***	-0.627***
R for hockey-stick model	0.752***	0.647***	0.796***	0.649***
p for adding threshold (X_T)	0.014	0.33	<0.001	0.131
antilog *a* (blade/background *Y* value; mg/kg)	0.4	0.3	116	111
95% CI	0.21 to 0.74	0.14 to 0.73	96 to 141	92 to 136
b (slope of shaft)	–2.08	-1.32	-0.98	-0.42
95% CI	–2.81 to -1.36	-1.90 to -0.69	–1.20 to -0.72	-0.6 to -0.19
antilog X_T (threshold distance; km)	2.8	5.5	2	4.3
95 % CI	1.7 to 4.6	2.1 to 14.1	1.5 to 2.6	1.8 to 10.3

Notes - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- Bivariate regressions = regressions of concentrations (*Y*) on distance from the nearest drill centre (*X*).
- *X* variables for hockey-stick models were distance from the nearest drill centre and the threshold distance (X_T).
- All *Y* and *X* variables were log-transformed.

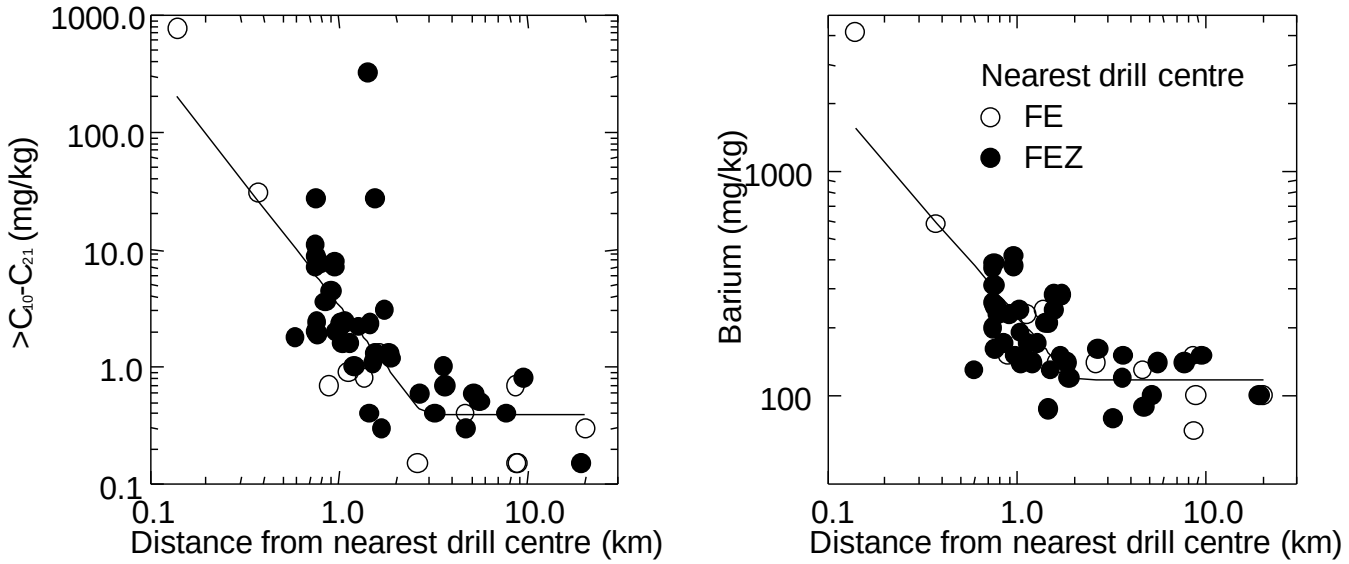


Figure 5-9 Distance Gradients for $>C_{10}$-C_{21} Hydrocarbons and Barium (2010)

As relationships weaken, threshold distances become increasingly difficult to define, while estimates of those distances usually increase, and 95% CI for those estimates widen (e.g., Table 5-10). Therefore, the threshold distance of approximately 3 km based on all stations is considered a reasonable approximation of the zone of influence for $>C_{10}$-C_{21} hydrocarbons. Within 3 km of drill centres, 31 of 39 $>C_{10}$-C_{21} hydrocarbon concentrations were greater than 1 mg/kg, whereas all 14 concentrations at stations more than 3 km from drill centres were 1 mg/kg or less.

Except for stations 30(FE) and 31(FE), $>C_{10}$-C_{21} hydrocarbon concentrations at stations nearest the FE drill centre were relatively low (Figure 5-9). Concentrations at those other stations were below 1 mg/kg except at station 27(FE), 1.6 km from the FE drill centre (concentration = 1.3. mg/kg). Thus, any effects of the FE drill centre were largely dependent on differences between elevated concentrations at stations 30(FE) and 31(FE) and the relatively low concentrations at other stations more than 0.5 km from the FE drill centre. For that reason, the effects of the FE drill centre were weak and rarely significant when stations 30(FE) and 31(FE) were excluded, or when the influence of the two stations was reduced in rank-rank regressions (e.g., as in Table 5-9). 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).

Effects of the FE drill centre on barium concentrations also depended largely on differences between elevated concentrations at stations 30(FE) and 31(FE) and lower concentrations at other stations more than 0.5 km from the FE drill centre (Figure 5-9). In 2010, FEZ distance gradients for both $>C_{10}$-C_{21} hydrocarbons and barium were stronger and more significant than FE distance gradients after the effects of stations 30(FE) and 31(FE) were reduced or removed, which was also true in other EEM years after drilling began at the FE drill centre (Section 5.4.1.2).

Except for redox, other sediment variables analyzed in distance regressions decreased with distance from the nearest drill centre and also with distance from the nearest FEZ drill centre (Table 5-9). Partial correlations with distance from the FE drill centre were generally weaker than partial correlations with distance from the FEZ drill centres and, of the two significant correlations, one was positive (organic carbon) and one was negative (fines). Any negative effects of the FE drill centre were generally limited to station 30(FE) and occasionally station 31(FE).

In 2010, fines content decreased significantly with distance from both the FEZ and FE drill centres (Table 5-9). Fines content was relatively high (2.2%) at station 30(FE), 0.14 km from the FE drill centre, but fines content was higher at station 11(SE) (2.68% fines), 0.95 km from the SE drill centre and at station 44(FEZ) (2.5% fines), 0.95 km from the SW drill centre (Figure 5-10). Fines content varied widely among stations within 2 km of drill centres and was low at more remote stations.

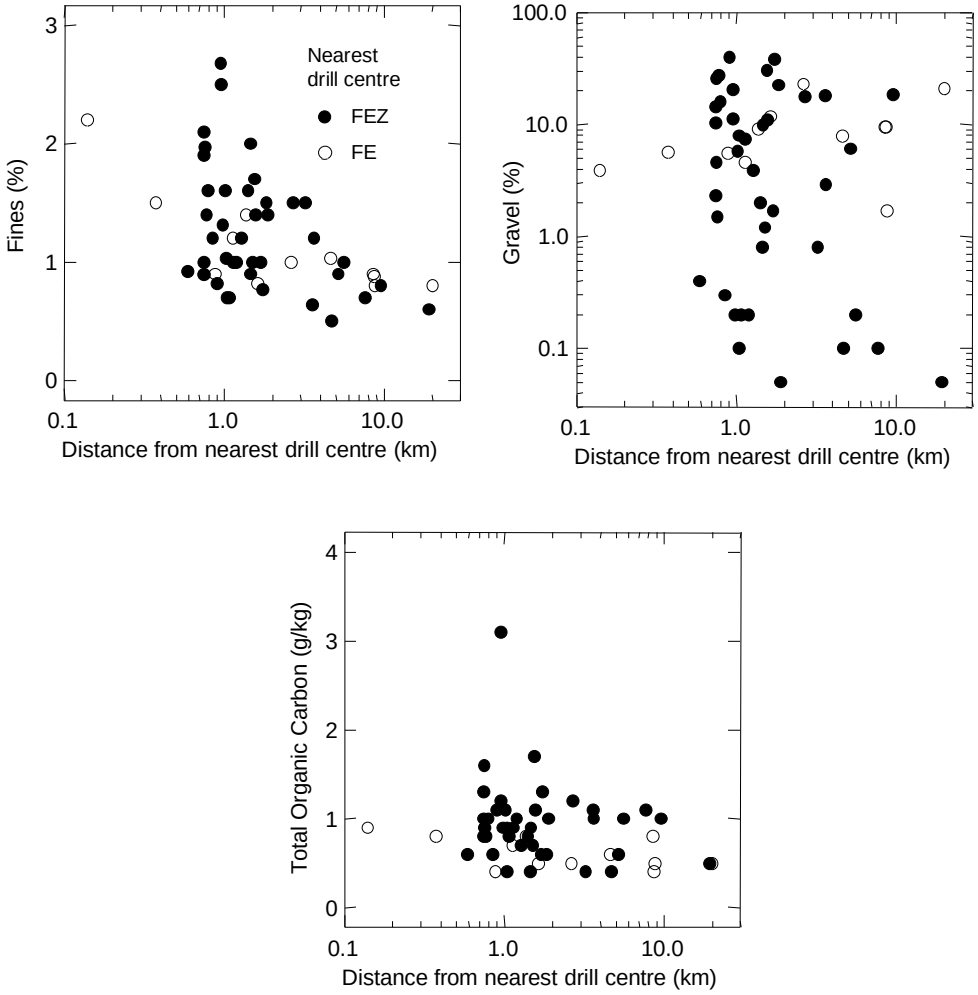


Figure 5-10 Distance Gradients for Fines, Gravel and Total Organic Carbon Content (2010)

In 2010, gravel content varied widely at all distances (Figure 5-10) and distance correlations were weakly negative and not significant (Table 5-9). Organic carbon was significantly negatively correlated with distances from the FEZ drill centres and the nearest drill centre, but was significantly positively correlated with distance from the FE drill centre (Table 5-9).

Metals PC1 scores, but not Metals PC2 scores, were elevated at station 30(FE) relative to most of the field (Figure 5-11). Metals PC1 and PC2 scores decreased, but not significantly, with distance from the FEZ and FE drill centres (Table 5-9). Metals PC1 scores decreased significantly ($0.01 < p < 0.05$) with distance from the nearest drill centre, although the multiple regression on distances from the FEZ and FE drill centres was not significant ($0.05 < p < 0.10$).

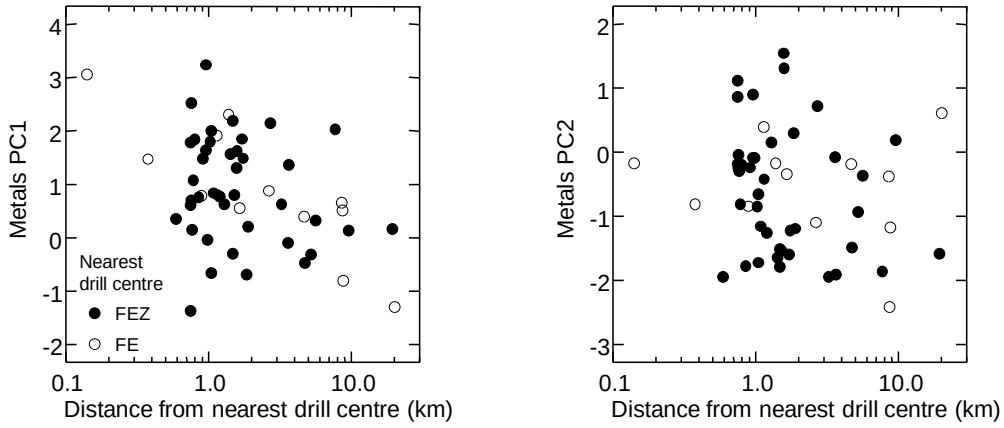


Figure 5-11 Distance Gradients for Metals PCs (2010)

In 2010, sulphur concentrations decreased significantly with distance from the FEZ drill centres and distance from the nearest drill centre (Table 5-9). The highest concentration (0.23%) occurred at station 30(FE) and was the only concentration exceeding 0.1% (Figure 5-12). Concentrations at other stations near the FE drill centre, including station 31(FE), were near or below the laboratory detection limit of 0.03%. Therefore, any effects of the FE drill centre on sulphur concentrations were localized and the partial correlation for distance from the FE drill centre was not significant. Although significant at $p < 0.001$, the FEZ distance gradient for sulphur largely depended on a few high concentrations at stations within 2 km of the FEZ drill centres (Figure 5-12).

Distance gradients for sulphide and redox were not significant (Table 5-9), and levels at stations 30(FE) and 31(FE) were intermediate (Figure 5-12). The highest sulphide levels occurred at distances of 1 to 10 km from drill centres. Redox values varied over a relatively narrow range (approximately 2-fold), with the two lowest values occurring approximately 1 km from FEZ drill centres. Ammonia concentrations decreased significantly with distance from the nearest drill centre (Table 5-9). Concentrations were not elevated at station 30(FE), but were elevated at station 31(FE) and a few stations within 2 km of the FEZ drill centres (Figure 5-12).

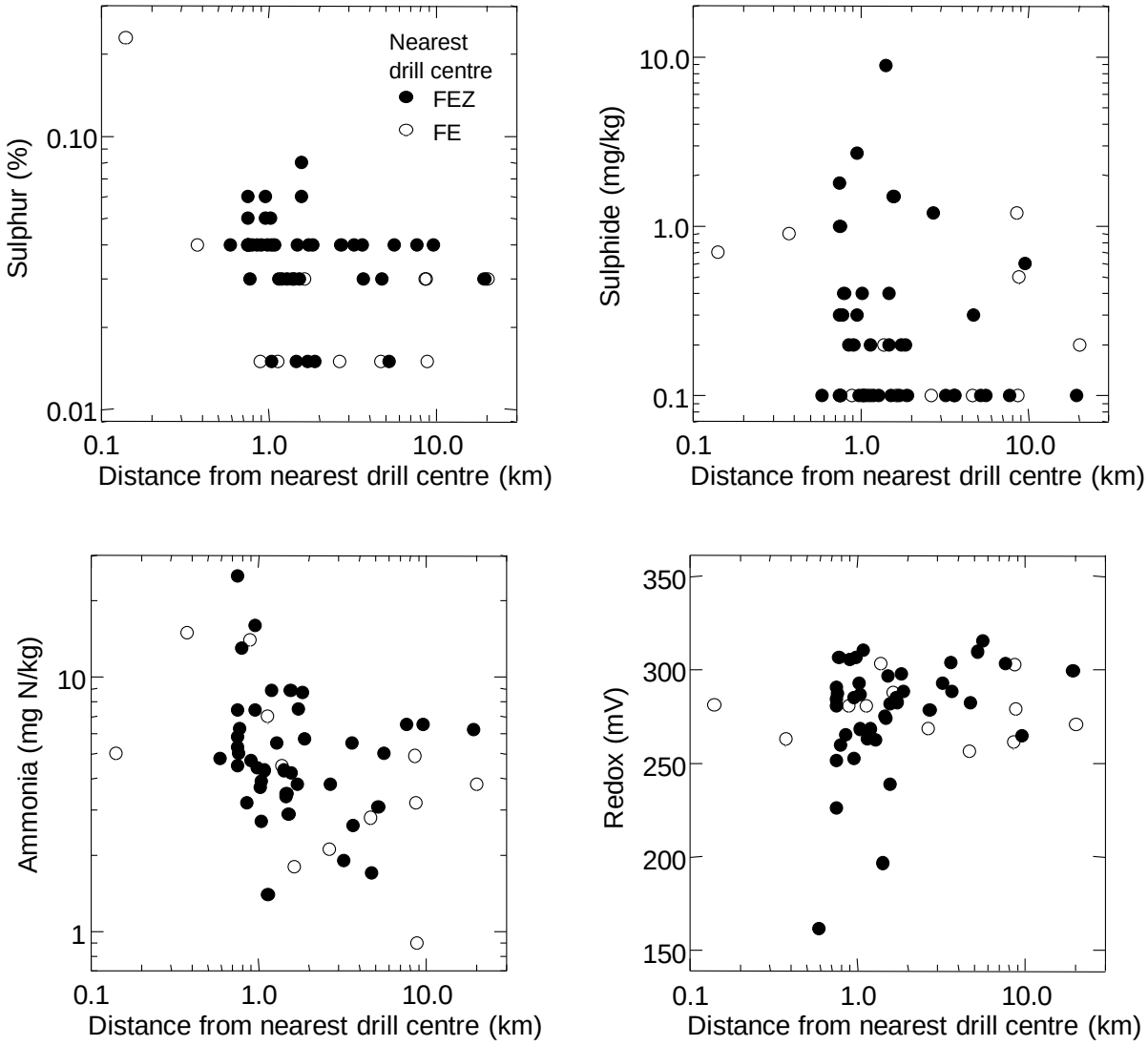


Figure 5-12 Distance Gradients for Sulphur, Sulphide, Ammonia and Redox (2010)

5.4.1.3 Comparison Among Years

Hydrocarbons and Barium

Figure 5-13 provides rank correlations (r_s) between >C_{10}-C_{21} hydrocarbon and barium concentrations versus distance to the nearest active drill centre from 1997 to 2010. The baseline (1997) distance correlation for >C_{10}-C_{21} hydrocarbons is shown as 0 in Figure 5-13, based on the assumption that all concentrations in 1997 were near or below the current detection limit of 0.3 mg/kg. In EEM years, distance correlations were approximately –0.8 and were slightly stronger in 2004 and 2006 than in other years.

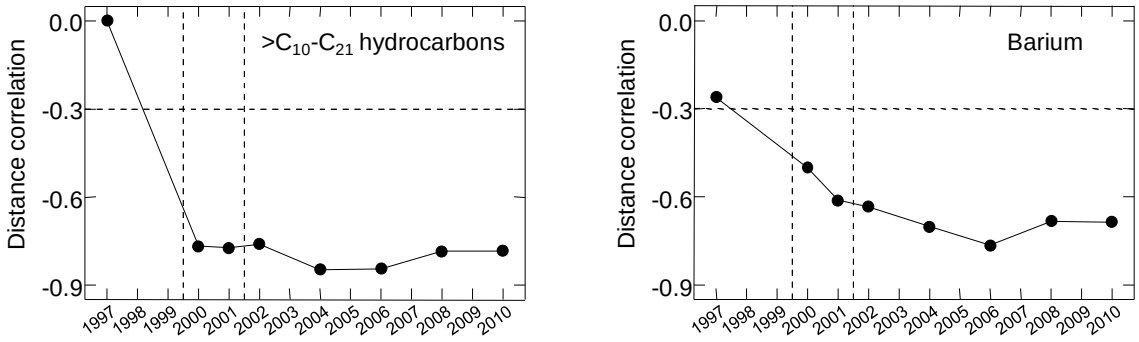


Figure 5-13 Annual Distance Correlations (r_s) for >C_{10}-C_{21} Hydrocarbons and Barium (All Stations)

Notes: The vertical dashed line before the year 2000 in Figure 5-13 and figures that follow marks the beginning of drilling at the NE and SW drill centres. Drilling began at the NW and SE drill centres before EEM program sampling in 2000, and drilling began at the FE drill centre before EEM program sampling in 2002 (indicated by second vertical line before 2002). The horizontal dashed line in this and other figures of distance correlations (r_s) indicates $r_s = -0.3$, which is a significant negative correlation at $0.01 < p < 0.05$ for the 49 to 54 stations sampled in each year. A positive correlation of 0.3 would also be significant, but positive distance correlations rarely occurred except for redox. The correlation (Y) scale is the same for >C_{10}-C_{21} hydrocarbons and barium so that distance correlations can be directly compared between them.

In 1997, barium concentrations decreased with distance from the centre of the development, although that baseline distance gradient was weak (Figure 5-13). The distance correlation was –0.261 ($0.05 < p < 0.10$) with the NE and SW drill centres considered active[14]. Barium distance correlations progressively increased in strength from 2000 to 2006, then decreased slightly in strength in 2008 and 2010. Barium distance relationships have generally been weaker than those for hydrocarbons.

Figure 5-14 provides annual distributions of individual >C_{10}-C_{21} hydrocarbon concentrations, median, 20th and 80th percentiles for EEM years. Medians and 80th percentiles for >C_{10}-C_{21} hydrocarbons increased approximately 5-fold from 2000 to 2002, and decreased approximately 2-fold after 2006. The highest concentration in every year from 2002 to 2010 occurred at station 30(FE) (0.17 km from the FE drill centre).

Median barium concentrations increased from 120 mg/kg in 1997 to 170 mg/kg in 2006, then decreased to 140 and 150 mg/kg in 2008 and 2010, respectively (Figure 5-14). Barium concentrations at station 30(FE) were higher than concentrations at other stations from 2002 to 2008 (highest values in the distributions of individual values in Figure 5-14; the second highest values from 2004

[14] The NE and SW drill centres were 'considered active' in 1997 for comparison to distance relationships in 2000 when the two drill centres were, in fact, active. Change in distance correlations from 1997 to 2000 need to be assessed using the same reference points. As such, in 1997, the NE and SW drill centres were just geospatial coordinates used to assess distance gradients in that year.

to 2010 were from station 31(FE)). 80th percentiles were greater from 2002 to 2010 than in 1997, 2000 and 2001 because concentrations also increased at some stations near FEZ drill centres (see left panel in Figure 5-14).

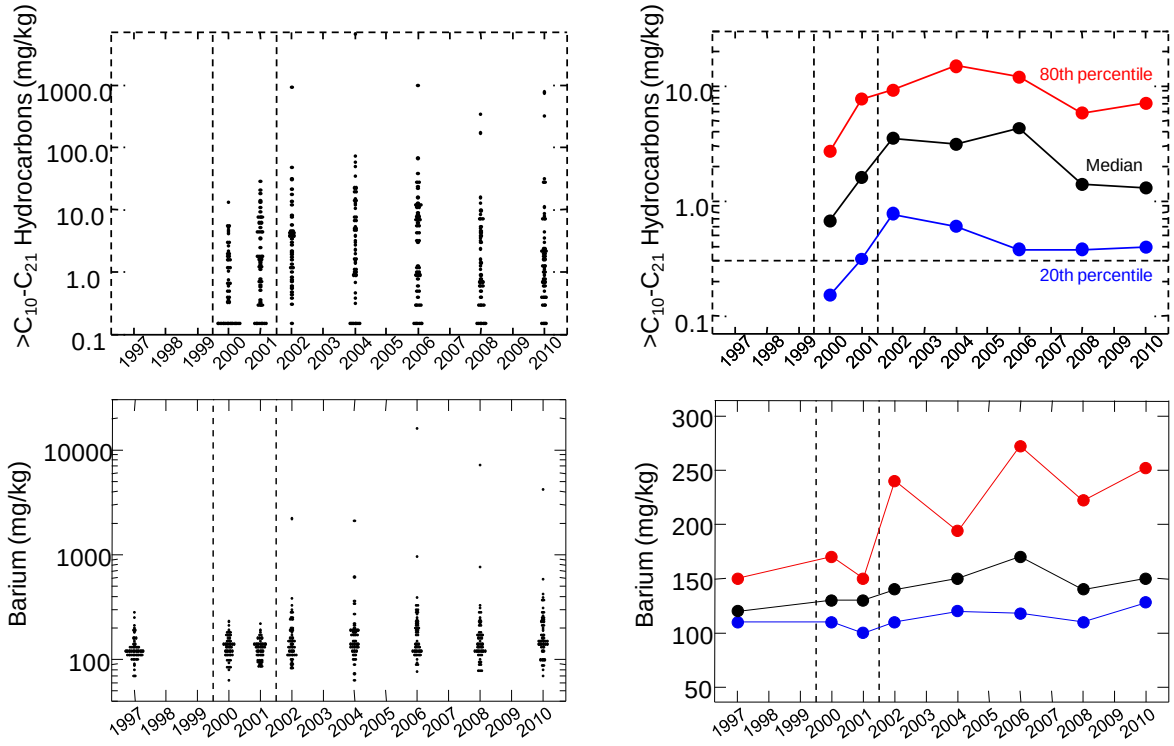


Figure 5-14 Annual Distributions, Medians, and 20th and 80th Percentiles for >C_{10}-C_{21} Hydrocarbons and Barium (All Stations)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. The horizontal dashed line for hydrocarbons is the detection limit of 0.3 mg/kg, with individual values less than detection limit plotted as 0.15 mg/kg.

Table 5-11 provides results of repeated-measures analyses of log-log distance regressions for >C_{10}-C_{21} hydrocarbons and barium, with stations 30(FE) and 31(FE) excluded, for stations sampled in every EEM year (*n* = 46 stations). Appendix B-4 provides details on the repeated-measures models, and a discussion of the effects of including stations 30(FE) and 31(FE). Briefly, when stations 30(FE) and 31(FE) were included in the parametric repeated-measures analyses, the linear log-log regressions were a poor fit after drilling began at the FE drill centre.

For interpretation of repeated-measures regression results in Table 5-11 and elsewhere:

1. **The Among Stations terms** test relationships between EEM *Y* means and the two distance (*X*) measures (FEZ and FE *d*). Significant relationships

indicate consistent long-term distance gradients unless various terms testing for changes in those gradients over time are also significant.

2. **The Among Stations Error 1 term** tests for carry-over effects (persistent differences among stations unrelated to distance).
3. **The Within Stations terms** test for differences in intercepts (Year terms) or slopes (Year $\times$ *d* terms) of distance regressions over time. Significant differences in intercepts indicate that changes in *Y* values over time were similar at all or most stations, unless distance gradients (i.e., slopes) also differ at $p \leq 0.01$. In the latter cases, changes over time may differ among stations and distances.
4. **The Within Stations Overall terms** test for any differences in slopes or intercepts among years.
5. **The Within Stations Before versus After contrasts** test for specific types of differences: Before versus After drilling began at the FE drill centre (2000-2001 versus 2002 to 2010) and Before versus After drilling began at the NW and SE drill centres (2000 versus 2001).
6. **The Trend (2002 to 2010) contrasts** test for linear or quadratic (parabolic or U-shaped) relationships between *Y* values (Year terms) or the strength of distance gradients (Year $\times$ *d* terms) over time after drilling began at the FE drill centre and continued at the FEZ drill centres. The Linear Trend should be interpreted with caution when the quadratic trend (a non-linear relationship that may indicate recent recovery from past effects) is significant.

Results in Table 5-11 are presented as *F* values.

In EEM years, $>C_{10}$-C_{21} hydrocarbon concentrations decreased significantly with distance from the nearest FEZ drill centre ($p \leq 0.001$ for the Among Stations FEZ *d* term in Table 5-11). The decreases with distance were evident in every EEM year. Negative FEZ regression slopes in Figure 5-15 represent the distance gradient after considering the influence of the FE drill centre. In this case, that influence was near zero. However, there were some significant changes in FEZ distance gradients over time ($p \leq 0.01$ for the Within Stations Year $\times$ FEZ *d* terms in Table 5-11). FEZ distance gradients increased in strength (became more negative) from 2000 to 2004/2006 and then decreased in strength in 2008 and 2010. Those changes in parametric FEZ regression slopes in EEM years were similar to changes in non-parametric distance correlations (Figure 5-13), which were driven largely by FEZ distance gradients. Repeated-measures results pertaining to FEZ distance gradients were similar with and without stations 30(FE) and 31(FE) included in the analysis (Appendix B-4).

Table 5-11 Results (F Values) of Repeated-measures Regressions Comparing Sediment Physical and Chemical Characteristics Among EEM Years (2000 to 2010)

Term	>C_{10}-C_{21} hydrocarbons	Barium	Fines	Gravel	TOC	Metals PC1	Metals PC2	Ammonia	Redox
Among Stations									
FEZ *d*	230.5***	42.2***	14.9***	0.5	17.3***	9.5**	1.1	8.1**	35.0***
FE *d*	7.5**	0.3	0.0	1.6	5.8*	0.4	1.5	1.8	0.1
Error 1 (Carry-over)	3.9***	10.7***	6.7***	14.0***	19.0***	7.1***	9.9***	2.4***	0.8
Within Stations									
Overall									
Year	7.1***	6.6***	5.3***	1.0	1.8	3.9***	2.9**	0.9	16.6***
Year × FEZ *d*	4.0**	4.5***	1.0	0.3	2.5*	1.9	2.6*	1.0	3.7**
Year × FE *d*	1.2	0.2	1.0	0.6	0.6	0.8	2.1	0.4	4.7***
Before versus After NW, SE Drilling (2000 vs 2001)									
Year	3.6	1.0	21.3***	0.0	0.0	0.0	0.7	Not tested	13.1***
Year × FEZ *d*	6.6*	0.3	1.8	0.2	0.4	1.3	11.5**		6.3*
Year × FE *d*	1.1	0.3	6.9*	0.1	0.0	0.8	4.3*		1.2
Before versus After FE Drilling (2000-2001 vs 2002 to 2010)									
Year	17.3***	21.2***	1.1	0.2	0.2	1.4	0.0	4.8*	12.5***
Year × FEZ *d*	1.9	14.4***	0.1	0.1	1.6	3.5	3.1	0.6	12.5***
Year × FE *d*	3.6	0.4	0.2	1.3	1.2	0.2	0.0	0.2	0.3
Trends (2002 to 2010)									
Linear									
Year	8.6**	3.2	0.4	1.0	5.3*	9.3**	0.8	0.4	2.8
Year × FEZ *d*	3.6	0.4	2.8	1.0	5.8*	0.8	0.2	0.4	12.1**
Year × FE *d*	0.0	0.4	0.1	0.1	0.1	0.1	1.8	0.8	3.9
Quadratic									
Year	1.6	0.0	7.1*	0.0	3.0	10.0**	14.5***	0.0	23.3***
Year × FEZ *d*	6.3*	0.1	0.0	0.1	1.8	1.6	0.2	0.1	0.1
Year × FE *d*	0.2	0.0	0.9	0.9	2.2	3.8	5.6*	0.6	8.1**

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- *n* = 46 stations.
- Stations 30(FE) and 31(FE) excluded.
- Ammonia was not measured in 2000.
- Distance variables (*X*) and *Y* variables, except for Metals PCs, were log-transformed.
- See Appendix B-4 for description and interpretation of terms in the repeated-measures regression models.

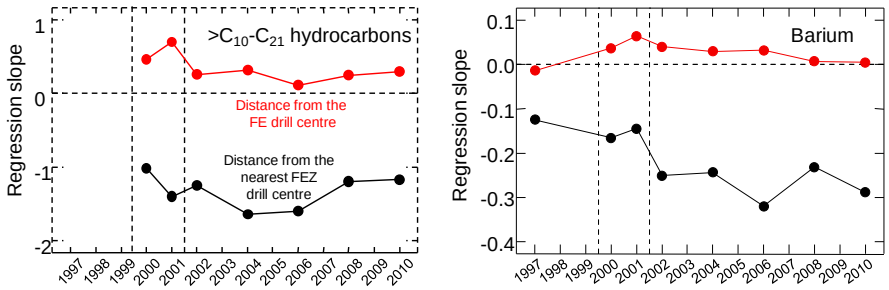


Figure 5-15 Annual Multiple Regression Distance Slopes for >C_{10}-C_{21} Hydrocarbons and Barium (Stations 30(FE) and 31(FE) Excluded)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. 1997 regression slopes for barium were based on the 31 stations sampled in both 1997 and in EEM years.

$>C_{10}$-C_{21} hydrocarbon concentrations were also significantly related to distance from the FE drill centre ($p \leq 0.01$ for the Among Stations FE *D* term in Table 5-11). However, with stations 30(FE) and 31(FE) excluded, concentrations increased rather than decreased with distance from the FE drill centre in every EEM year (note positive FE regression slopes in Figure 5-15). Variation in the magnitude of FE distance gradients over time were not significant ($p > 0.05$ for Within Stations Year $\times$ FE *d* terms). Inclusion of stations 30(FE) and 31(FE) in repeated-measures regression increased the significance of the FE distance gradient; and positive distance gradients in Figure 5-15 became negative reflecting high hydrocarbon concentrations near those two drill centres (Appendix B-4).

There were also some highly significant variation in distance regression intercepts for $>C_{10}$-C_{21} hydrocarbons ($p < 0.001$ for Overall Within Stations Year term in Table 5-11). Those changes in intercepts paralleled changes in median concentrations in Figure 5-14, with intercepts and medians first increasing then decreasing over time. The significant of those variations did not change with or without stations 30(FE) and 31(FE) included.

Results of tests of distance gradients for barium were generally weaker versions of results for $>C_{10}$-C_{21} hydrocarbons (Table 5-11). The overall FEZ distance gradient for barium in EEM years was highly significant ($p \leq 0.001$ for Among Stations FEZ *d* term), with barium concentrations decreasing with distance from the FEZ drill centres in every EEM year (Figure 5-15). From 2002 to 2010, distance gradients for the FEZ drill centres were significantly stronger (slopes more negative) than in 2000 and 2001. As was the case for $>C_{10}$-C_{21} hydrocarbons, FEZ distance gradients accounted for most of the overall significant non-parametric distance correlations in Figure 5-13. FEZ distance slopes, as well as distance correlations, were also negative in 1997, although not as strong as in EEM years (Figure 5-15).

With stations 30(FE) and 31(FE) excluded, the overall FE distance gradient for barium was not significant and gradients did not change significantly over time (i.e., no FE *d* terms in Table 5-11 were significant). Changes in intercepts for barium distance regressions were similar to changes in medians (i.e., increasing from 2000 to 2006, then decreasing in 2008 and 2010; Figure 5-14). With stations 30(FE) and 31(FE) included, the FE distance gradient was significant, with strong negative slopes from 2002 to 2010.

Carry-over effects, or persistent spatial differences over time, were highly significant ($p \leq 0.001$) for $>C_{10}$-C_{21} hydrocarbons and barium (Among Stations Error 1 term in Table 5-11). Carry-over effects for $>C_{10}$-C_{21} hydrocarbons should be considered persistent small-scale or localized project-related effects unrelated to distance, assuming that background concentrations were near or below the current detection limit of 0.3 mg/kg and would not vary naturally. Carry-over effects for barium were stronger than carry-over effects for $>C_{10}$-C_{21} hydrocarbons because barium carry-over effects incorporated both natural and project-related persistent small-scale spatial variance.

As discussed in the analysis of 2010 distance relationships (Section 5.4.1.2), Appendix B-4 and elsewhere, threshold (hockey-stick) models may be more appropriate for $>C_{10}$-C_{21} hydrocarbons and barium than the linear log-log regressions used in the repeated-measures and other analyses, especially with stations 30(FE) and 31(FE) included. Table 5-12 provides results for hockey-stick models for $>C_{10}$-C_{21} hydrocarbons and barium for all years, with all stations included.

Table 5-12 Distance Relationships and Thresholds for $>C_{10}$-C_{21} Hydrocarbons and Barium (1997 to 2010)

Variable	Year	*r* bivariate	*R* hockey-stick	*p* threshold	Threshold distance (km)	95% CI (km)
$>C_{10}$-C_{21} hydrocarbons	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
Barium	1997	–0.247	0.247	1.000	Not estimated	
	2000	–0.480***	0.480***	1.000	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***	0.801***	<0.001	2.0	1.5 to 2.6

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.
- Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2010. 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 and 2010.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

From 2000 to 2002, adding a threshold in hockey-stick models did not significantly reduce error variances for >C_{10}-C_{21} hydrocarbons and a threshold distance was not estimated (Table 5-12). From 2004 to 2010, adding a threshold significantly reduced error variances. Estimated thresholds (zones of influence) for >C_{10}-C_{21} hydrocarbons decreased from 2004 and 2006 to 2008 and 2010. There was minimal overlap in 95% CI for threshold distances between the earlier and recent years (Figure 5-16).

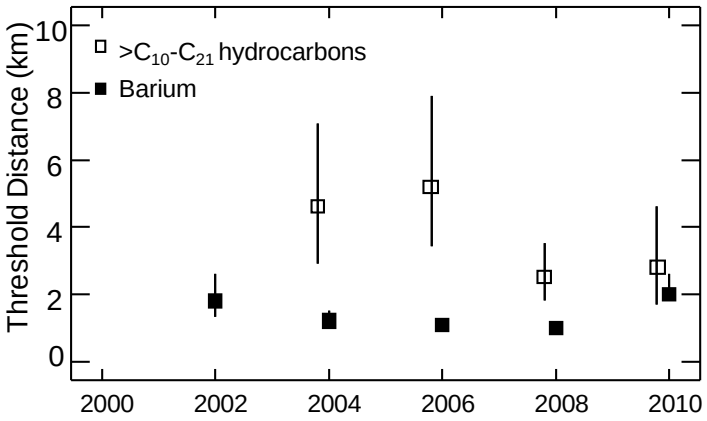


Figure 5-16 Threshold Distances (km) for >C_{10}-C_{21} Hydrocarbons and Barium

Note: 95% Confidence Limits for threshold values are indicated by vertical lines.

Threshold distances for barium could not be estimated from 1997 and 2000, when distance correlations were relatively weak (Table 5-12). In 2001, adding a threshold did not significantly reduce error variance. From 2002 to 2010, adding a threshold significantly reduced error variances ($p < 0.001$ for all five sample years), primarily because the high concentrations at station 30(FE) and 31(FE) were extreme outliers for bivariate log-log regressions. Estimated thresholds for barium have remained relatively constant at between 1 to 2 km since 2002 (Figure 5-16).

Sediment Particle Size and Organic Carbon Content

Weak negative distance correlations (decreases with distance) were noted for fines content in 1997 (baseline) (Figure 5-17). Distance correlations were stronger in EEM years and these correlations were significant in 2000, 2001, 2006 and 2010. Median fines content decreased from 1997 to 2000 and then progressively increased from 2000 to 2004 (Figure 5-18). Medians in 2006 to 2010 were similar to baseline values. These changes in summary statistic values over time were a function of changes occurring at all or most stations, rather than changes in project-related distance gradients (see discussion of repeated-measures regression results below).

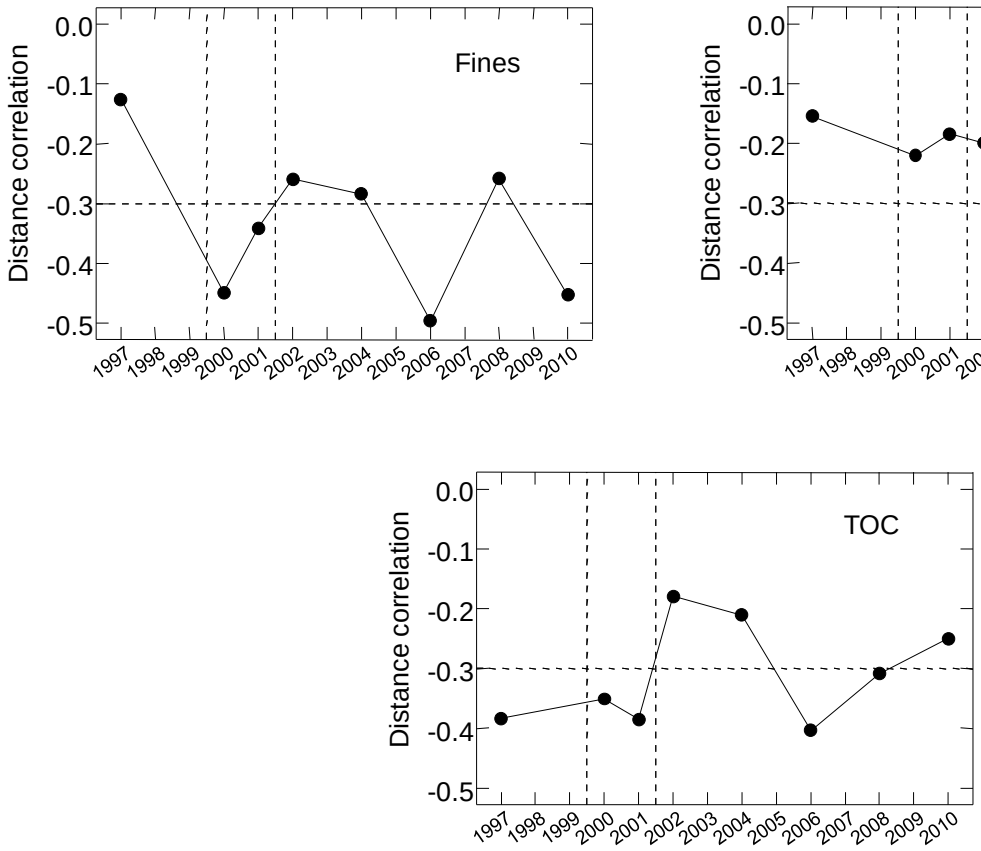


Figure 5-17 Annual Distance Correlations (r_s) for Sediment Fines, Gravel and TOC Content (All Stations)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. The horizontal dashed line indicates r_s = - 0.3, which is a significant negative correlation at 0.01 < p < 0.05.

Distance correlations for gravel have never been significant (Figure 5-17). Medians and 80th percentiles for gravel content generally increased from 1997 to 2010, by 2-fold or more, but these increases were small relative to the wide range of individual values (more than 100-fold) within years (Figure 5-18).

Organic carbon content has decreased with distance from drill centres and decreases were significant in 1997, 2000, 2001, 2006 and 2008 (Figure 5-17). The baseline (1997) correlation of approximately –0.4 was among the strongest observed. Organic carbon content in all years has generally been low, with most values between 0.5 and 1 g/kg (Figure 5-18). Annual 20th percentiles, medians and 80th percentiles in EEM years were all within 0.1 g/kg of baseline values.

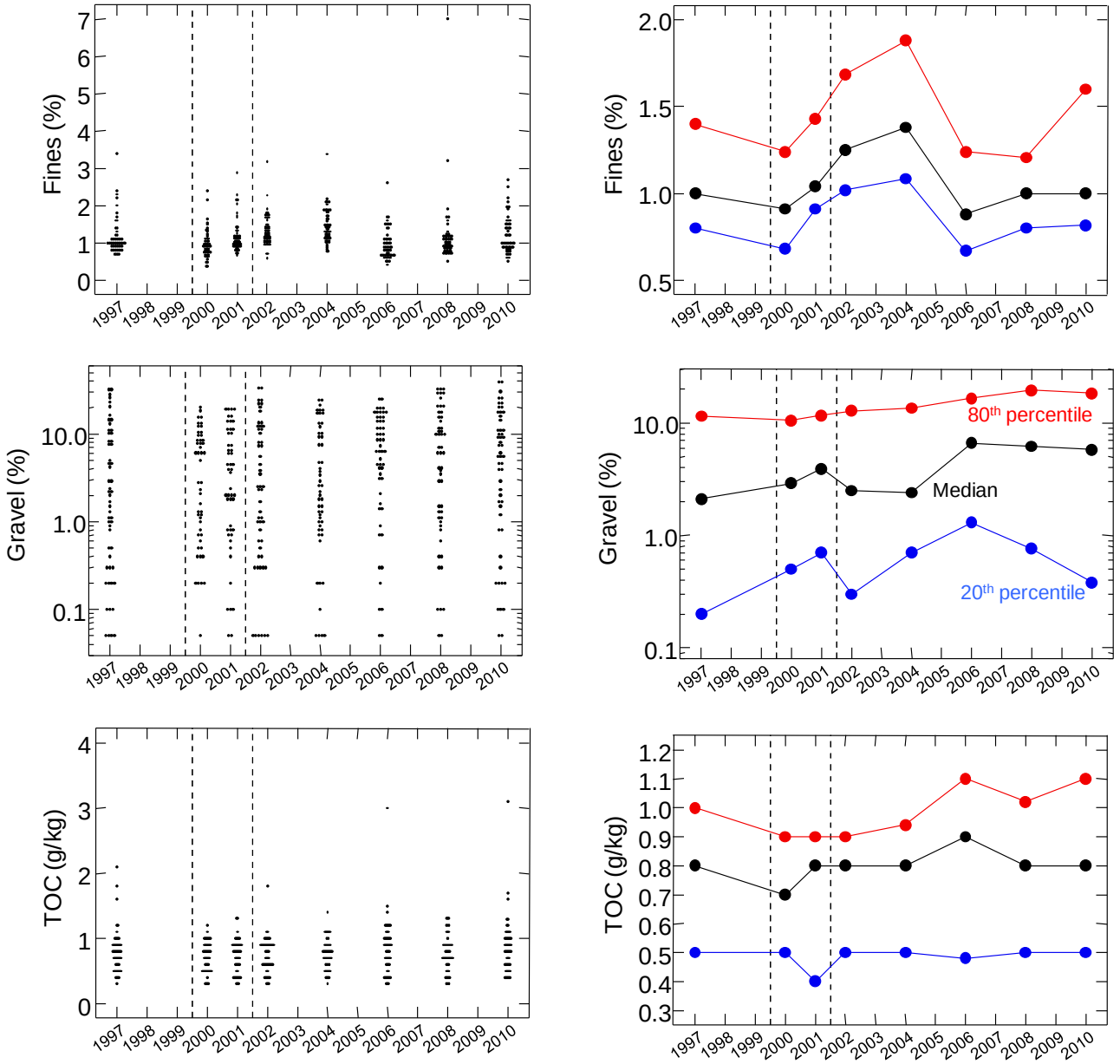


Figure 5-18 Annual Distributions, Medians, and 20th and 80th Percentiles for Fines, Gravel and Organic Carbon Content (All Stations)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

Table 5-11 provides results of repeated-measures regression analyses comparing EEM years for sediment fines, gravel and organic carbon content with stations 30(FE) and 31(FE) excluded. Carry-over effects, or persistent spatial differences over time unrelated to distance, were significant at $p \leq 0.001$ for all variables except redox, and strongest for gravel and TOC content (see results for Error 1 in Table 5-11).

Temporal (year-to-year) variance at most stations was the major factor affecting fines content, as indicated by the significant Within Stations Year terms in Table 5-11 and changes in summary statistics in Figure 5-18. The overall FEZ distance gradient for fines content was significant (Table 5-11), with fines content decreasing with increasing distance from the FEZ drill centres in every year including baseline (1997) (note negative regression slopes in Figure 5-19). The FEZ distance gradient did not change significantly over time (Table 5-11), although parametric distance slopes for the FEZ drill centres were steepest in 2000, 2006 and 2010 (Figure 5-19), when nonparametric distance correlations were also strongest (Figure 5-17). The significance of the FEZ distance gradient did not change with the inclusion of stations 30(FE) and 31(FE) (Appendix B-4).

With stations 30(FE) and 31(FE) excluded, FE distance gradients for fines did not differ significantly between 2000 and 2001 versus 2002 to 2010 (Table 5-11). Instead, with the two stations excluded, the largest and only significant change in FE distance gradients occurred between 2000 and 2001, before drilling began at the FE drill centre. The FE distance slope reversed from positive to negative from 2000 to 2001, and returned to values near 0 in subsequent years (Figure 5-19). Inclusion of stations 30(FE) and 31(FE) changed the significance and direction of the overall FE distance gradients, with negative slopes (decreases with distance) from 2004 to 2010 (Appendix B-4).

Fines content increased at station 30(FE), and to a lesser extent at station 31(FE), after drilling began at the FE drill centre prior to 2002 sampling (Figure 5-20). From 1997 to 2002, fines content at the two stations was similar to the median fines content for other stations. From 2004 to 2010, fines content at station 30(FE) was greater than 2%, higher than medians for other stations. In 2004 and 2006 fines content at station 30(FE) was higher than at any other station. In 2004, 2006 and 2010, fines content at station 31(FE) was also higher than medians for other stations. It should be noted that although fines content was elevated near the FE drill centre in 2004 to 2010, none of the values for stations 30(FE) and 31(FE) exceeded the baseline maximum of 3.4% (see Figure 5-18).

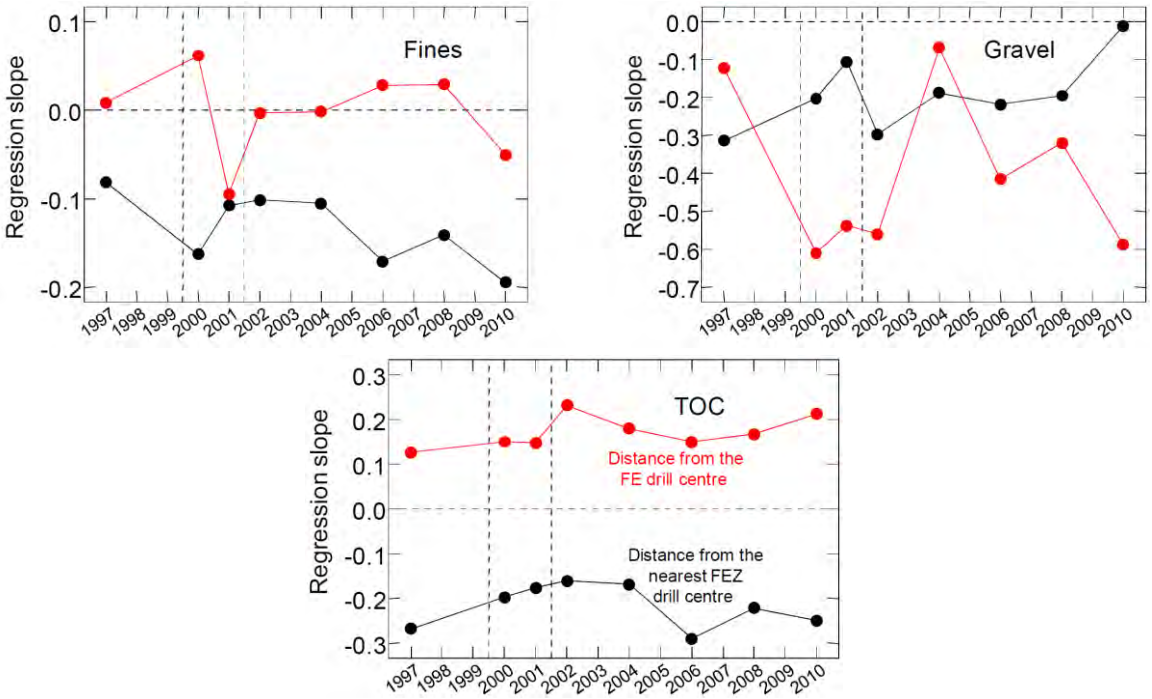


Figure 5-19 Multiple Regression Distance Slopes for Fines, Gravel and TOC Content (Stations 30(FE) and 31(FE) Excluded)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

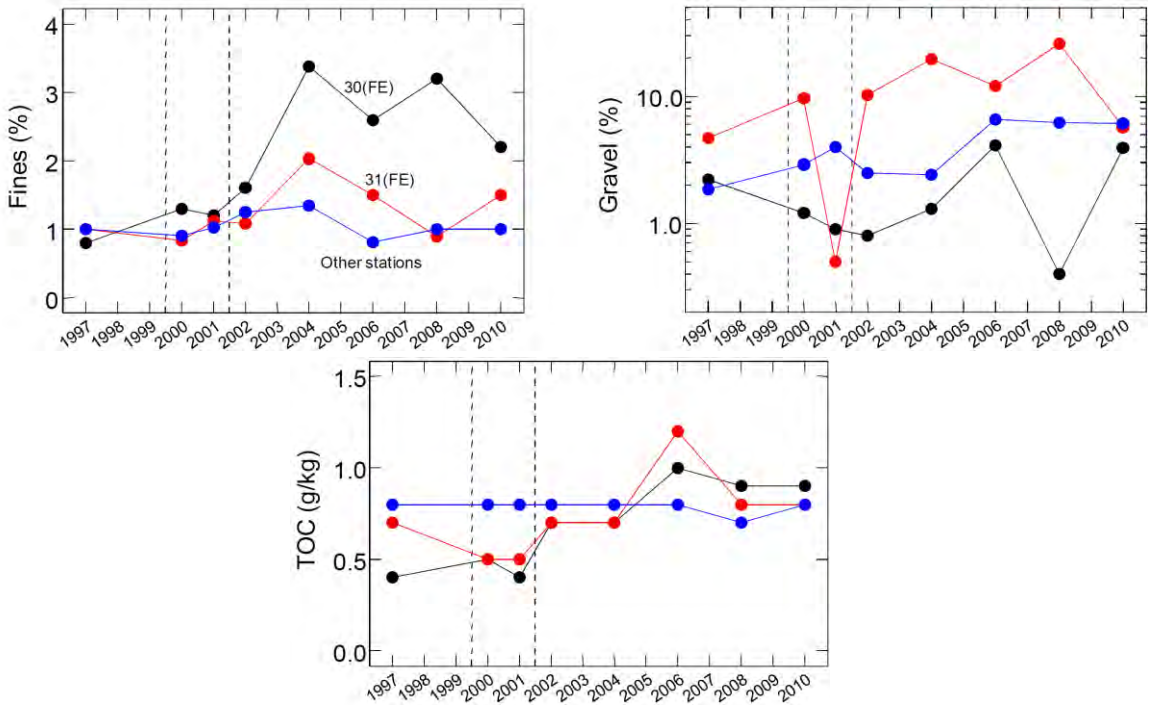


Figure 5-20 Annual Sediment Fines, Gravel and TOC Content at Stations 30(FE) and 31(FE) versus Medians for Other Stations

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

Carry-over effects (persistent spatial differences over time) were the only significant term for gravel content in repeated-measures regression analyses (Table 5-11). Although weak and not significant, FEZ and FE distance gradients for gravel content were consistent over time, with multiple regression slopes for both distance measures negative in every year (Figure 5-19). Inclusion of stations 30(FE) and 31(FE) did not change the nature or significance of distance gradient for gravel Appendix B-4). In every EEM year, gravel content at station 30(FE) was lower than medians for other stations (Figure 5-20).

The overall FEZ distance gradient for total organic carbon in EEM years was highly significant ($p < 0.001$ for Among Stations FEZ *d* term in Table 5-11), because organic carbon decreased with distance from the FEZ drill centres in all years (Figure 5-19). The FEZ distance slope for 1997 (baseline) were as strong as in EEM years.

With stations 30(FE) and 31(FE) excluded, organic carbon content increased with increasing distance from the FE drill centre in EEM years and in 1997 (baseline) (Figure 5-19). The overall FE distance gradient was significant, and there were no significant changes in that gradient over time (Table 5-11). Inclusion of stations 30(FE) and 31(FE) has no substantive effect on the nature of the FE distance gradients (Appendix B-4). In 2000 and 2001 (and also 1997), organic carbon content (0.4 to 0.5 g/kg) at stations 30(FE) and 31(FE) was lower than at most other stations (annual medians = 0.8 g/kg), but from 2002 to 2010, organic carbon content approached or exceeded medians for other stations (Figure 5-20).

Metals

Metals PC1 scores decreased with minimum distances to drill centres in every year (Figure 5-21). The strongest distance correlation occurred in 2001 ($r_s \approx -0.6$; $p < 0.001$). Correlations in other EEM years varied around $r_s = -0.3$ and $p = 0.05$. 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.

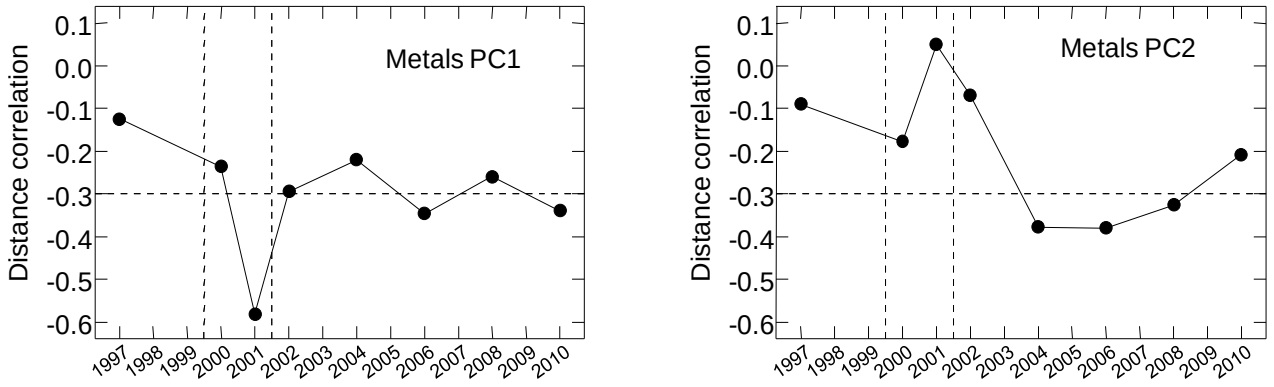


Figure 5-21 Annual Distance Correlations (r_s) for Metals PC1 and PC2 (All Stations)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. The horizontal dashed line indicates r_s = - 0.3, which is a significant negative correlation at 0.01 < p < 0.05.

Medians for Metals PC1 in 2000 to 2008 were similar to or lower than baseline (1997) medians, but medians in 2010 were greater than in any other year (Figure 5-22). 80th percentiles did not change substantially from 1997 to 2002, but progressively increased from 2002 to 2010. Therefore, in recent years, there have been more high Metals PC1 scores, particularly in 2010 (see plot of individual values in Figure 5-22). 20th percentiles, medians and 80th percentiles for Metals PC2 scores in EEM years were usually similar to or above baseline (1997) values, but decreased in 2010 (Figure 5-22). Overall, the largest year-to-year changes in metal concentrations and mixtures (increases in PC1; decreases in PC2) across the field occurred between 2008 and 2010.

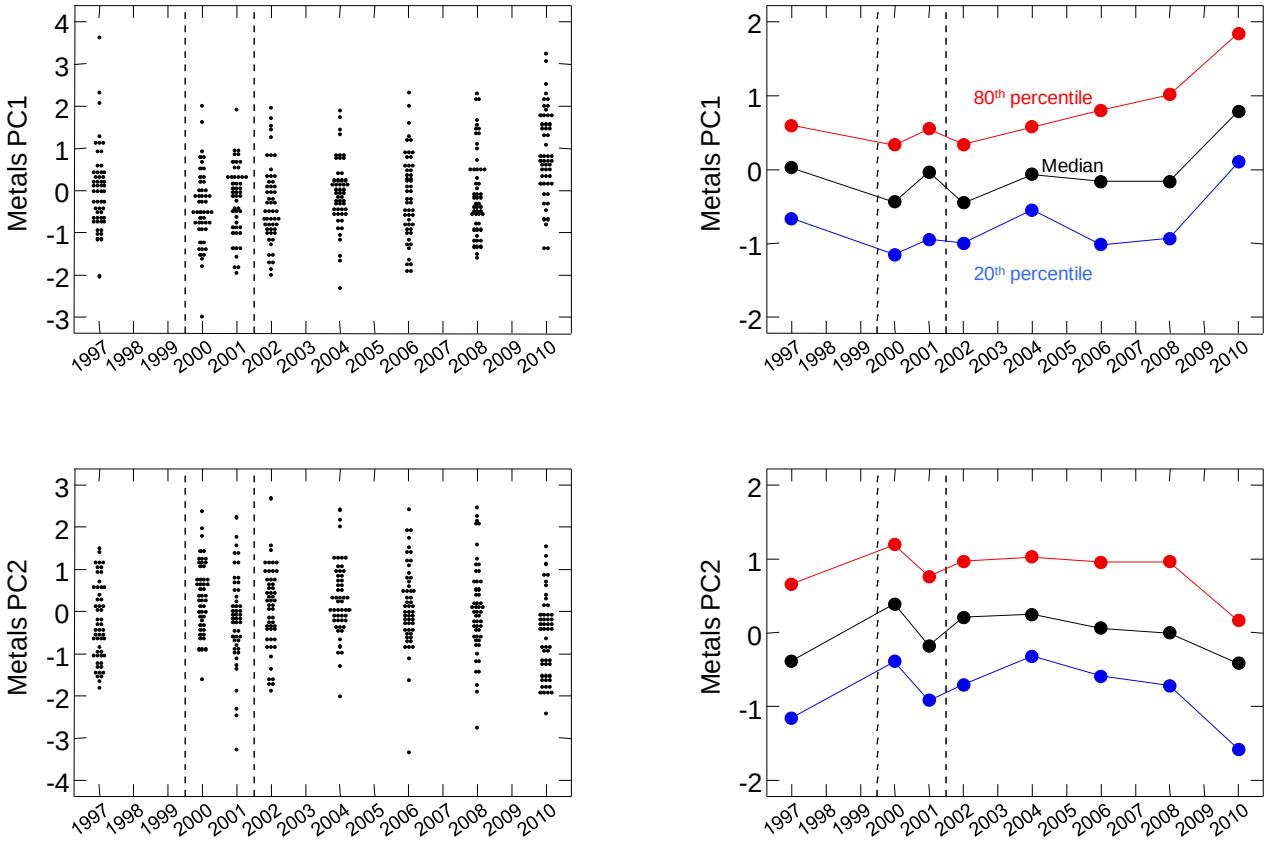


Figure 5-22 Annual Distributions, Medians, and 20th and 80th Percentiles for Metals PC1 and PC2 (All Stations)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

Differences in repeated-measures regression intercepts (annual averages) among years for Metals PCs were significant (see Within Stations Overall and 2002-2010 Trend Year terms in Table 5-11), and with significant "linear" and "quadratic" terms, reflecting an increase over time (after 2002) for metals PC1 and a decrease over time for metals PC2 (Figure 5-22).

The overall FEZ distant gradient for Metals PC1 in EEM years was significant (F = 9.5, Table 5-11), with PC1 scores decreasing with distance from the FEZ drill centres in every year, including 1997 (negative FEZ distance slopes in Figure 5-23).

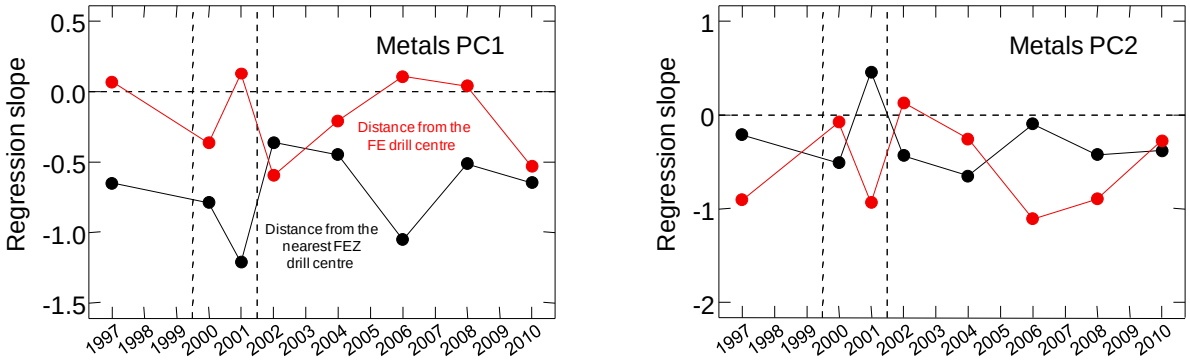


Figure 5-23 Multiple Regression Distance Slopes for Metals PC1 and PC2 (Stations 30(FE) and 31(FE) Excluded)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

With stations 30(FE) and 31(FE) excluded, there were no significant changes in FE distance gradients for Metals PC1 over time (F = 0.1 for linear trend, F = 3.8 for quadratic trend) and the overall gradient was not significant (F = 1.9, Table 5-11). With stations 30(FE) and 31(FE) included, the FE distance gradient was generally more significant and negative (Overall F = 5.7 for the Fe *d* term, Table 5 in Appendix B-4).

Metals PC1 scores increased at station 30(FE) after drilling began in 2002 at the FE drill centre, and were also high at station 31(FE) in 2008 and 2010 (Figure 5-24), which may indicate some localized effects of drilling (i.e., increased metal concentrations) at these two stations.

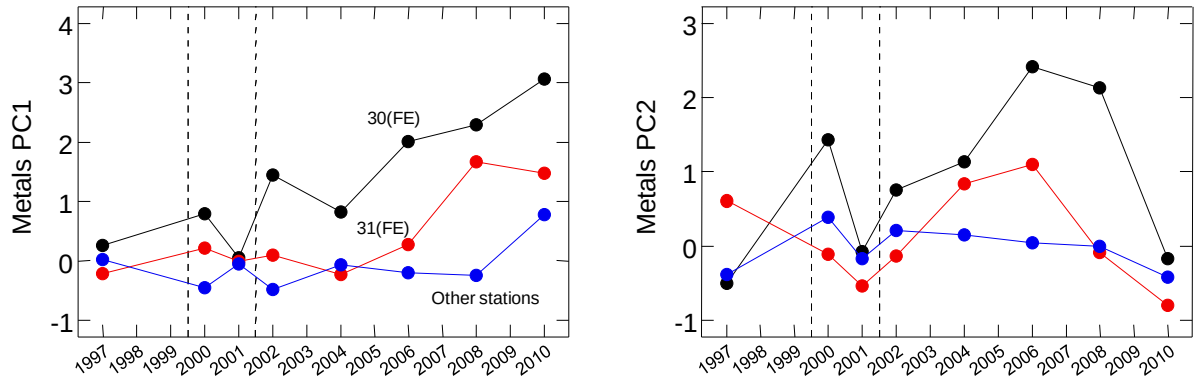


Figure 5-24 Annual Sediment Metals PC1 and PC2 Scores for Stations 30(FE) and 31(FE) versus Medians for Other Stations

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

The overall FEZ distance gradient for Metals PC2 was not significant (F = 1.1, Table 5-11). FEZ distance slopes changed from negative to positive (reversed) between 2000 and 2001, and reversed again between 2001 and 2002 (Figure 5-23). With stations 30(FE) and 31(FE) excluded, the overall FE distance gradient for Metals PC2 was not significant (F = 1.5, Table 5-11). FE distance slopes were near 0 or negative (decrease with distance) in all years, including 1997 (Figure 5-23). The baseline distance gradient was as strong or stronger than the distance gradients in EEM years; and among EEM years, strongest in 2001, 2006 and 2008. Inclusion of stations 30(FE) and 31(FE) in repeated-measures regression resulted in no substantive influence on the nature or magnitude of the FEZ and FE distance gradients (Appendix B-4).

Ammonia, Redox, Sulphur and Sulphide

Ammonia concentrations, measured since 2001, did not decrease significantly with distance from the nearest active drill centre in any year except 2010 (Figure 5-25). 20^{th} percentile, median and 80^{th} percentiles in 2001 were approximately double values in subsequent years (Figure 5-26). As a result, differences in repeated-measures regression intercepts between 2001 versus 2002 to 2010 were significant (Table 5-11). Despite the weak non-parametric distance correlations, the overall FEZ distance gradient for ammonia was significant in repeated-measures regression analyses (Table 5-11), with FEZ distance slopes negative in every year (Figure 5-27). There was no evidence that drilling at the FE drill centre elevated ammonia concentrations near that drill centre. With stations 30(FE) and 31(FE) excluded, the overall FE distance gradient was not significant (Table 5-11). Inclusion of stations 30(FE) and 31(FE) did not change the nature or significant of the FE or FEZ distance gradients for ammonia (Appendix B-4). Ammonia concentrations at stations 30(FE) and 31(FE) did not increase after drilling began at the FE drill centre prior to 2002 sampling (Figure 5-28). In 2001, the ammonia concentration at station 31(FE), but not at station 30(FE), was greater than the median for all other stations.

Redox distance correlations varied from approximately 0 in 2001 and 2008 to significantly positive and greater than 0.3 in 2000, 2002 and 2004 (Figure 5-25).

Redox medians decreased from 2001 to 2004, increased in 2006, decreased in 2008, then increased in 2010 (Figure 5-26). There was one extreme high value (863 mV) in 2008, at the Southeast Reference (station 6(SE)). Otherwise, most values were between 100 and 300 mV.

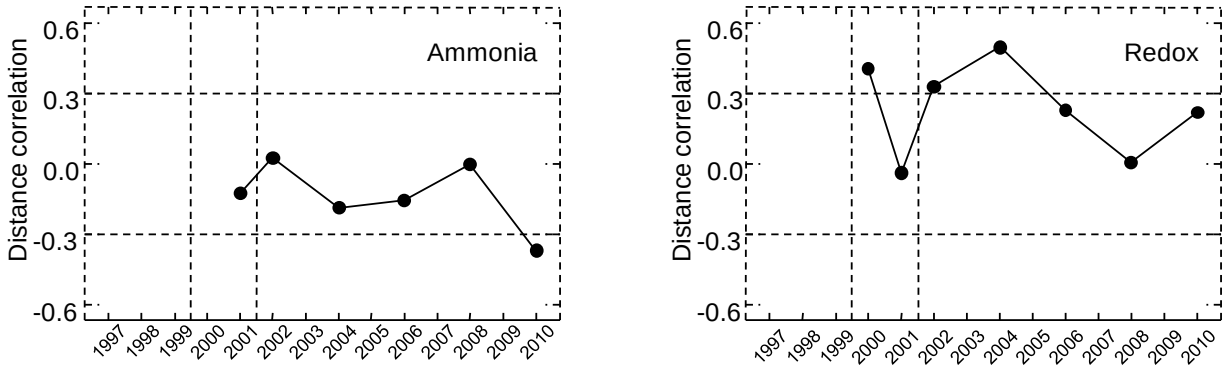


Figure 5-25 Annual Distance Correlations (r_s) for Ammonia and Redox (All Stations)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. The horizontal dashed line indicate $|r_s| = 0.3$, which is a significant correlation at $0.01 < p < 0.05$.

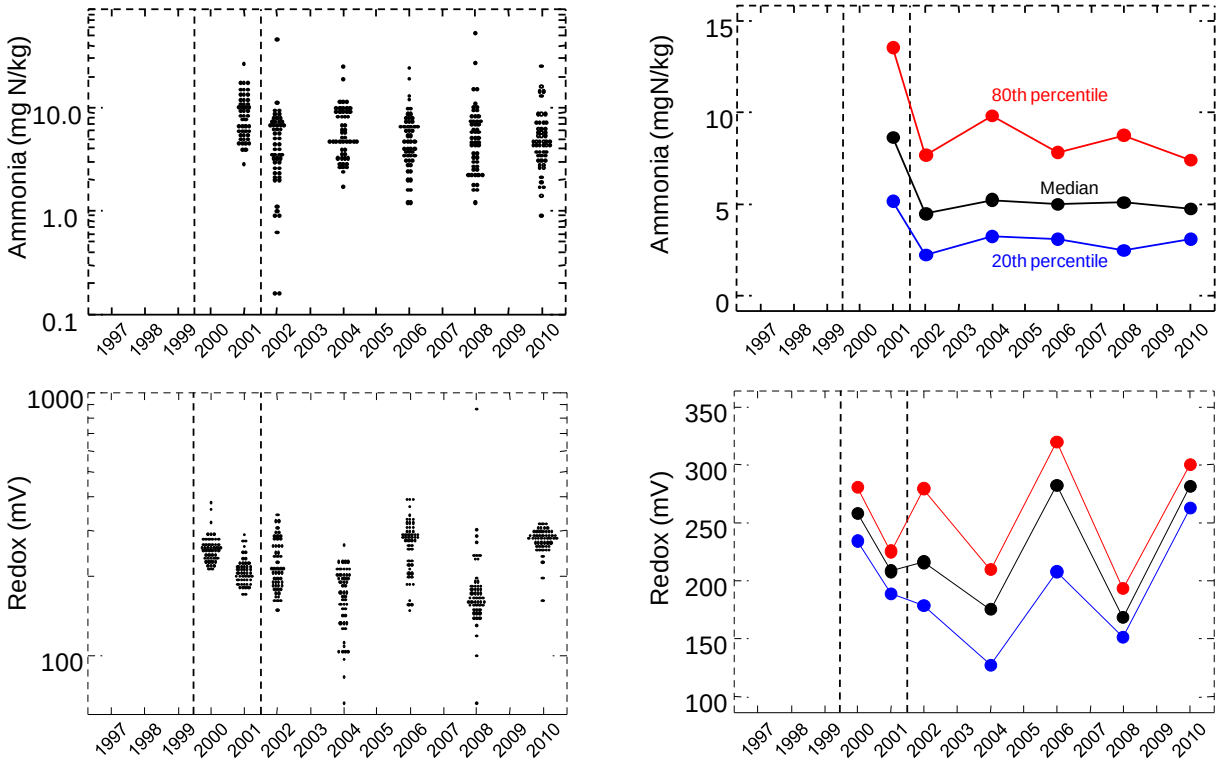


Figure 5-26 Annual Distributions, Medians, and 20th and 80th Percentiles for Ammonia and Redox (All Stations)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

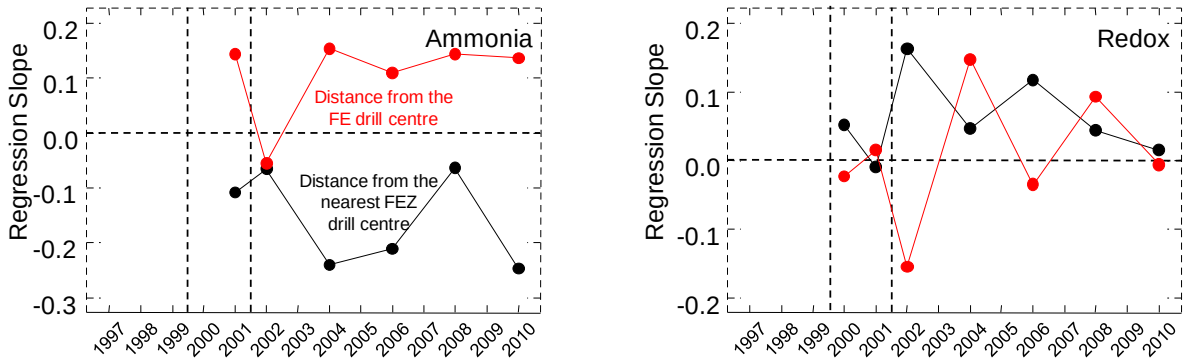


Figure 5-27 Multiple Regression Distance Slopes for Ammonia and Redox (Stations 30(FE) and 31(FE) Excluded)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

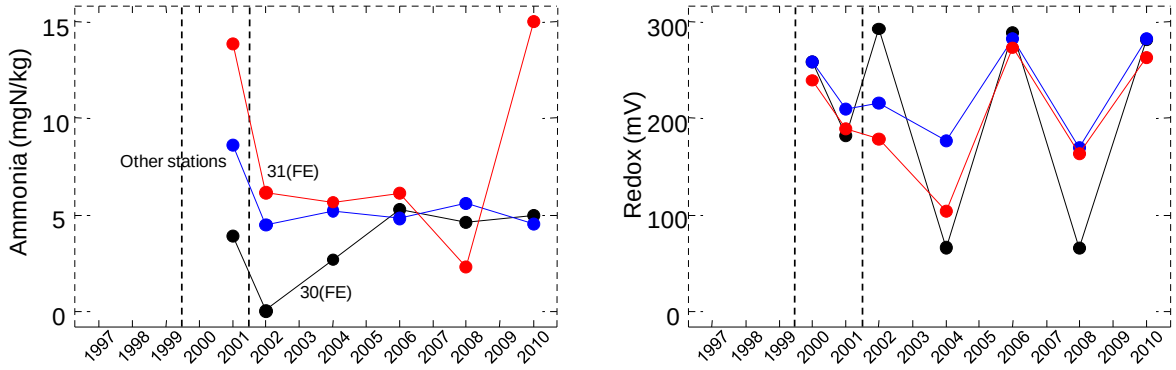


Figure 5-28 Annual Sediment Ammonia and Redox Values for Stations 30(FE) and 31(FE) versus Medians for Other Stations

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

The overall FEZ distance gradient was highly significant for redox, but the gradient changed significantly over time (Table 5-11). FEZ distance slopes were positive in all years except 2001 (Figure 5-27). FEZ distance gradients were significantly stronger in 2000 than in 2001, significantly stronger from 2002 to 2010 than in 2000 and 2001, and decreased significantly over time from 2002 to 2010 (see Within Stations Year × FEZ *d* contrasts in Table 5-11 and regression slopes in Figure 5-27). Inclusion of stations 30(FE) and 31(FE) did not affect these conclusions (Appendix B-4).

With stations 30(FE) and 31(FE) excluded, FE distance slopes for redox were approximately 0 in 2000 and 2001 (Figure 5-27). FE distance slopes were negative in 2002, positive in 2004 and 2008 and approximately 0 in 2006 and 2010. There were no net significant differences in FE distance gradients Before versus After drilling began at the FE drill centre (Table 5-11). The 2002-2010 Within Stations

Quadratic Year × FE *d* contrast was significant but, for redox, that contrast was largely a test for "no simple pattern". Inclusion of stations 30(FE) and 31(FE) did not affect these conclusions (Appendix B-4).

Sulphur concentrations have been measured since 2001 and have decreased with distance from the nearest active drill centre in every year since then (Figure 5-29). The distance correlations were significant in every year except 2008. However, sulphur concentrations in 2008 were higher than in other years (Figure 5-30). Sulphur concentrations at station 30(FE) increased after drilling began at the FE drill centre (Figure 5-31). Sulphur concentrations at station 31(FE) were elevated relative to concentrations at other stations only in 2004 and 2006.

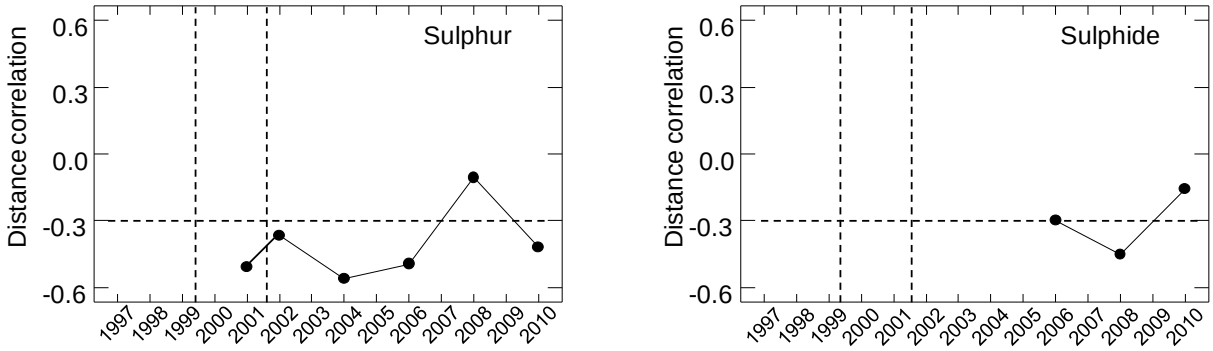


Figure 5-29 Annual Distance Correlations (r_s) for Sulphur and Sulphide (All Stations)

Notes: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres. The horizontal dashed line indicates r_s = - 0.3, which is a significant negative correlation at 0.01 < p < 0.05.

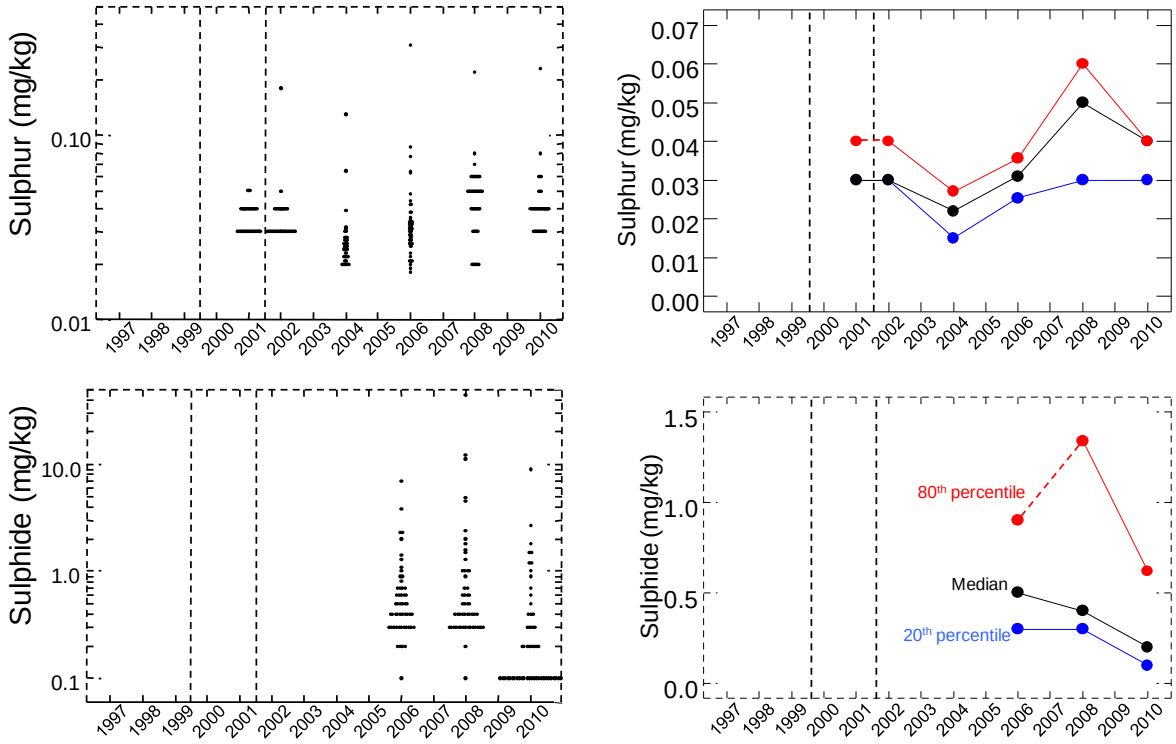


Figure 5-30 Annual Distributions, Medians, and 20th and 80th Percentiles for Sulphur and Sulphide (All Stations)

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

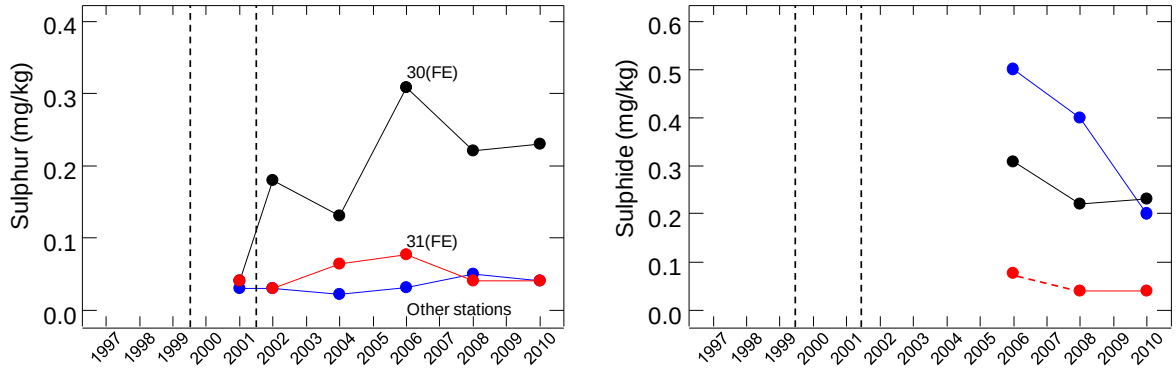


Figure 5-31 Annual Sediment Sulphur and Sulphide Values for Stations 30(FE) and 31(FE) versus Medians for Other Stations

Note: The vertical dashed lines indicate the start of drilling first at the FEZ, then at the FE drill centres.

Sulphide data with a consistent detection limit (0.2 mg/kg) were only available for 2006, 2008 and 2010. Concentrations decreased significantly with distance from the nearest active drill centre in 2006 (r_s = –0.299; p < 0.05) and 2008 (r_s = –0.450; p < 0.001) (Figure 5-29). In those two years, most concentrations were above laboratory detection limit, although medians were not substantially greater than

laboratory detection limit (Figure 5-30). In contrast, 27 of 53 concentrations in 2010 were below laboratory detection limit and the decrease with distance (r_s = –0.157) was not significant. In all three years, sulphide concentrations at stations 30(FE) and 31(FE) were higher than medians at other stations (Figure 5-31).

5.4.2 TOXICITY

5.4.2.1 Analysis of 2010 Data

Appendix B-5 provides Microtox IC50s and amphipod survival results from 1997 to 2010. In 2010, Microtox IC50s ranged from 2,707 to >197,000 mg wet/L. IC50s were less than 197,000 mg wet/L (the highest concentration tested) in 15 (of 53) samples. Thirteen of those samples were classified as toxic based on Environment Canada (2002) sample-specific interpretative guidance. IC50s less than 50,000 mg wet/L (the broader definition of toxic used in this report) occurred in eight samples.

Amphipod survival ranged from 64 to 99%, with a median survival of 91%, in 2010. The lowest survival (64%) occurred in sediments from Reference station 1(SW), more than 20 km from the nearest drill centre, and that was the only sediment sample classified as toxic based on comparison to Control sediments following Environment Canada (1998) interpretative guidance. Survival in sediments from the other Reference station (6(SE)) was 87%, also lower than the median for all stations. Given the low survival in Reference station sediments, no sediment sample was classified as toxic based on comparison to Reference and Environment Canada interpretative guidance.

Relationships with Sediment Physical and Chemical Characteristics

Microtox IC50s and amphipod survival were uncorrelated (r_s = –0.020; p >> 0.05) over all 53 samples tested in 2010.

Microtox IC50s were negatively correlated with all sediment physical and chemical variables except redox (Table 5-13), indicating that negative responses increased as values of those variables increased. 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 5-13). In 2010, strontium was the strongest correlate of Microtox IC50s, as has been the case in past EEM years (Section 5.4.4.1). Correlations between IC50s versus adjusted

fines, sulphur, sulphide and ammonia, which can negatively affect Microtox test organisms, were significant[15].

Table 5-13 Spearman Rank Correlations (r_s) Between Toxicity Test Responses and Sediment Physical and Chemical Characteristics (2010)

Physical/Chemical Variable	Microtox IC50 (wet weight)	Amphipod survival
$>C_{10}$-C_{21} hydrocarbons	–0.101	–0.045
Barium	–0.283*	–0.073
% fines	–0.429**	0.145
% adjusted fines	**–0.490*** **	0.073
% gravel	**–0.481*** **	–0.135
TOC	–0.239	–0.090
Metals PC1	–0.265	0.033
Metals PC2	–0.424**	–0.053
Strontium	**–0.621*** **	–0.046
Sulphur	–0.358**	–0.220
Sulphide	**–0.443*** **	–0.072
Ammonia	–0.337*	–0.057
Redox	0.076	–0.129

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

All correlations between amphipod survival and sediment physical and chemical variables were weak (r_s = –0.220 to 0.145) and not significant (Table 5-13). Survival at stations 30(FE) and 43(FEZ), the two stations with the highest $>C_{10}$-C_{21} hydrocarbon concentrations, was 81% and 98%, respectively. The lowest survival (64%) occurred at Reference station 1(SW), where $>C_{10}$-C_{21} hydrocarbons were not detected.

Distance Relationships

In 2010, Microtox IC50s were uncorrelated with distances from drill centres (Table 5-14). Instead, the lowest values generally occurred at intermediate distances of approximately 1 to 3 km (Figure 5-32).

[15] Correlations in Table 5-14 are not necessarily indicative of direct negative effects of sediment physical and chemical characteristics on Microtox test organisms. For instance, in 2010, gravel content was one of the strongest correlates of IC50s but gravel is excluded from the tests.

Table 5-14 Results of Rank-Rank Regressions of Toxicity Test Responses (Y) on Distance (X) Variables (2010)

Y variable	Regression on distance to nearest FEZ drill centre, and distance to FE drill centre			Regression on distance to nearest drill centre
	Multiple *R*	Partial *r*		
		Y-FEZ *d*/ FE *d* constant	*Y*-FE *d*/ FEZ *d* constant	*r* (=r_s)
Microtox IC50	0.096	0.043	0.076	–0.034
Amphipod survival	0.150	–0.109	–0.081	–0.077

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

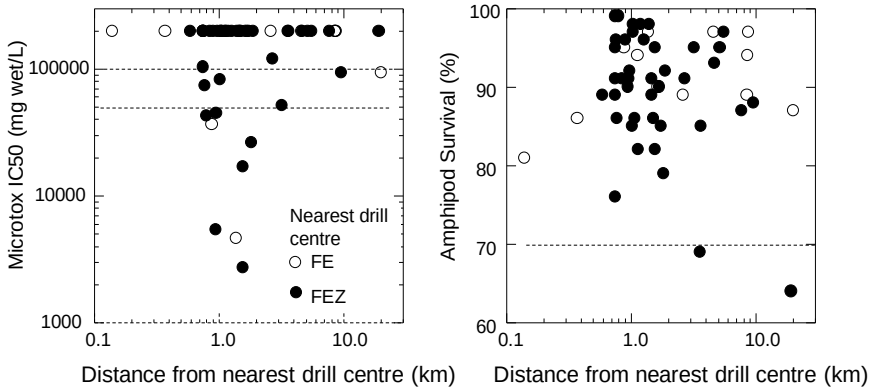


Figure 5-32 Distance Gradients for Toxicity Test Responses (2010)

Notes: The horizontal dashed lines in Figure 5-32 (left panel) are the benchmarks of 50,000 and 98,500 mg wet/L, used in this report to define 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. Based on Environment Canada (2002) interpretative guidance, negative responses would also be considered evidence of toxicity.

In 2010, amphipod survival was uncorrelated with distances from drill centres (Table 5-14). The two survival values less than 70% occurred at stations more than 3 km from drill centres (Figure 5-32).

5.4.2.2 Comparison Among Years

Table 5-15 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 from 1997 to 2010. In 1997, there were only four samples with negative responses, one of which (from station 12(NE), 8.77 km from the FE drill centre) was toxic. Frequencies of negative responses and toxicity were greater in EEM years. Frequencies of negative responses decreased from 30 to 40% in 2000, 2001 and 2002 to approximately 20% in 2004, 2006, 2008 and 2010. However, a decrease over time was less evident for toxicity (Table 5-15), as frequencies of toxicity were generally between 15 to 20% in EEM years except for 2001 (27%) and 2006 (11%).

Table 5-15 Frequencies of Samples with Negative Microtox Responses (1997 to 2010)

Year	No. stations	IC50 <98,500 mg wet/L		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
Total (All years)	416	99	21	65	16
Total (EEM years)	362	95	26	64	18

As in 2010, Microtox IC50s in past years were not strongly correlated with distances from the drill centres (Table 5-16). Distance correlations for the FEZ drill centres were strongest (and 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 distance from the FE drill centre did not increase in strength after drilling began there prior to 2002 sampling.

Table 5-16 Spearman Rank Correlations (r_s) Between Microtox IC50s and Distance Measures (1997 to 2010)

Year	No. stations	Distance from:		
		Nearest active drill centre	Nearest FEZ drill centre	FE drill centre
1997	54	–0.111	–0.067	0.147
2000	49	0.326*	0.349*	0.219
2001	49	0.175	0.175	0.161
2002	53	0.172	0.199	0.196
2004	52	0.058	0.175	0.122
2006	53	0.023	0.089	0.079
2008	53	0.161	0.100	0.197
2010	53	0.034	0.059	0.086

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- Active drill centres were NE, SW in 2000; all FEZ drill centres in 2001; all drill centres from 2002 to 2006. The NE and SW drill centres were considered "active" for analysis of 1997 (baseline) data.

As in 2010, negative responses and toxicity in past EEM years occurred mostly at intermediate distances. Figure 5-33 provides box plots of distances from the nearest active drill centre for IC50s greater than versus less than 98,500 and 50,000 mg wet/L. Median distances were similar for stations with and without negative responses, consistent with the weak positive correlations between IC50s and distance in EEM years (Figure 5-33). However, negative responses and toxicity were restricted to a narrower distance range, with a distance mid-range of 1 to 2 km from drill centres versus 1 to 5 km for other stations.

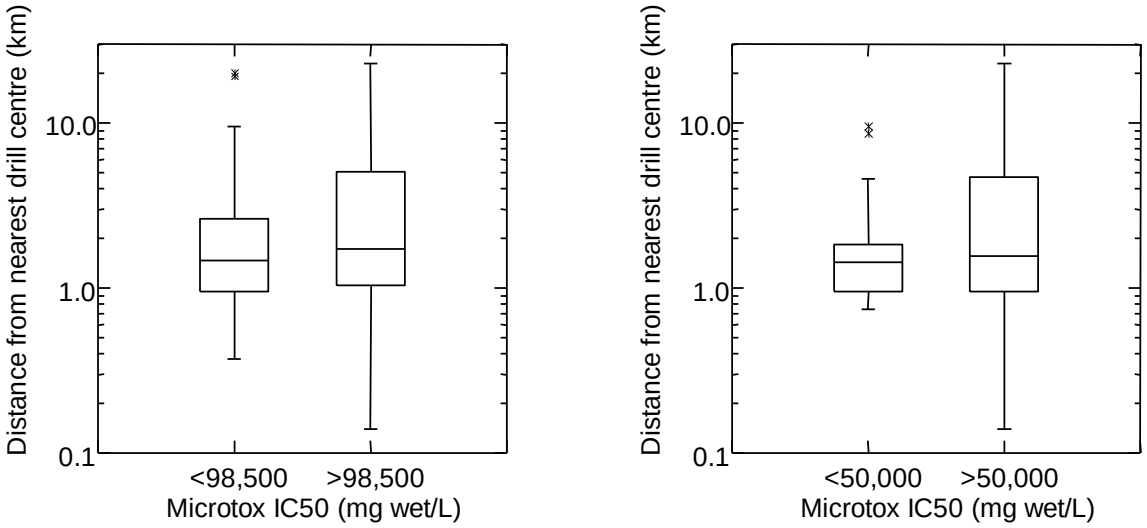


Figure 5-33 Distributions of Distances for Microtox Negative Responses and Toxicity (2000 to 2010)

Notes: The central boxes include the middle 50% of distance values (the mid-range); the horizontal lines in the boxes are medians; the vertical lines ("whiskers") include most of the remaining values; the asterisks are "outside" values (i.e., outliers).

As noted above, frequencies of Microtox toxicity (IC50s less than 50,000 mg wet/L) have been relatively constant in EEM years. Table 5-17 summarizes Microtox results for the 21 stations with IC50s less than 50,000 mg wet/L in at least one EEM year. Ten of the 21 stations listed in Table 5-17 were also sampled in baseline (1997), but baseline IC50s were greater than 98,684 mg/wet/L for nine of those stations (Station 52(FEZ), with IC50 = 50,537 mg wet/L in 1997 was the exception).

Toxicity occurred in sediments from stations 32(FE), 44(FEZ) and 49(FEZ) in all seven EEM years (Table 5-17). Negative responses or toxicity occurred in five or more EEM years at stations 9(SE), 11(SE), 15(NE), 33(FEZ), 38(FEZ) and 46(FEZ). Therefore, nine stations (less than 20% of the stations sampled annually) accounted for 47 (73%) of the 64 toxic sediments noted over all EEM years. Station 23(NW) was the only station with toxic sediments in 2010 but not in previous EEM years.

The timing of toxicity generally did not coincide with the onset of drilling at the NW and SE drill centres prior to 2001 sampling, and the FE drill centre prior to 2002 sampling, for stations near these drill centres. Toxicity has never occurred at stations 30(FE) and 31(FE), the two stations within 0.5 km of the FE drill centre, even after drilling began at that drill centre.

Table 5-17 Stations with Microtox IC50s < 50,000 mg wet/L in One or More EEM Years

Station	Nearest drill centre	Distance (km)	Year						
			2000	2001	2002	2004	2006	2008	2010
Transect stations (*n*=224 samples)									
7(SE)*	FE	8.53	O	●●	O	O	O	O	O
9(SE)*	SE	2.69	●	●●	●	●●	●●	●●	O
11(SE)*	SE	0.95	●●	●●	●●	●●	O	●●	●●
15(NE)*	NE	1.83	●●	●●	●●	●●	O	O	●●
18(NW)*	NW	9.56	O	●●	●	O	O	O	●
23(NW)*	NW	0.80	O	O	O	O	O	O	●●
29(FE)*	FE	0.88	●	●●	O	O	O	O	●●
32(FE)*	FE	1.37	●●	●●	●●	●●	●●	●●	●●
FEZ stations (n=138 samples)									
33(FEZ)	NW	0.75	●●	●●	●	●●	O	●●	O
37(FEZ)	NE	0.75	●●	●	●	O	O	O	O
38(FEZ)	NE	1.47	●●	●●	●	●●	O	●●	O
39(FEZ)	SE	1.46	O	O	O	O	O	●●	O
40(FEZ)	SE	0.76	O	O	O	O	●●	O	O
41(FEZ)	SE	0.75	●●	●●	●	O	O	●●	O
43(FEZ)	SW	1.41	O	O	●●	O	O	O	O
44(FEZ)	SW	0.95	●●	●●	●●	●●	●●	●●	●●
46(FEZ)	SW	0.78	●	●●	●●	●●	O	O	●
48(FEZ)	SW	1.14	●●	O	O	NS	O	O	O
49(FEZ)	NW	1.55	●●	●●	●●	●●	●●	●●	●●
51(FEZ)*	NE	1.28	NS	NS	●	O	●●	O	O
52(FEZ)*	SE	1.57	NS	NS	●●	●●	O	O	●●

Notes: - ●● - IC50 < 50,000; ● - 50,000 < IC50 < 98,500; O - IC50 > 98,500; units for IC50s are mg wet/L.
- * Sampled in baseline (1997); NS = Not Sampled.

5.4.3 BENTHIC COMMUNITY STRUCTURE

5.4.3.1 Overview

Over the eight sample years (1997, 2000, 2001, 2002, 2004, 2006, 2008 and 2010), 165 invertebrate families have been collected (Table 5-18), excluding meiofauna (oligochaetes, protodrilids, copepods, ostracods, nematodes, nemerteans).

In 2010, 46,557 benthic macro-invertebrates (i.e., excluding meiofauna) from 113 families were collected in 106 samples from 53 stations (Table 5-18). Samples were dominated by polychaetes, which accounted for approximately 86% of total abundance in previous years, and 82% in 2010. Molluscs and crustaceans were the only other phyla accounting for more than 1% of total abundance in 2010 samples. Bivalves were the most abundant molluscs. Amphipods were the most abundant crustaceans.

Table 5-18 Abundant Taxa (Families) in Benthic Invertebrate Elutriate Samples (2000 to 2010)

Taxon			2000 to 2008		2010	
Phylum or Subphylum	**Class or Order**	**Family**	**% of organisms**	**% of samples**	**% of organisms**	**% of samples**
Porifera			0.1	22	<0.1	13
Cnidaria			0.5	70	0.4	83
Platyhelminthes			<0.1	0.3	<0.1	1.9
Priapulida			<0.1	0.3	0	0
Annelida	Polychaeta	Sub-total	86	100	82	100
		Spionidae	37	100	38	100
		Syllidae	12	100	11	100
		Cirratulidae	16	100	8.9	100
		Phyllodocidae	3.4	99	4.0	100
		Sabellidae	2.2	87	3.7	89
		Paraonidae	2.8	87	3.6	92
		Pholoidae	3.8	88	2.2	87
		Capitellidae	1.2	90	1.7	91
		Orbiniidae	1.2	71	1.3	79
		Maldanidae	1.4	73	1.2	68
		Opheliidae	0.6	62	1.1	66
		Glyceridae	0.8	62	0.8	62
		Dorvilleidae	0.5	52	0.7	57
		Terebellidae	0.4	52	0.7	64
		Polynoidae	0.9	84	0.7	81
		Ampharetidae	0.7	50	0.6	58
		Nereidae	0.4	47	0.5	43
		Hesionidae	0.3	43	0.5	58
Sipuncula			0.2	28	0.4	57
Mollusca	Polyplacophora	Sub-total	<0.1	0.3	<0.1	2
	Bivalvia	Sub-total	2	100	3	100
		Tellinidae	1.1	72	1.7	94
		Hiatellidae	0.6	91	0.7	89
	Gastropoda	Sub-total	1.1	77	2.1	89
		Lepetidae	0.7	43	1.6	60
Crustacea	Amphipoda	Sub-total	4	98	4	100
		Phoxocephalidae	1.3	74	1.4	83
		Stenothoidae	0.9	51	0.7	66
		Oedicerotidae	0.6	74	0.6	83
		Ampeliscidae	0.4	35	0.5	34
	Cirripedia	Balanidae	2	56	3	57
	Cumacea		0	67	1	94
	Decapoda		<0.1	23	<0.1	25
	Isopoda		0.2	36	0.2	51
	Tanaidacea		2	56	2	77
Chelicerata	Pycnogonida		<0.1	2	<0.1	2
Brachiopoda					<0.1	2
Echinodermata			0.4	89	0.2	81
Hemichordata			0	11	1	62
Grand Total Count			219,713		46,557	

In 2010 and previous years, invertebrate communities were dominated by three polychaete families: Spionidae, Syllidae and Cirratulidae (Table 5-18). These three families were collected at every station in every year and accounted for almost 60% of the total number of invertebrates collected in EEM samples in 2010.

Table 5-18 also provides relative abundances and occurrences for families accounting for at least 0.5% of total abundance in 2010 and from 2000 to 2008. Most of the other common families were also polychaetes. Tellinidae (mostly *Macoma*) and Hiatellidae (*Cyrtodaria* and *Hiatella*) were the dominant bivalve families (Table 5-18). Lepetidae (*Lepeta*) was the dominant gastropod family. Tanaidacea (Order) was the most abundant crustacean. Phoxocephalidae (*Phoxocephalus*) was the dominant amphipod family.

Figure 5-34 is a plot of NMDS station scores for 348 Elutriate samples from 2000 to 2010. The stress coefficient, a measure of the fit between the original pair-wise B-C 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 B-C distances among the 348 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 B-C distance of relative (or %) abundances. In Figure 5-34, 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 5-35 is a plot of Spearman rank correlations (r_s) between relative abundances of individual families and the station scores along the two NMDS axes. This is effectively a plot of differences among taxa and the weighting of taxa along the NMDS axes. An “overlay” of Figure 5-35 onto Figure 5-34 would indicate approximately which stations taxa had high relative (%) abundances. For example, stations in the lower left quadrant of Figure 5-34 (negative NMDS1 and NMDS2 scores) would have greater relative abundances of taxa in the lower left quadrant of Figure 5-35 (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 5-35; i.e., r_s with both NMDS axes approximately 0).

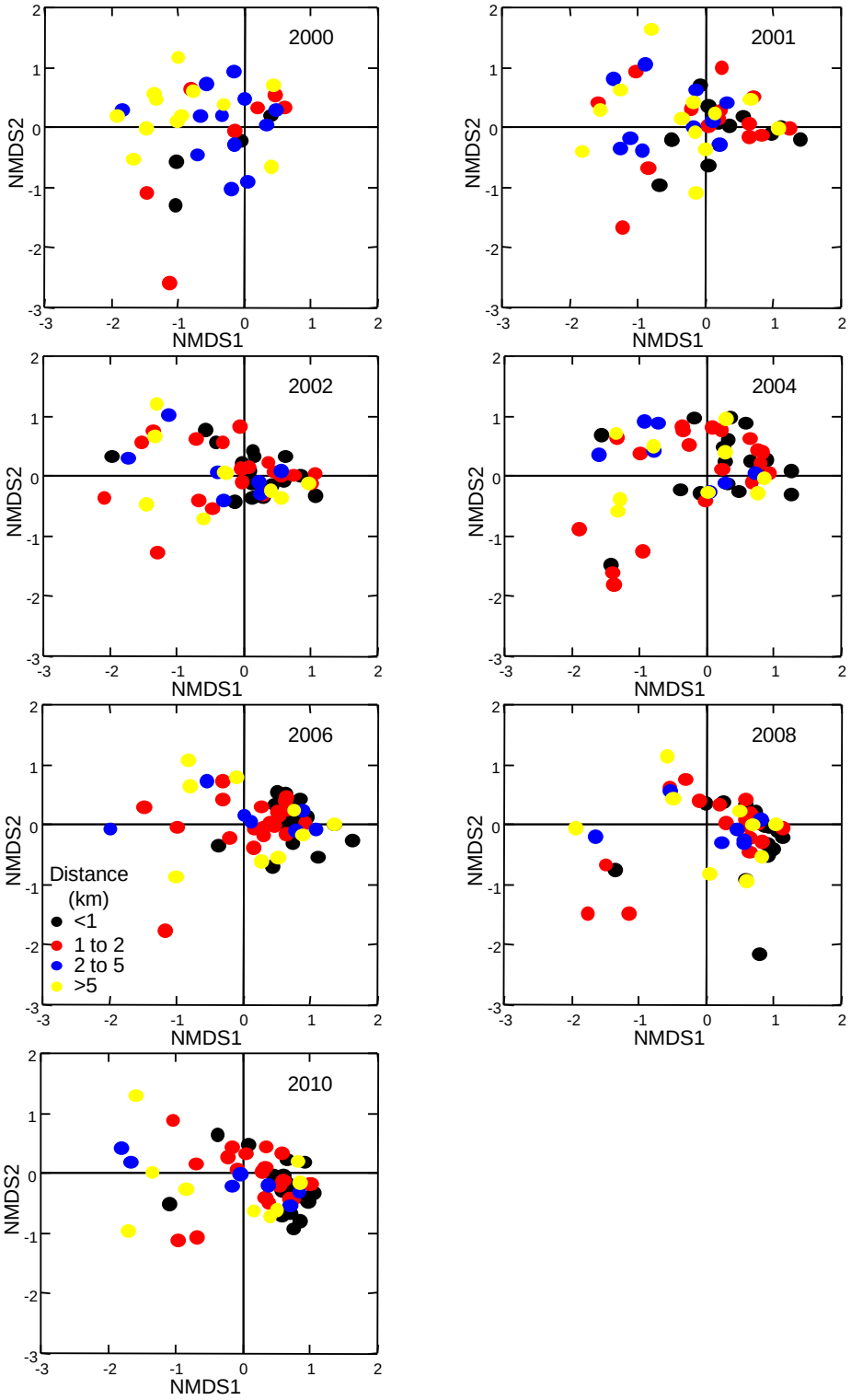


Figure 5-34 Non-Metric Multidimensional Scaling Plots Based on Relative Abundances of Invertebrate Taxa (2000 to 2010 Elutriate Samples)

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 2010).

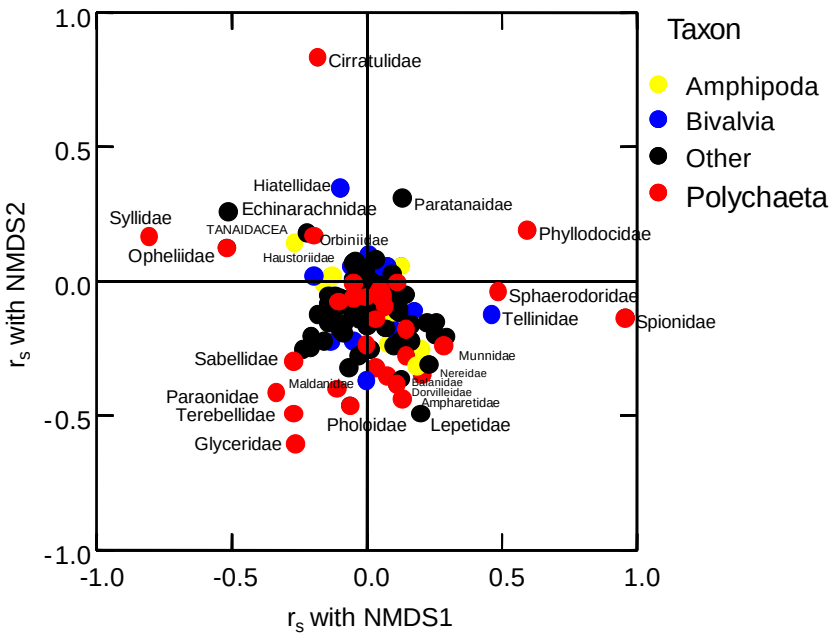


Figure 5-35 Spearman Rank Correlations (r_s) Between Family Relative (%) Abundances and Non-Metric Multidimensional Scaling (NMDS) Axes (2000 to 2010 Elutriate Samples)

The three dominant polychaete families (Spionidae, Syllidae and Cirratulidae) largely defined overall community differences along the NMDS axes among stations in Figure 5-34, and differences among taxa or groups of taxa in Figure 5-35. The first NMDS axis (NMDS1) was strongly positively correlated with the relative abundance of Spionidae and strongly negatively correlated with the relative abundance of Syllidae (Figure 5-35). In other words, NMDS1 scores represent a Spionidae versus Syllidae contrast or, more generally, Spionidae dominance. NMDS1 scores were also positively correlated with the relative abundances of the sub-dominant families Phyllodocidae (Polychaeta) and Tellinidae (Bivalvia) (Figure 5-35). Abundances of the polychaete family Sphaerodoridae was strongly positively associated with NMDS1 scores, but that family accounted for a minor fraction of the total numbers in 2010 (less than 0.4%). These correlations, which were evident with relative (%) abundances of various polychaete families, were also evident with absolute abundances of the same families (see Section 5.4.3.2). Therefore, NMDS1 scores reflected variations in percent composition (by family), and absolute abundances of those same taxa.

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). What makes the interpretation of NMDS2 scores somewhat challenging is that the scores were strongly negatively correlated with absolute numbers per station (not % abundances) of dominant polychaetes Spionidae, Syllidae and Paraonidae, and were uncorrelated with absolute numbers per station of Cirratulidae. The NMDS2 scores, therefore, clearly reflected variations in the relative contributions to the fauna made by those taxa, but not absolute numbers of those taxa. Negative NMDS2 scores occurred at stations with higher diversity of benthic fauna.

5.4.3.2 Analysis of 2010 Data

Summary Statistics

In 2010, total abundance varied by more than 10-fold (the range of values was 165 to 1,984) among stations, with standard deviations (SD) more than 60% of the mean (Table 5-19). Coefficients of Variations (CVs) were approximately 80 to 90% 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%, with abundances of 0 occurring at one or more stations. Biomass varied almost 25-fold (approximately 20 to 500 g wet/station) among stations, with a CV of 58% (Table 5-19).

Table 5-19 Summary Statistics for Invertebrate Community Variables (2010)

Variable	Unit/Interpretation	Min	Max	Median	Mean	SD	CV
Summary measures							
Total abundance (*N*)	No. organisms/station	165	1984	789	878	526	60
Biomass (*B*)	g wet/station	20	497	175	201	117	58
Richness (*S*)	No. taxa/station	15	56	37	36	12	34
Adjusted richness (*S2*)	Observed : Expected *S*	0.66	1.40	1.11	1.09	0.19	17
NMDS1	Spionidae dominance	-1.810	1.055	0.408	0.143	0.797	
NMDS2	Cirratulidae dominance	-1.117	1.289	-0.190	-0.155	0.485	
Taxon abundances							
Spionidae	No. organisms/station	9	967	262	332	269	81
Cirratulidae	No. organisms/station	4	333	54	78.0	73.0	94
Syllidae	No. organisms/station	13	304	80	100.5	66.0	66
Orbiniidae	No. organisms/station	0	79	4	11.6	17.7	152
Paraonidae	No. organisms/station	0	218	10	31.5	45.7	145
Phyllodocidae	No. organisms/station	2	101	31	34.9	25.6	73
Tellinidae	No. organisms/station	0	104	4	14.6	22.3	152
Amphipoda	No. organisms/station	1	245	21	38.1	42.8	112
Echinodermata	No. organisms/station	0	65	5	8.9	12.6	141

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).

Richness and adjusted richness varied less (i.e., had lower CV's) among stations than abundances and biomass (Table 5-22). In 2010, 15 to 56 taxa were collected per station. Average (i.e., mean and median) adjusted richness values were approximately 1.

In 2010, mean and median NMDS1 scores were slightly positive, and mean and median NMDS2 scores were slightly negative (Table 5-19). Therefore, communities in 2010 were shifted downwards and/or to the right in Figure 5-34.

Correlations Among Community Variables

Table 5-20 provides rank correlations among benthic invertebrate community summary measures for 2010 stations. Richness adjusted for abundance (adjusted richness) removed most of the positive correlation between raw richness and abundance, though those two variables still covaried in the 2010 data. NMDS1 scores were somewhat strongly correlated (r_s = 0.454) with total abundance, and uncorrelated with richness or adjusted richness. NMDS2 scores were strongly negatively correlated with total abundance (r_s = –0.612), richness (r_s = –0.662) and adjusted richness (r_s = –0.587; Table 5-20). Lower NMDS2 scores, therefore, corresponded with stations that had higher overall abundance and richness. Biomass was uncorrelated with other summary measures (Table 5-20).

Table 5-20 Spearman Rank Correlations (r_s) Among Primary Benthic Invertebrate Community Variables (2010)

	Total abundance (*N*)	Biomass (*B*)	Richness (*S*)	Adjusted Richness (*S2*)	NMDS1
Biomass (*B*)	0.147	1			
Richness (*S*)	**0.913*** **	0.161	1		
Adjusted richness (*S2*)	**0.545*** **	0.127	**0.814*** **	1	
NMDS1	**0.454*** **	0.137	0.264	-0.032	1
NMDS2	**-0.612*** **	-0.041	**-0.662*** **	**-0.587*** **	-0.268

Notes: - n = 53 stations including 30(FE) and 31(FE).
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

Correlations (all positive) between abundances of the three dominant polychaete families (Spionidae, Cirratulidae, Syllidae) and total abundance were significant (Table 5-21). Abundances of Tellinidae and Phyllodocidae, which co-varied with Spionidae abundance, were also significantly positively correlated with total abundance, as were amphipod and echinoderm abundances.

Table 5-21 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures versus Taxon Abundances (2010)

Taxon abundances	Summary measures					
	Total abundance (*N*)	**Biomass (*B*)**	**Richness (*S*)**	**Adjusted richness (*S2*)**	**NMDS1**	**NMDS2**
Spionidae	**0.895*** **	0.155	**0.771*** **	0.389**	**0.741*** **	**-0.456*** **
Cirratulidae	**0.566*** **	0.122	**0.490*** **	0.236	0.266	0.093
Syllidae	0.350*	-0.183	**0.449*** **	0.434**	**-0.442*** **	-0.341*
Orbiniidae	-0.011	-0.002	-0.060	-0.056	-0.073	0.007
Paraonidae	0.209	-0.200	0.231	0.244	-0.138	**-0.466*** **
Phyllodocidae	**0.644*** **	0.072	**0.520*** **	0.210	**0.714*** **	-0.184
Tellinidae	**0.526*** **	0.276*	**0.488*** **	0.251	0.416**	-0.147
Amphipoda	**0.671*** **	0.123	**0.672*** **	**0.486*** **	0.109	-0.370**
Echinodermata	**0.586*** **	0.107	**0.654*** **	**0.538*** **	-0.253	-0.435**

Note: - n = 53 stations including 30(FE) and 31(FE).
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

Biomass was weakly positively correlated with abundances of Tellinidae bivalves (Table 5-21).

As was the case for abundance, richness was positively and significantly correlated with abundances of all of the taxa listed in Table 5-21 except for Orbiniidae and Paraonidae. 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.

Abundances of Spionidae, Tellinidae and Phyllodocidae were positively correlated with NMDS1. Syllidae abundances were negatively correlated with NMDS1. Cirratulidae abundances were positively correlated with NMDS2, and Spionidae, Paraonidae, amphipod and echinoderm abundances were negatively correlated with NMDS2 (Table 5-21).

Detailed correlations between benthic invertebrate community measures and sediment physical and chemical characteristics and with sediment toxicity results are presented in Appendix B-4.

Distance Regressions

Correlations between benthic community variables and distance from the nearest FEZ drill centre were generally stronger than correlations between the community

variables and distance from the FE drill centre (Table 5-22; Figure 5-36; Figure 5-37). For many community variables, r_s with distance from the nearest drill centre (Min *d*) were similar to *R* for multiple regressions on distances from the FEZ and FE drill centres, indicating that a single distance measure (Min *d*) was usually adequate to detect and describe distance gradients. There were no indications from the 2010 data that threshold models (hockey-stick models) were necessary to describe the relationship between benthic community variables and distance to drill centre (see Figures 5-36 and 5-37).

Table 5-22 Results of Rank-Rank Regressions of Benthic Invertebrate Community Variables (Y) on Distance (X) Variables (2010)

Community (*Y*) variable	Regression on distance from nearest FEZ drill centre (FEZ *d*), and distance from FE drill centre (FE *d*)			Regression on distance from nearest drill centre
	Multiple *R*	Partial *r*		*r* (=r_s)
		Y-FEZ *d*/ FE *d* constant	*Y*-FE *d*/ FEZ *d* constant	
Summary measures				
Total abundance (*N*)	0.101	-0.097	0.048	-0.081
Biomass (*B*)	0.347*	-0.151	0.339*	0.061
Richness (*S*)	0.105	0.019	-0.105	-0.025
Adjusted richness (*S2*)	0.299*	0.246	-0.226	0.117
NMDS1	0.404**	-0.394**	0.183	-0.409**
NMDS2	0.186	-0.186	0.024	-0.017
Taxon abundances				
Spionidae	0.261	-0.260	0.037	-0.267
Cirratulidae	0.302*	-0.299*	0.021	-0.236
Syllidae	**0.512*** **	**0.448*** **	-0.384**	0.314*
Orbiniidae	**0.598*** **	**0.500*** **	0.329*	**0.637*** **
Paraonidae	**0.678*** **	**0.670*** **	0.006	**0.613*** **
Phyllodocidae	**0.555*** **	**-0.554*** **	0.122	**-0.485*** **
Tellinidae	**0.457*** **	**-0.457*** **	0.115	-0.346*
Amphipoda	0.409**	0.302*	0.240	0.386**
Echinodermata	0.362**	0.357**	-0.144	0.249

Notes: - n = 53 stations including 30(FE) and 31(FE).
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

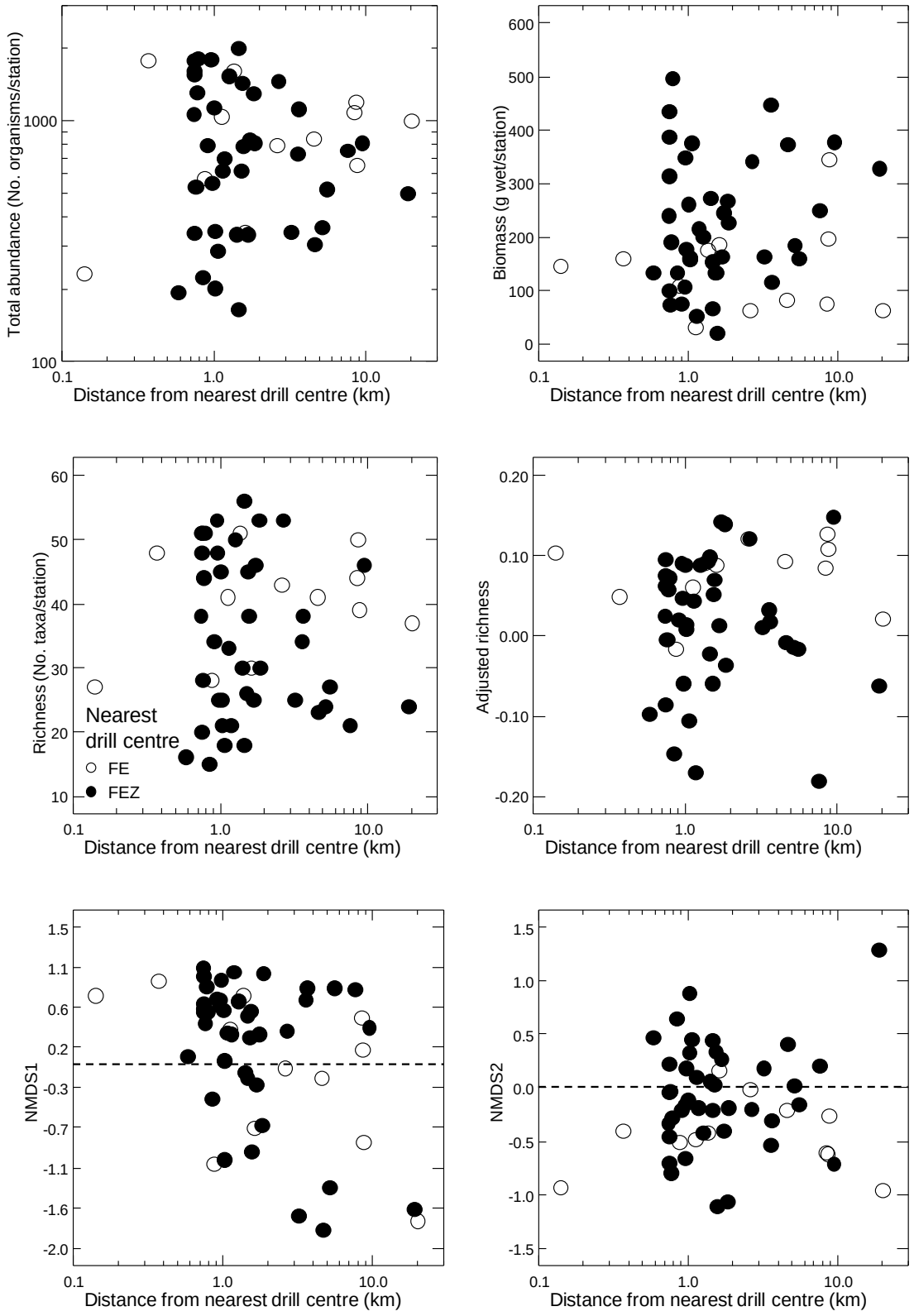


Figure 5-36 Distance Gradients for Benthic Invertebrate Summary Measures (2010)

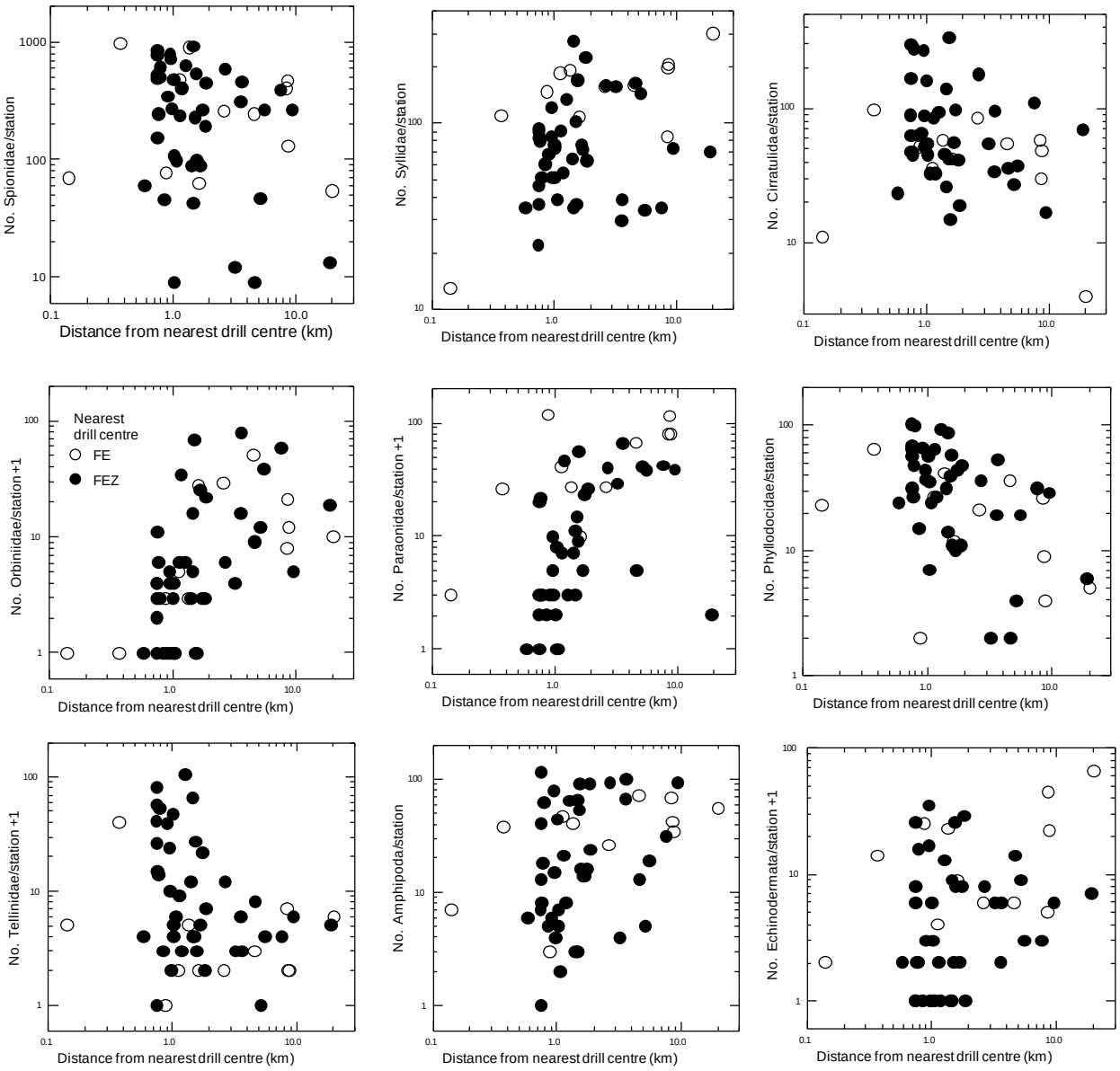


Figure 5-37 Distance Gradients for Benthic Invertebrate Taxon Abundances (2010)

Total abundance, richness, NMDS2 and abundances of the dominant polychaete taxa Spionidae were uncorrelated with distances to drill centres. Biomass, adjusted richness, NMDS1 scores and absolute abundances of Cirratulidae, Syllidae, Orbiniidae, Paraonidae, Phyllodocidae, Tellinidae, Amphipoda and Echinodermata did vary in relation to distance from drill centres (Table 5-22). Distance relationships were stronger for NMDS1, Syllidae, Orbiniidae, Paraonidae, Phyllodocidae and Tellinidae.

NMDS1 scores decreased with increasing distances from the nearest drill centre, reflecting an overall change in community composition. Abundance of Syllidae was lowest at station 30(FE), 0.14 km from the FE drill centre and abundances generally increased with increasing distance. Abundances of Orbiniidae and Paraonidae polychaetes were lower (less than 10 per station) near drill centres and increased (to upwards of 100 per station) with distance from drill centres, while abundances of Phyllodocidae polychaetes were higher (about 100 per station) near drill centres and decreased (to less than 10 per station) with distance from drill centres (Figure 5-37). Tellinide abundance decreased with distance from drill centres.

Abundance, biomass, richness and NMDS2 were relatively low at station 30(FE), and NMDS1 and adjusted richness were relatively high, but values at station 30(FE), the station nearest to a drill centre, were within the range of values noted at other stations (i.e., values were not extremes). Among the individual taxa, Syllidae abundances were lower at station 30(FE) than elsewhere.

5.4.3.3 Comparison Among Years

Figure 5-38 provides Spearman rank (r_s) correlations between invertebrate community summary variables and distance to the nearest active drill centre, while Figure 5-39 provides the same for dominant taxon abundances. In each figure, the distance correlation is presented on the Y-axis. The horizontal dashed lines in Figures 5-38 and 5-39 indicate Spearman rank correlations of ± 0.3, which would be significant (i.e., 5% likelihood of occurring by chance, p = 0.05) given the sample sizes involved during EEM years (i.e., 38 to 53 stations).

Total abundances decreased with distance from the nearest drill centre only in 2004, with distance correlations not significant in other years. Biomass increased with distance from the nearest drill centre only in 2004. Correlations for richness have never been significant. Adjusted richness has increased significantly with distance to the nearest drill centre in 2004, 2006 and 2008. NMDS1 scores have decreased significantly with distance from the nearest drill centre in all years except 2002 and 2004. NMDS2 scores increased significantly with distance from the nearest drill centre in year 2000. Of the summary invertebrate community variables, only NMDS1 scores varied significantly with distance from the nearest active drill centre in 2010; all of the other distance correlations in 2010 were not significant (Figure 5-38).

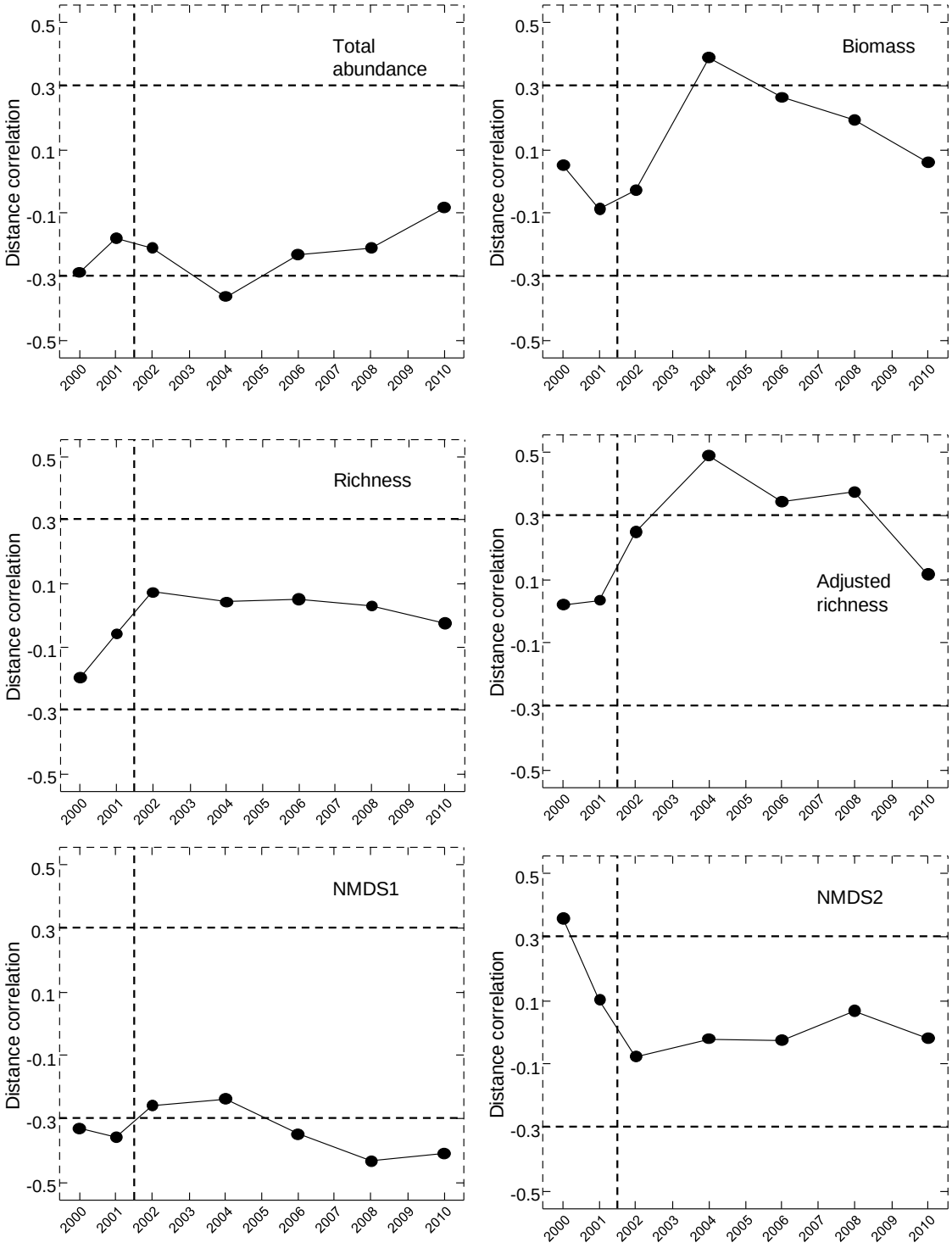


Figure 5-38 Annual Distance Correlations (rs) for Benthic Invertebrate Community Summary Measures (Elutriate Samples from All Stations)

Notes: The vertical dashed line indicates the start of drilling at the FE drill centre. The horizontal dashed line indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 < p < 0.05$.

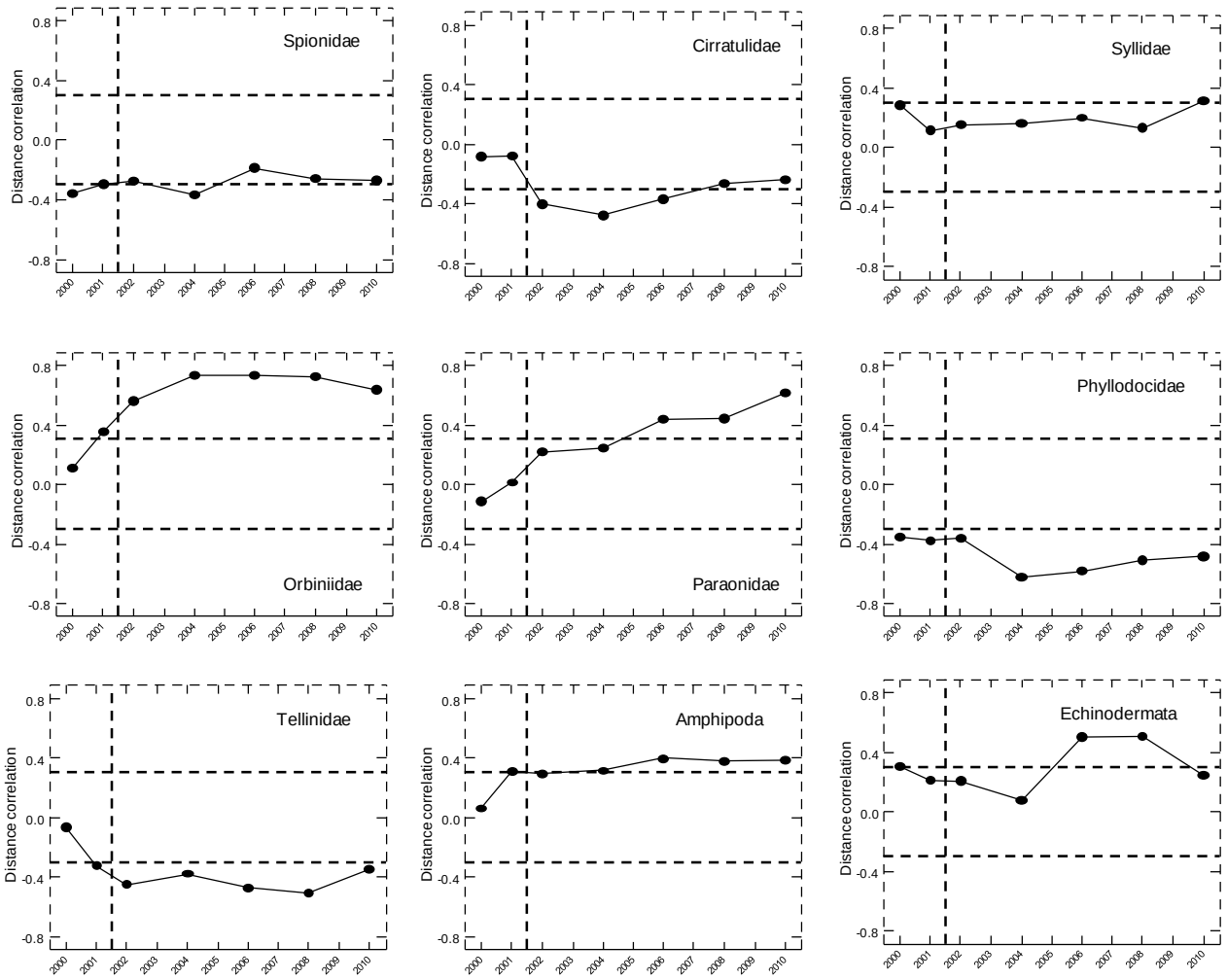


Figure 5-39 Annual Distance Correlations (r_s) for Benthic Invertebrate Taxon Abundances (Elutriate Samples from All Stations)

Notes: The vertical dashed line indicates the start of drilling at the FE drill centre. The horizontal dashed line indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 < p < 0.05$.

Distance correlations for selected dominant taxa were generally stronger than distance correlations for summary community variables. Orbiniidae polychaete abundances increased significantly with distance to the nearest drill centre since 2004, and the distance correlation for Paraonidae polychaetes steadily increased in strength from year 2000 to 2010, with significant correlations in 2006, 2008 and 2010 (Figure 5-39). Abundances of amphipods have increased significantly with distance from drill centres since 2004. Echinoderm abundances have generally increased with distance, though the distance correlations have been statistically significant only in 2006 and 2008.

Negative distance correlations, with abundances decreasing with distance from the nearest drill centre, were noted for other taxa. Negative distance correlations for Spionidae polychaete were only significant in 2004. Negative correlations were significant in 2002, 2004 and 2006 for Cirratulidae polychaetes. Negative distance correlations for Tellinidae bivalve have been significant since 2002, while Phyllodocidae polychaete distance correlations have been negative since 2000.

Figures 5-40 through 5-42 (community variables) and 5-43 (dominant taxa) illustrate variations over time during EEM years with elutriate samples with dot-density diagrams, and estimates of 20^{th}, 80^{th} and medians for each variable. Total abundance increased from 2000 to 2010 (Figure 5-40). Approximately 200 and 1,000 organisms per station were noted in 2000; between 200 and 2,000 organisms per station were noted in 2010. Abundance medians approximately doubled from 500 to 1,000 organisms/station between 2000 and 2010. Overall, biomass has remained relatively consistent since year 2000, ranging between approximately 50 and 400 g wet/station, and with median biomass remaining relatively consistent at just less than 200 g wet/station. Biomass values in 2002 were slightly lower than in remaining years (Figure 5-40).

Richness varied between 20 and 50 taxa per station in year 2000, and between about 15 and 55 in 2010, with medians slightly higher since 2006 than in previous years (Figure 5-41). Adjusted richness values were generally higher in 2000, 2001 and 2002 than in subsequent years, but values have increased since 2004 (Figure 5-41). There has been a steady increase over time in the median of NMDS1 scores, and a steady decline in the median of NMDS2 scores over the period of study from 2000 to 2010 (Figure 5-42).

Numbers of Paraonidae and Echinodermata have been relatively low in all years. Paraononid polychaete abundances have varied between fewer than five organisms per station to between 25 and 40 organisms per station, across all study years (Figure 5-43). The median echinoderm abundance has been less than five organisms per station in all years.

Spionidae and Phyllodocidae abundances have increased over time. Spionidae median abundances increased from about 100 organisms per station in 2000 to about 300 organisms per station in 2010. Median abundances of Phyllodocidae increased from about 10 to 30 organisms per station over the study period.

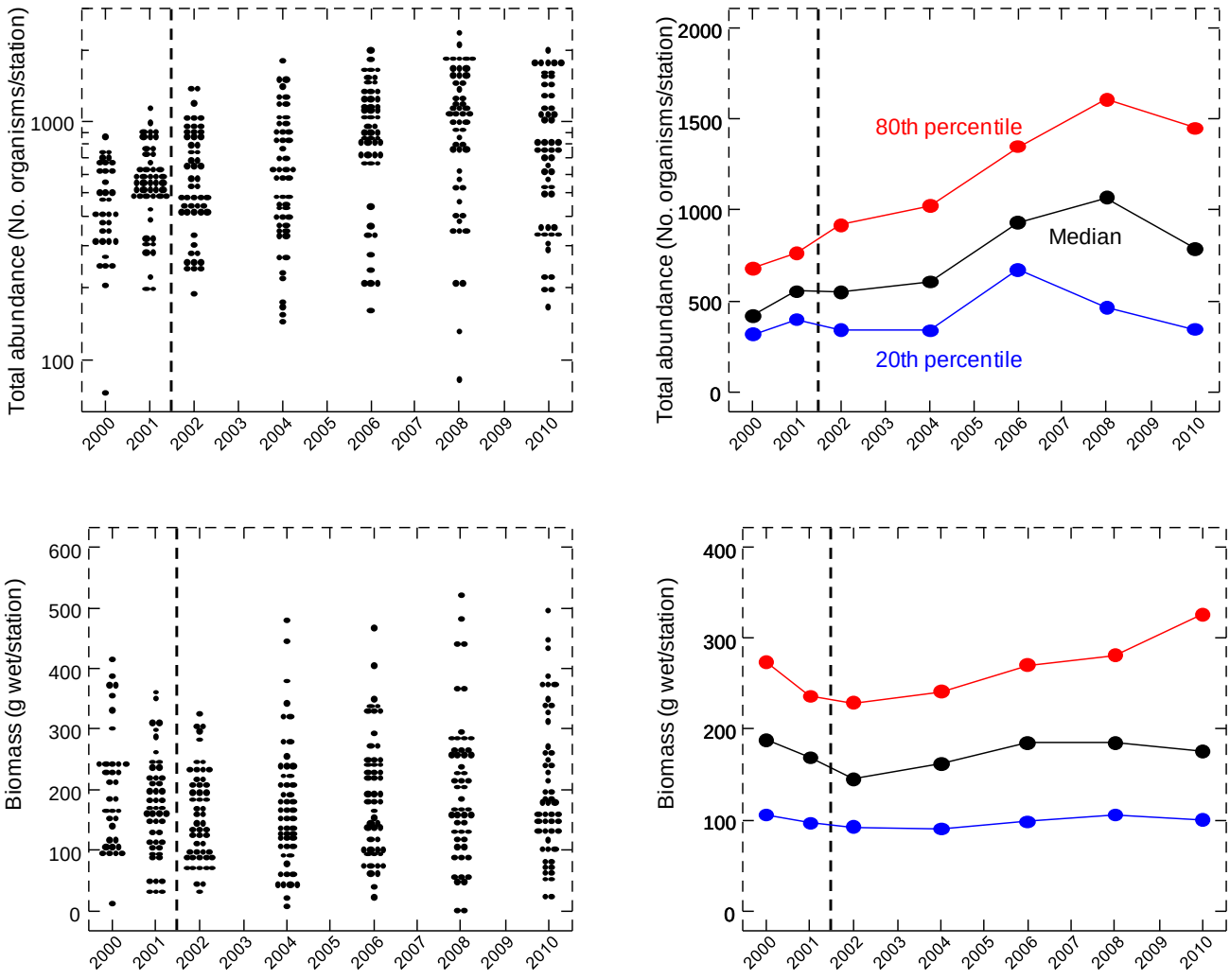


Figure 5-40 Annual Distributions, Medians and 20th and 80th Percentiles for Total Abundance and Biomass (Elutriate Samples from All Stations)

Note: The vertical dashed line indicates the start of drilling at the FE drill centre.

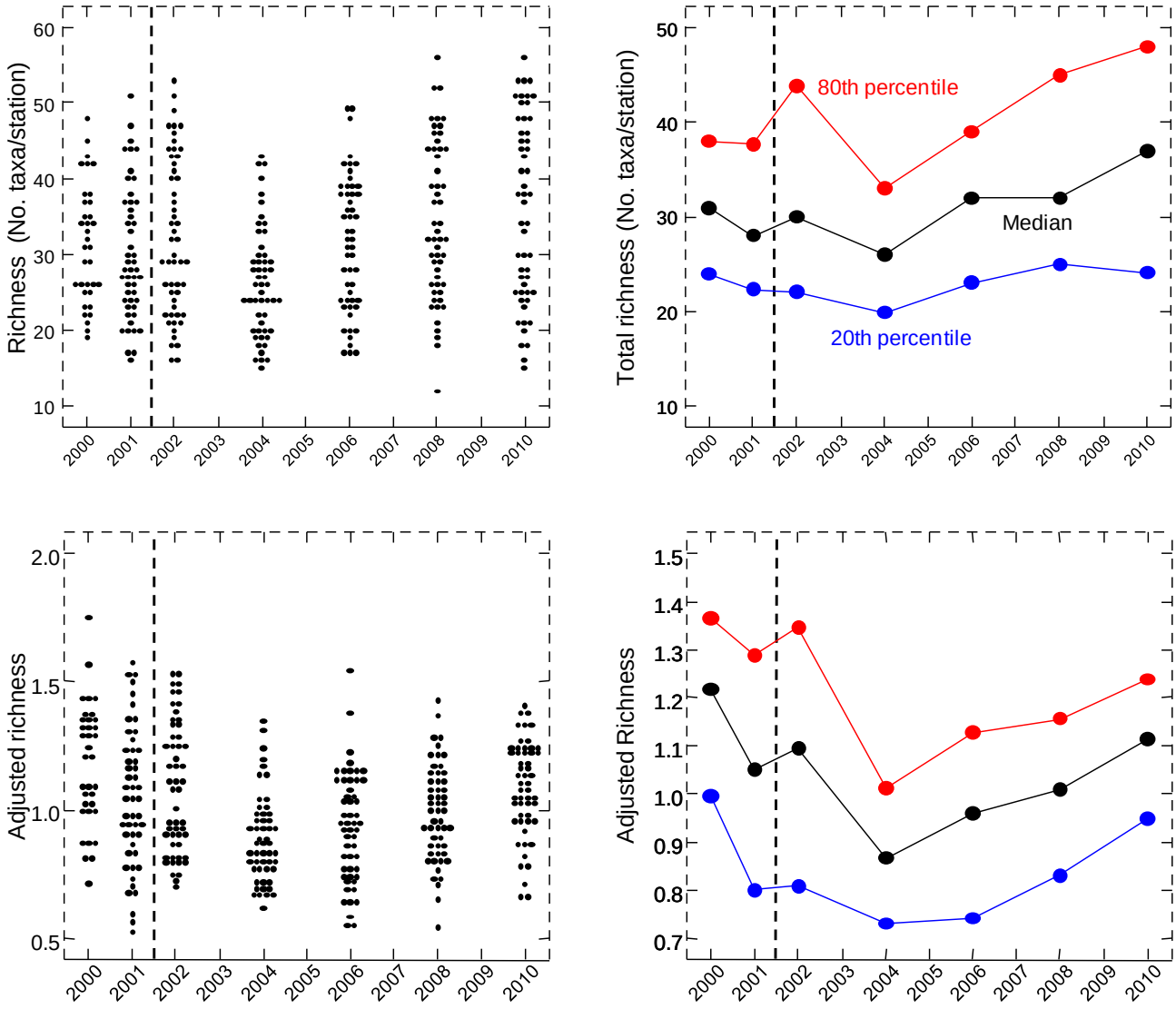


Figure 5-41 Annual Medians and 20th and 80th Percentiles for Richness and Adjusted Richness (Elutriate Samples from All Stations)

Note: The vertical dashed line indicates the start of drilling at the FE drill centre.

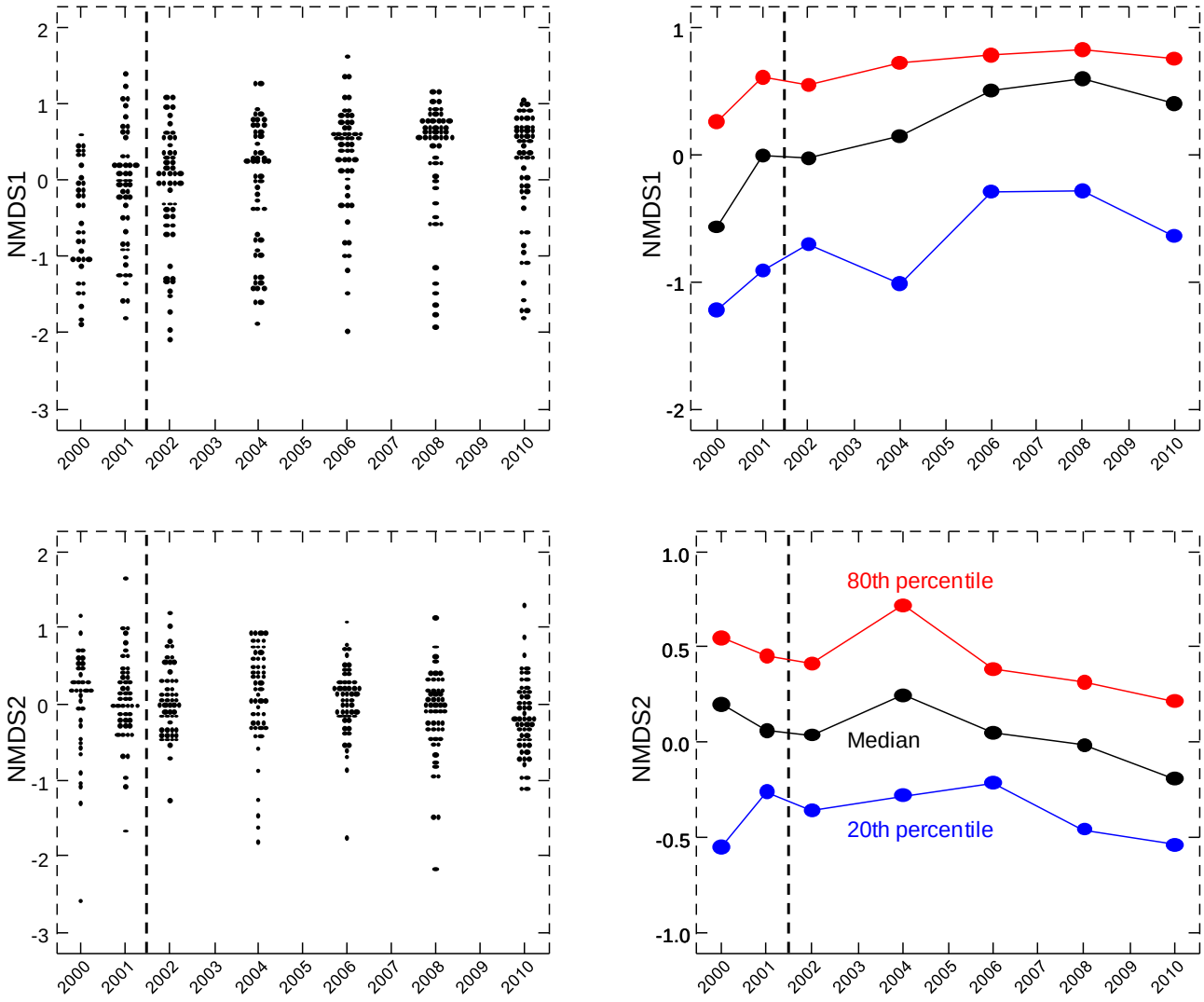


Figure 5-42 Annual Distributions, Medians and 20th and 80th Percentiles for NMDS1 and NMDS2 (Elutriate Samples from All Stations)

Note: The vertical dashed line indicates the start of drilling at the FE drill centre.

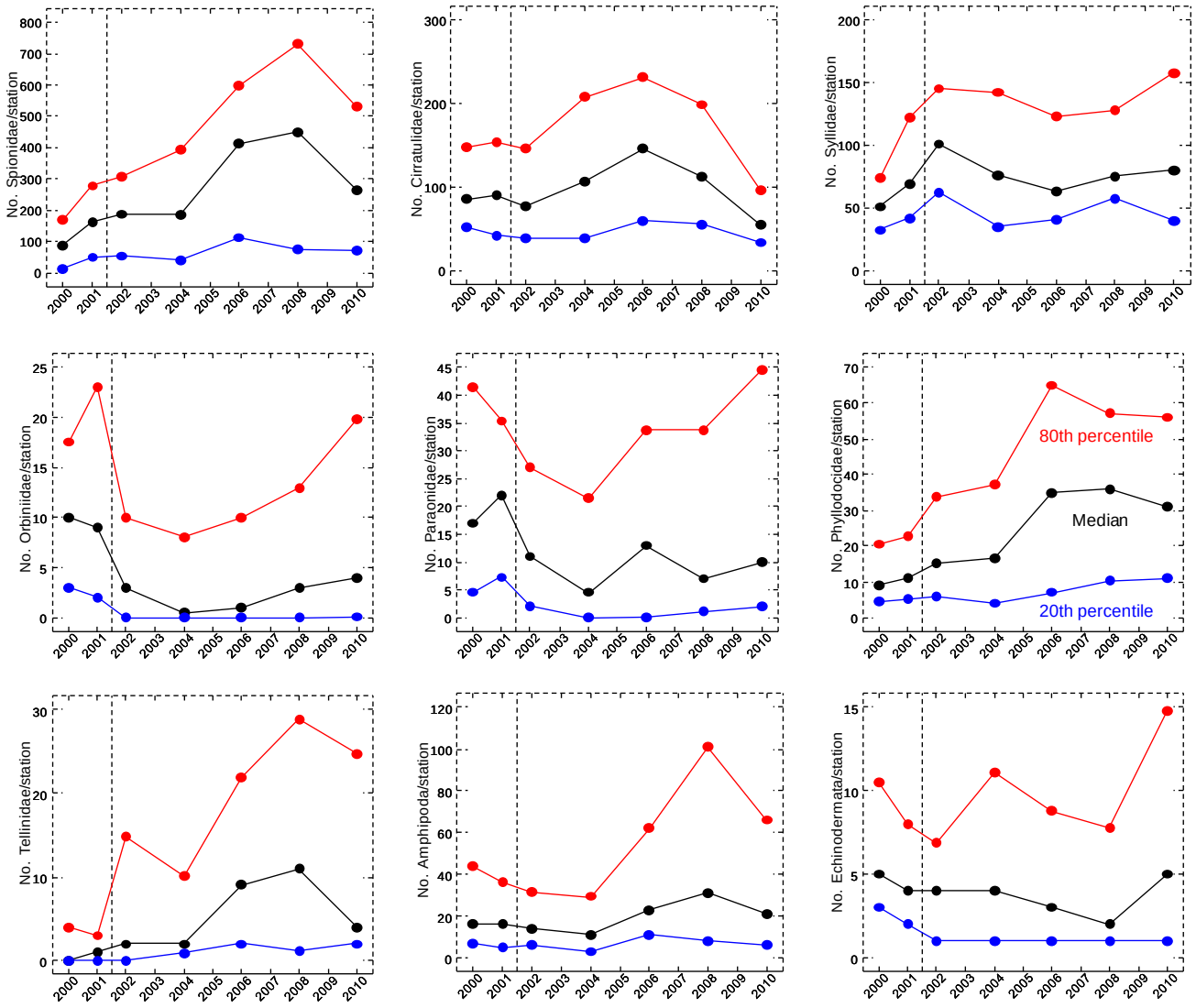


Figure 5-43 Annual Median and 20th and 80th Percentiles for Dominant Benthic Invertebrate Taxon Abundances (Elutriate Samples from All Stations)

Note: The vertical dashed line indicates the start of drilling at the FE drill centre.

The range of Tellinidae and Amphipoda abundances increased over the study period: Tellinidae abundances increased from 0 to 5 organisms per station in 2000 to approximately 2 to 25 organisms in 2010; amphipod abundances increased subtly from 10 to 40 organisms per station in 2000 to 10 to 65 organisms per station in 2010. The range of abundances of Cirratulidae polychaetes declined in 2010 (50 to 100 organisms per station) from a more typical range (for this group) of between 50 and 150 organisms per station in prior years.

Table 5-23 provides results of repeated-measures regression analysis comparing benthic invertebrate community summary measures among years. Appendix B-4 provides details on the repeated-measures models. Stations included were the 46 stations re-sampled every year from 2001 to 2010 and processed using the Elutriate recovery method, but excluding stations 30(FE) and 31(FE), which were outliers for most variables. Repeated-measures analysis results including stations 30(FE) and 31(FE) are provided in Appendix B-4.

For interpretation of repeated-measures regression results in Table 5-23 and elsewhere:

1. **The Among-Stations terms** test relationships between multi-year means and the two distance (*X*) measures (FEZ and FE *d*) (i.e., overall relationships between community variable values and distance to the FE or FEZ). The Error 1 term tests for carry-over effects (persistent differences among stations unrelated to distance).
2. **The Within-Stations terms** test for differences in intercepts (Year terms) or slopes (Year $\times$ *d* terms) of distance regressions over time. Significant differences in intercepts indicate that differences in community variable values over time were similar at all or most stations. If distance slopes also differ, changes over time also differ among with distance.
3. **The Within-Stations Overall terms** test for *any* differences in intercepts or distance gradients among years.
4. **The Before-versus-After contrasts** tests for a difference in intercepts or distance slopes between before (2001) and after (2002 to 2010) drilling at the FE drill centre. A significant effect on intercepts (Year term) would imply that mean variable values varied significantly from before to after drilling across the study field, potentially implying a drilling effect or another regional phenomenon. A significant effect on distance slopes would imply that the change from before to after depended on distance from the drilling centre (either FE or FEZ, depending on which was significant).
5. **The Linear Trend (2002 to 2010) contrasts** test for a progressive increase or decrease in intercepts or distance slopes over time after drilling began. A significant linear time trend in intercepts (average values) would suggest that the mean variable values are increasing or decreasing steadily across the study field, and could be used to infer that the effects of drilling are being manifest across the study field, or some other regional phenomenon. A significant linear time trend in distance slopes would suggest that changes

in community variable values depends on distance, and potentially that effects near drill centres are increasing over time.

6. **The Quadratic Trend (2002 to 2010) contrasts** test for a parabolic increase-decrease (or vice-versa) in intercepts or distance slopes over time after drilling at the FE drill centre began. A significant quadratic time trend in intercepts could be used to infer that summary benthic community variable values increased/decreased for some time, then decreased/increased later. The response might be used to imply a change from the period prior to drilling at the FE drill centre, and subsequent recovery across the study field, and may or may not reflect a drilling effect or a regional phenomenon. A quadratic time trend in distance slopes would reflect that changes in community variable values depends on distance; slopes increasing/ decreasing, then decreasing/increasing could imply that effects increased near drill centres then decreased between 2002 and 2010. A significant quadratic effect could imply that drilling had effects in the past, with subsequent recovery, or that the observed variations are part of the natural background (i.e., are cyclic).

Results in Table 5-23 are presented as *F* values, with $F > 1$ indicating added variance attributable to the effect tested.

The Among stations Error 1 (carry-over) term was highly significant (Table 5-23) for each of the benthic community variables (abundance, biomass, richness, adjusted richness, NMDS1 and NMDS2), indicating a high degree of influence of prior-year community composition on composition in subsequent years (F-ratios varied between 1.9 for biomass and 18.6 for NMDS1 scores). That conclusion was robust to the inclusion/exclusion of data from stations 30(FE) and 31(FE).

The only community variable that did not vary among years, or with distance from drill centres was NMDS2 (none of the Year or Distance terms were significant in Table 5-23). NMDS2 is not considered further, here. For other summary measures, the overall differences among years described in relation to Figures 5-40 to 5-42 were significant (Table 5-23).

Table 5-23 Results (F Values) of Repeated-measures Regressions Comparing Benthic Invertebrate Community Variables Among EEM Years (2001 to 2010)

Term	Total Abundance (*N*)	Biomass (*B*)	Richness (*S*)	Adjusted Richness (*S2*)	NMDS1	NMDS2
Among Stations						
FEZ *d*	4.4*	2.4	0.3	9.8**	17.3***	0.1
FE *d*	<0.1	**29.0*** **	0.9	1.9	6.9*	0.6
Error 1	**8.1*** **	**1.9*** **	**16.0*** **	**6.7*** **	**18.6*** **	**12.3*** **
Within Stations						
Overall						
Year	2.4*	3.3**	4.6**	4.1**	**8.6*** **	1.3
Year × FEZ *d*	1.5	0.9	0.6	3.1*	0.9	0.9
Year × FE *d*	1.0	**3.0***	1.2	1.8	3.3**	0.5
Before versus After FE Drilling (2001 vs 2002 to 2010)						
Year	1.6	0.5	0.1	2.1	7.4***	0.6
Year × FEZ *d*	1.3	0.5	1.1	4.2*	<0.1	2.1
Year × FE *d*	0.3	0.6	0.2	<0.1	2.3	0.5
Linear Trend (2002 to 2010)						
Year	0.9	0.1	7.4**	8.7**	**26.9*** **	3.2
Year × FEZ *d*	1.0	1.1	<0.1	0.8	<0.1	0.3
Year × FE *d*	0.9	0.8	1.0	5.6*	**8.8*** **	0.3
Quadratic Trend (2002 to 2010)						
Year	1.8	**10.0*** **	0.3	4.0	0.3	<0.1
Year × FEZ *d*	4.8*	1.7	0.8	6.5*	1.3	1.2
Year × FE *d*	0.3	**8.6*** **	1.1	2.2	0.9	1.9

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- Distance variables (*X*), total abundance and adjusted richness were log-transformed.
- Stations 30(FE) and 31(FE) excluded, $n = 46$.
- *A*ll samples processed with the Elutriate recovery method.
- See Appendix B-4 for description and interpretation of terms in the repeated-measures regression models.

FEZ distance gradients for abundance were significantly negative (i.e., higher abundance near drill centres) while FE distance gradients were generally not significant (see Among Stations FEZ and FE terms in Table 5-23). There was a significant quadratic time trend in the FEZ distance gradient reflecting more negative slopes in 2004, 2006 and 2008 than in 2002 and 2010 (Figure 5-44). Those observations were robust to the inclusion of stations 30(FE) and 31(FE) in the repeated-measures regressions (Appendix B-4).

There was no significant distance gradient between biomass and distance from the FEZ drill centre, with or without stations 30(FE) and 31(FE) included in analysis. The relationship between biomass and distance from the FE drill centre varied among years (the overall Year X Fe *d* term was significant in Table 5-23). Distance slopes from the FE drill centre for biomass were weakest in 2002, stronger in 2004 and

2006 and decreased in strength from 2008 to 2010 (Figure 5-44) (hence the significant quadratic trend Year X FE *d* term in Table 5-23). Those observations were robust to the inclusion of stations 30(FE) and 31(FE) in the repeated-measures regressions (Appendix B-4).

There were no strong/significant distance gradients for taxa richness (Table 5-23, Figure 5-44) with stations 30(FE) and 31(FE) excluded. With those stations considered in the repeated-measures regressions, the regression slopes were smaller in magnitude.

Adjusted richness values generally increased with distance from the FEZ drill centres, and decreased with distance from the FE drill centre from 2006 to 2010 (Figure 5-44). That observation was robust to the inclusion of data from stations 30(FE) and 31(FE) (Appendix B-4). Inclusion of data from stations 30(FE) and 31(FE) resulted in the quadratic trend to be significant for the intercept term ($F = 20.5$ in Table 6 of Appendix B-4), reflecting that adjusted richness values were generally lower in 2004 than in periods earlier or later (with stations 30(FE) and 31(FE) included).

NMDS1 scores varied negatively with distance to the FEZ drill centres and positively with distance to the FE drill centre (see significant Among Stations FEZ *d* and FE *d* terms in Table 5-23 and Figure 5-44). Those tendencies were generally true with and without stations 30(FE) and 31(FE), with the exception that from 2006 to 2010, the FE distance gradient slopes were approximately zero (Appendix B-4). The FE distance gradient slopes tended to decrease linearly over time from 2002 to 2010, both with and without stations 30(FE) and 31(FE).

FE and FEZ distance gradients for NMDS2 were not significant when stations 30(FE) and 31(FE) were excluded from repeated-measures regression (Table 5-23), but were generally significant with the data from those two locations included (Table 6 in Appendix B-4). However, the distance gradient slopes (see Figure 5-44 and Figure 5 in Appendix B-4) were similar with the data included or excluded, but just stronger with stations 30(FE) and 31(FE) included. FE distance gradients with stations 30(FE) and 31(FE) included were generally positive; FEZ distance gradients were generally negative (Figure 5 in Appendix B-4).

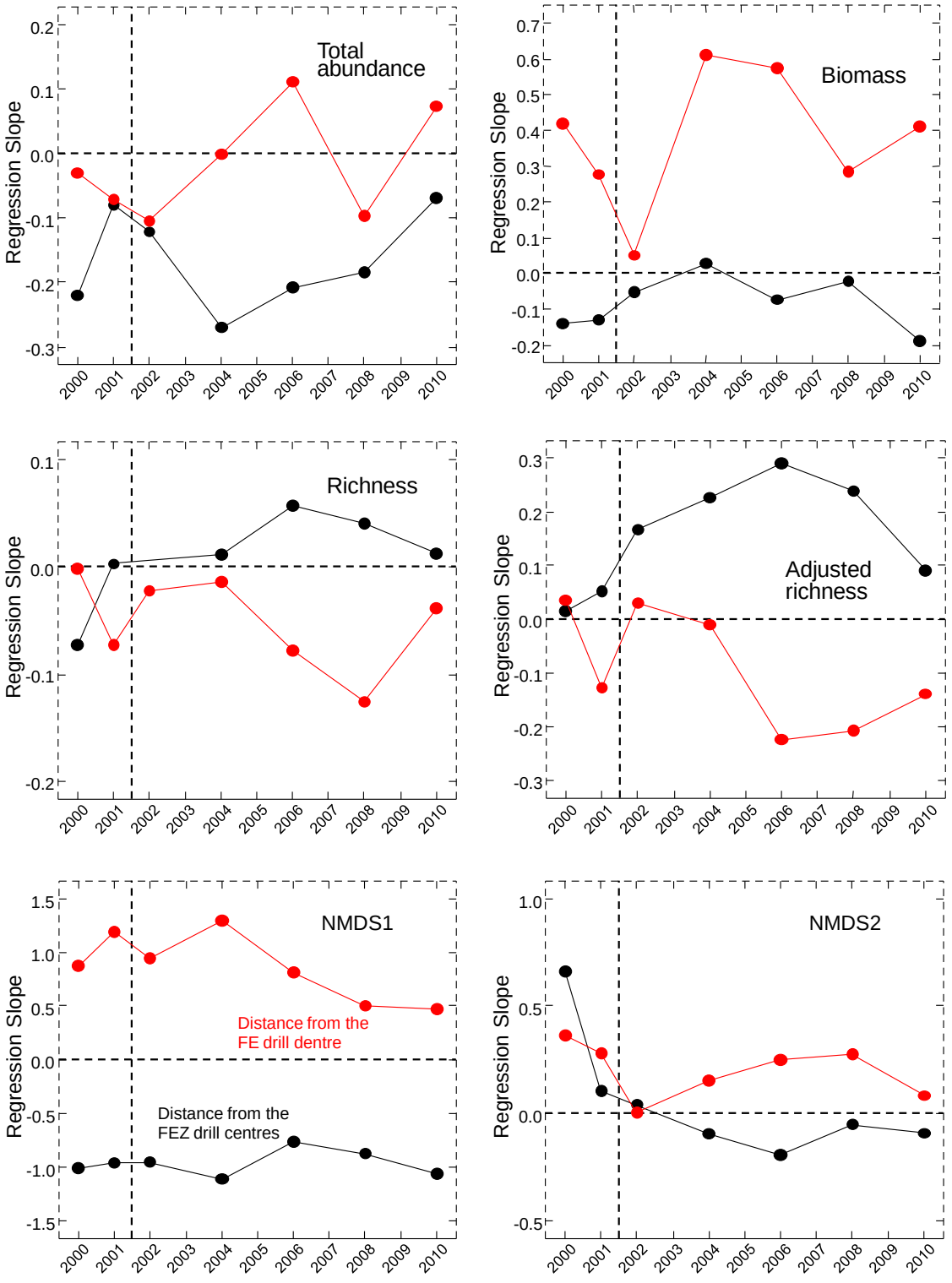


Figure 5-44 Multiple Regression Distance Slopes for Benthic Invertebrate Summary Measures (Elutriate Samples with Stations 30(FE) and 31 (FE) Excluded)

Note: The vertical dashed line indicates the start of drilling at the FE drill centre.

5.4.3.4 Integrated Assessment

Various correlations, and repeated-measures regressions, have been used to describe the bivariate relationships among chemical, physical, toxicological and biological measures in the previous sections. 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:

- 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 describe the physical configuration and organic content of the sediments, factors that fundamentally influence benthic community composition;
- Sediment toxicity: Microtox IC50 was selected because it indicated both toxic and non-toxic sediments, whereas percent laboratory amphipod survival did not (only one sample, from a Reference station, was toxic to laboratory amphipods);
- Sediment biology: Summary invertebrate community measures including abundance, biomass, richness, adjusted richness, NMDS1 scores and NMDS2 scores were selected because they collectively represent the principal attributes of interest in the community. NMDS axis scores covaried with dominant and sub-dominant groups of benthic invertebrates, including Spionidae, Cirratulidae, and Phyllodocidae; and
- Distance to drill centres: the variable Min *d* was used as the single measure of distance to active drill centres on the basis that most physical, chemical or biological variables that were apparently influenced by proximity to a drill centre correlated at least somewhat with this measure.

The analysis was carried out in two parts. The first part consisted of a principal component analysis (PCA) of ranks of the core variables listed above. The PCA was carried out two times; the first PCA used all the data from 2000 to 2010 (i.e., 348 observations), while the second PCA used only the data from 2010 (i.e., 53 observations). The PCA results were used to identify a further subset of variables on which to explore (in the second part of this analysis) associations over

the period of study (2000 to 2010) using scatterplots and some additional Spearman rank correlations.

Correlations of the original variables (ranks) with the principal component axes are provided in Table 5-24. Correlations of magnitude > |0.6| were considered important and strongly associated with a PCA axis and are used to interpret the axes. The correlations of variables with the PCA axes were generally similar regardless of whether all the data were used, or only the data from 2010 were used. The first PCA axis, using all the data, reflected a gradient of increasing to decreasing total abundance (N), taxa richness (S), barium concentrations, $>C_{10}$-C_{21} hydrocarbons, metals PC1 scores, total organic carbon content of sediments and percent gravel. Sediments with a high concentration of gravel generally had high total organic carbon content, high benthic total abundance, high richness (number of taxa), high barium and hydrocarbons and high concentrations of metals other than barium. Distance to the nearest active drill centre (Min *d*) was weakly negatively correlated (r_p = 0.52) with the first PCA axis, reflecting that > C_{10}-C_{21} hydrocarbons and barium concentrations were higher nearer drill centres. The second PCA axis scores were strongly correlated with richness and adjusted richness (S2) values. Distance to the nearest active drill centre (Min *d*) was again weakly correlated (r_p = -0.44), reflecting that taxa diversity increased with distance from drill centres. Only biomass was strongly correlated with the third PCA axis, suggesting that this variable tended to vary independently.

Table 5-24 Correlations (rp) Between Core Sediment Variables and Principal Component Axis Station Scores Using All Data, and Data From 2010 Only.

Variable	Principal Component					
	All Years			2010 Only		
	1	2	3	1	2	3
Min *d*	-0.52	-0.44	-0.34	-0.40	**-0.63**	-0.24
Abundance	**0.74**	-0.10	-0.32	**0.79**	-0.38	-0.23
Biomass	-0.06	0.07	**-0.68**	0.05	-0.07	**-0.70**
Richness	**0.63**	**-0.68**	-0.19	**0.81**	-0.52	-0.07
Adjusted Richness	0.17	**-0.85**	0.00	**0.61**	-0.57	0.14
NMDS1	0.57	0.47	-0.50	**0.61**	0.44	-0.48
NMDS2	-0.49	0.53	0.07	**-0.67**	0.46	0.13
Microtox	-0.35	0.32	-0.43	-0.40	0.34	-0.38
Barium	**0.84**	0.25	0.10	**0.80**	0.43	0.10
$>C_{10}$-C_{21} Hydrocarbons	**0.61**	0.55	0.22	**0.61**	0.55	0.04
Metals PC1	**0.63**	0.15	0.06	0.54	0.44	0.23
Total Organic Carbon	**0.75**	0.24	-0.29	**0.70**	0.36	-0.35
Fines	0.57	0.03	0.40	**0.68**	0.19	0.31
Gravel	**0.68**	-0.47	0.06	**0.70**	-0.43	0.17
Var. Exp.	34.0	19.0	10.5	39.6	19.3	9.6

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

One of the limitations of PCA is the assumption that relationships among variables are linear, even if the data are transformed into ranks. Relationships among variables may be stronger assuming a non-linear relationship (e.g., hockey-stick, threshold, etc.). Correlations of variable combinations, in addition to scatterplots of the original measures, were used in the next step of the analysis to further illustrate the nature and magnitude of associations. A further reduced selection of variables was used in the second step, based on the results of the PCA above. All of the 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. Percent of sediments comprised by gravel was retained because it correlated strongly with PCA axis 1.

Total benthic abundances and richness covaried (see the PCA, Table 5-24) and were significantly positively correlated with barium and percent gravel (Figures 5-45 and 5-46). The positive relationships with barium may have been driven by substrate texture. First, the correlations between abundance and richness with percent gravel were general stronger (i.e., $r_s \geq 0.5$) than they were with barium concentrations (i.e., $r_s \approx 0.3$ to 0.4). Review of the scatterplots in Figure 5-45 and 5-46 further reveals that the relationships between abundance and barium, and richness and barium were linear and positive through barium concentrations ranging from approximately 50 and 700 mg/kg. However, in excess of 700 mg/kg, the relationship between abundance and barium concentrations may be negative (although the low number of observations at the higher barium levels precluded a thorough assessment).

Total abundances and richness were also correlated significantly negatively with Microtox IC50s in 2010, as well as most EEM years, with higher abundances occurring at stations with lower IC50s (more toxic). Toxic sediments generally do not support more abundant and diverse benthic populations, so the observation may be an artefact of high gravel, higher fines content and higher strontium concentrations (see Section 5.4.2). The PCA in Table 5-24 had both gravel and Microtox IC50 covarying inversely with PCA axis 1 such that sediments with high gravel content would appear to have generally produced Microtox IC50 that were lower (more toxic). Metals PC1 also covaried with PCA axis 1. Strontium covaried with Metals PC1 (Table 5-6) and Microtox IC50 (Table 5-13), and has been implicated in this and

previous reports as being potentially responsible for higher toxicity in sediments with more fines and higher total organic carbon.

Biomass was not significantly correlated with selected measures of sediment quality or texture (Figure 5-47). Biomass decreased significantly in relation to barium concentration in 2004 and the relationship was generally negative (though weak and not significantly) in other years. The scatterplot of biomass in relation to barium concentrations indicated a potential threshold at between 700 and 1,000 mg/kg, but, as noted above, there were very few (6 of 248) observations where sediments contained concentrations of barium in excess of 700 mg/kg (generally only station 30(FE) sampled repeatedly over time). Biomass did not covary significantly with concentrations of $>C_{10}$-C_{21} hydrocarbons (Figure 5-47). Therefore, the evidence for an influence of drilling muds on biomass is weak.

Adjusted richness was significantly negatively correlated with $>C_{10}$-C_{21} hydrocarbon concentrations in 2004 through 2008 (Figure 5-48), an observation that was a potential artefact of low adjusted richness values at station 30(FE), which may have had high "leverage" on the relationships. Adjusted richness at station 30(FE) in 2010 was intermediate relative to other values in 2010, in spite of high $>C_{10}$-C_{21} hydrocarbon concentrations (Figure 5-48), and stations with high $>C_{10}$-C_{21} hydrocarbon concentrations had relative high adjusted richness, although the positive correlations was not significant. Overall, the influence of $>C_{10}$-C_{21} hydrocarbon concentrations on adjusted taxa richness are considered to be at best weak; the evidence would indicate that there was no causal relationship.

NMDS1 scores were significantly positively associated with both barium and $>C_{10}$-C_{21} hydrocarbon concentrations in all EEM years (2000 to 2010) (Figure 5-49). The relationship between NMDS1 scores and barium and hydrocarbons reflects higher abundances of Spionidae, and Phyllodocidae polychaetes, and of Tellinidae bivalves in sediments with higher concentrations of the two analytes (Figure 5-3, Table 2 in Appendix B-4). The relationship also reflects lower abundances of Syllidae and Paraonidae polychaetes in sediments with higher concentrations of barium and hydrocarbons, and agrees very well with bivariate correlations between individual taxa and barium and hydrocarbons (see Table 2 in Appendix B-4).

NMDS2 scores were significantly negatively associated with gravel content in sediments in every year (Figure 5-50). Variations in NMDS2 scores do not indicate a significant drilling-mud-related effect.

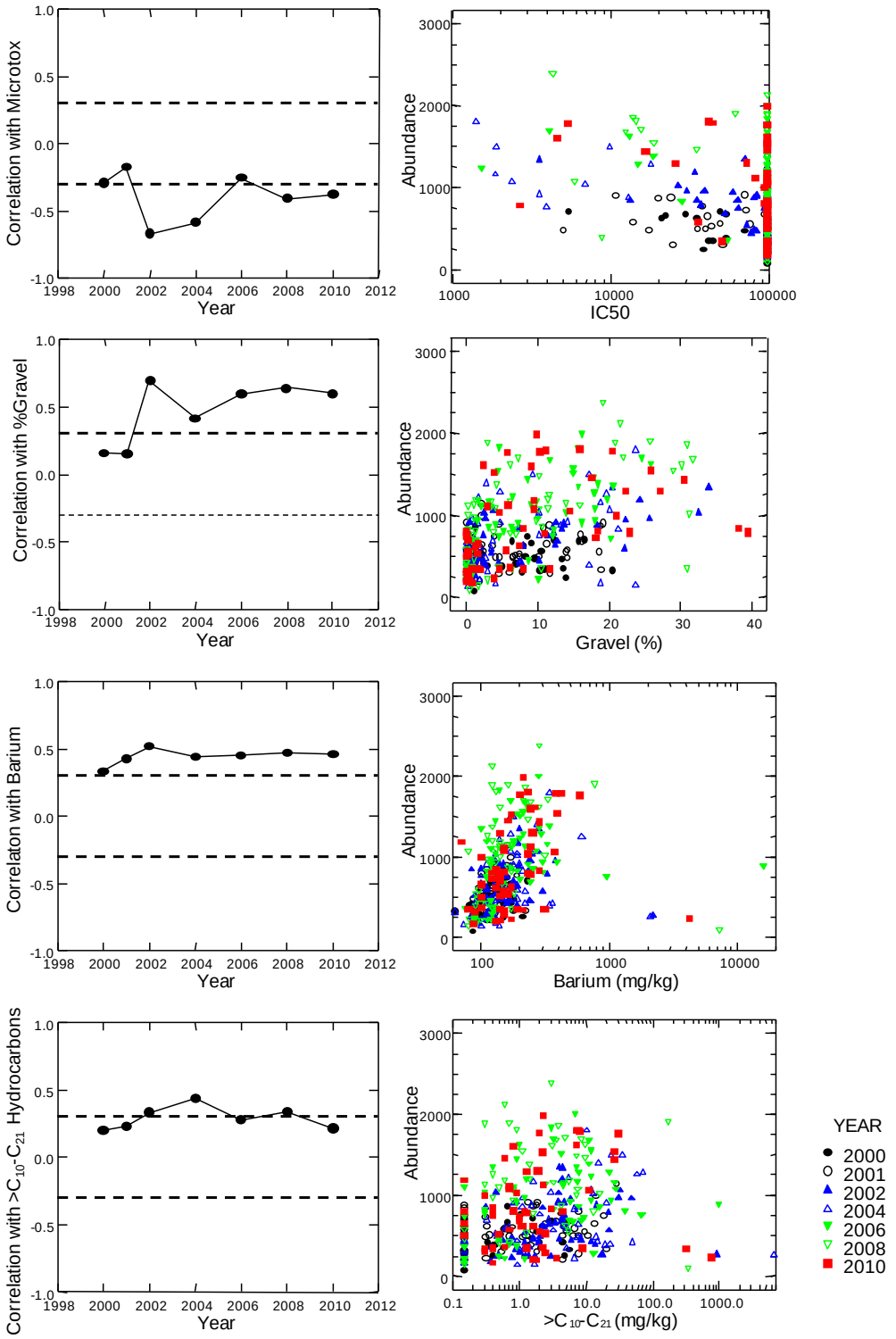


Figure 5-45 Correlations (r_s) Over Time and Scatterplots of Total Abundance in Relation to Microtox, % Gravel, Barium and $>C_{10}$-C_{21} Hydrocarbons

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

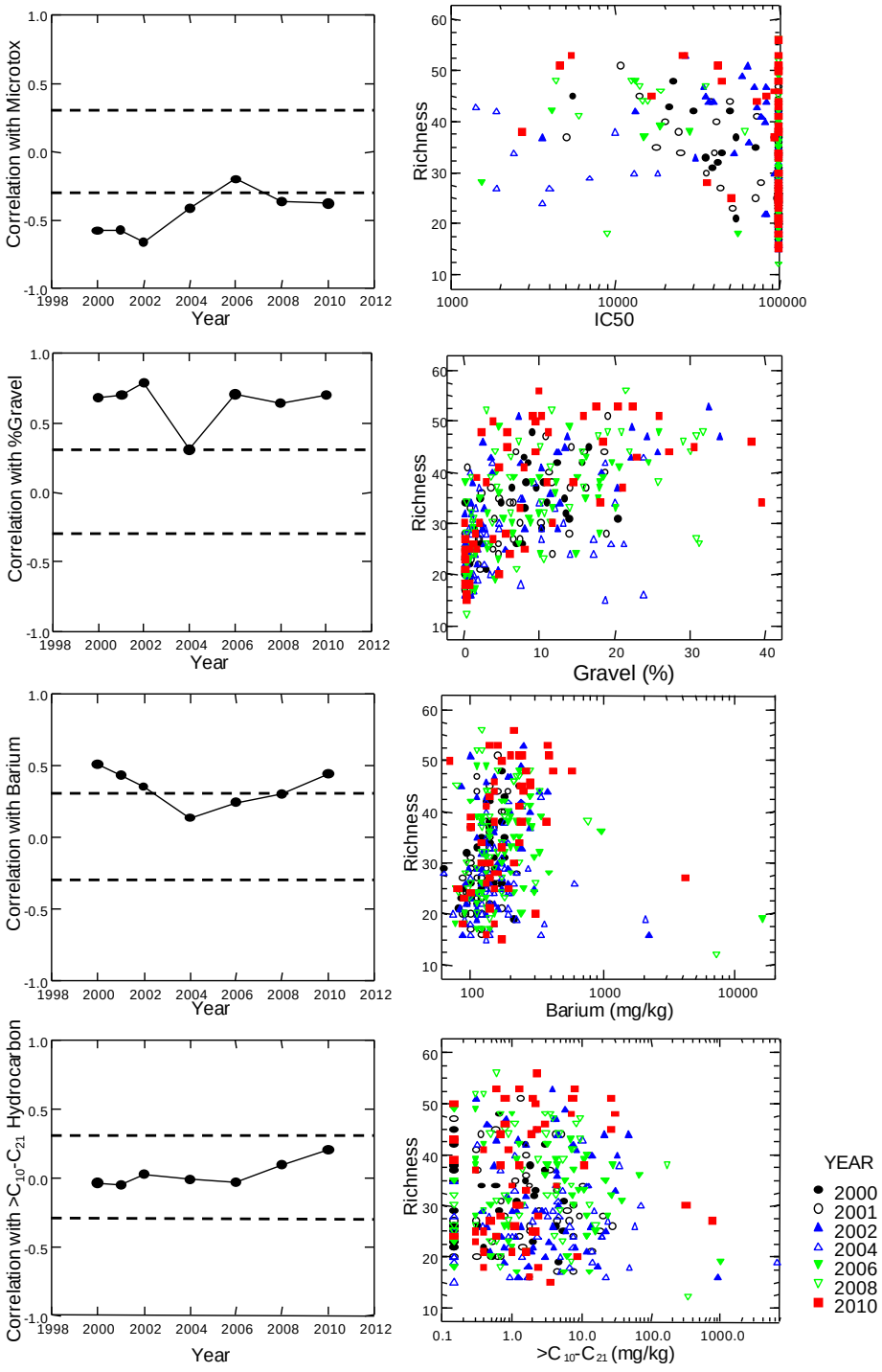


Figure 5-46 Correlations (r_s) Over Time and Scatterplots of Richness in Relation to Microtox, % Gravel, Barium and $>C_{10}$-C_{21} Hydrocarbons

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

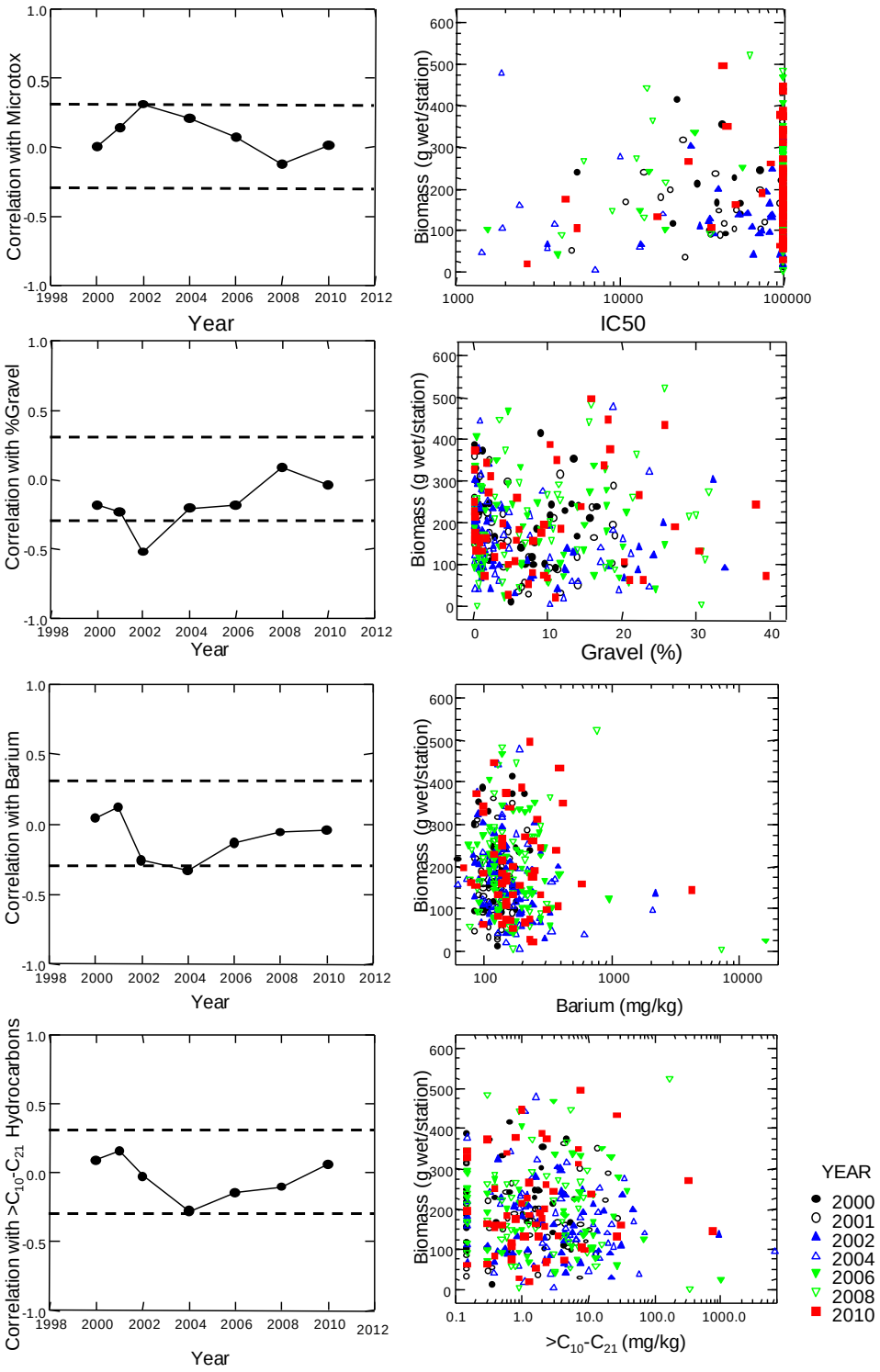


Figure 5-47 Correlations (r_s) Over Time and Scatterplots of Biomass in Relation to Microtox, % Gravel, Barium and >C_{10}-C_{21} Hydrocarbons

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

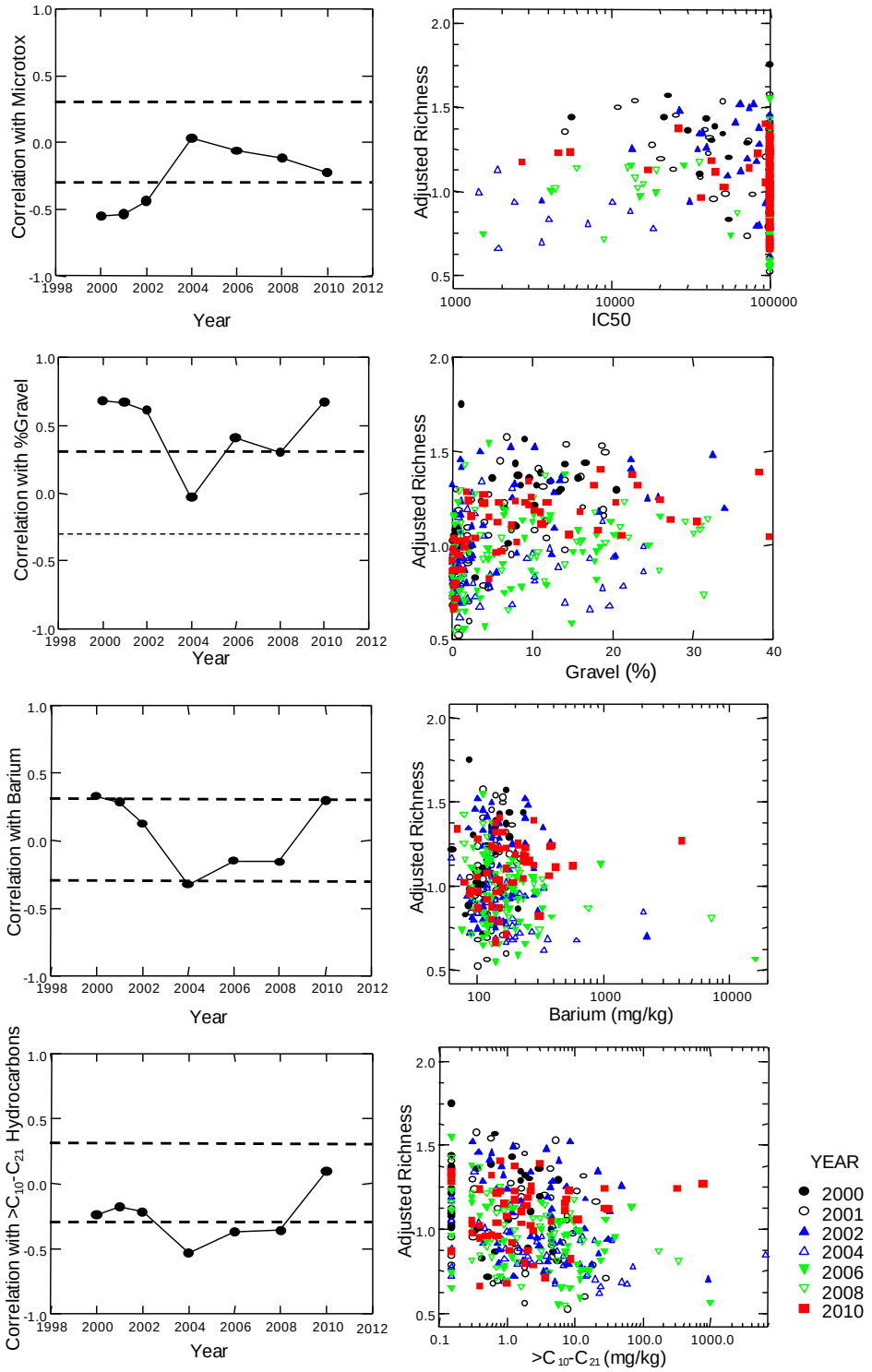


Figure 5-48 Correlations (r_s) Over Time and Scatterplots of Adjusted Richness in Relation to Microtox, % Gravel, Barium and >C_{10}-C_{21} Hydrocarbons

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

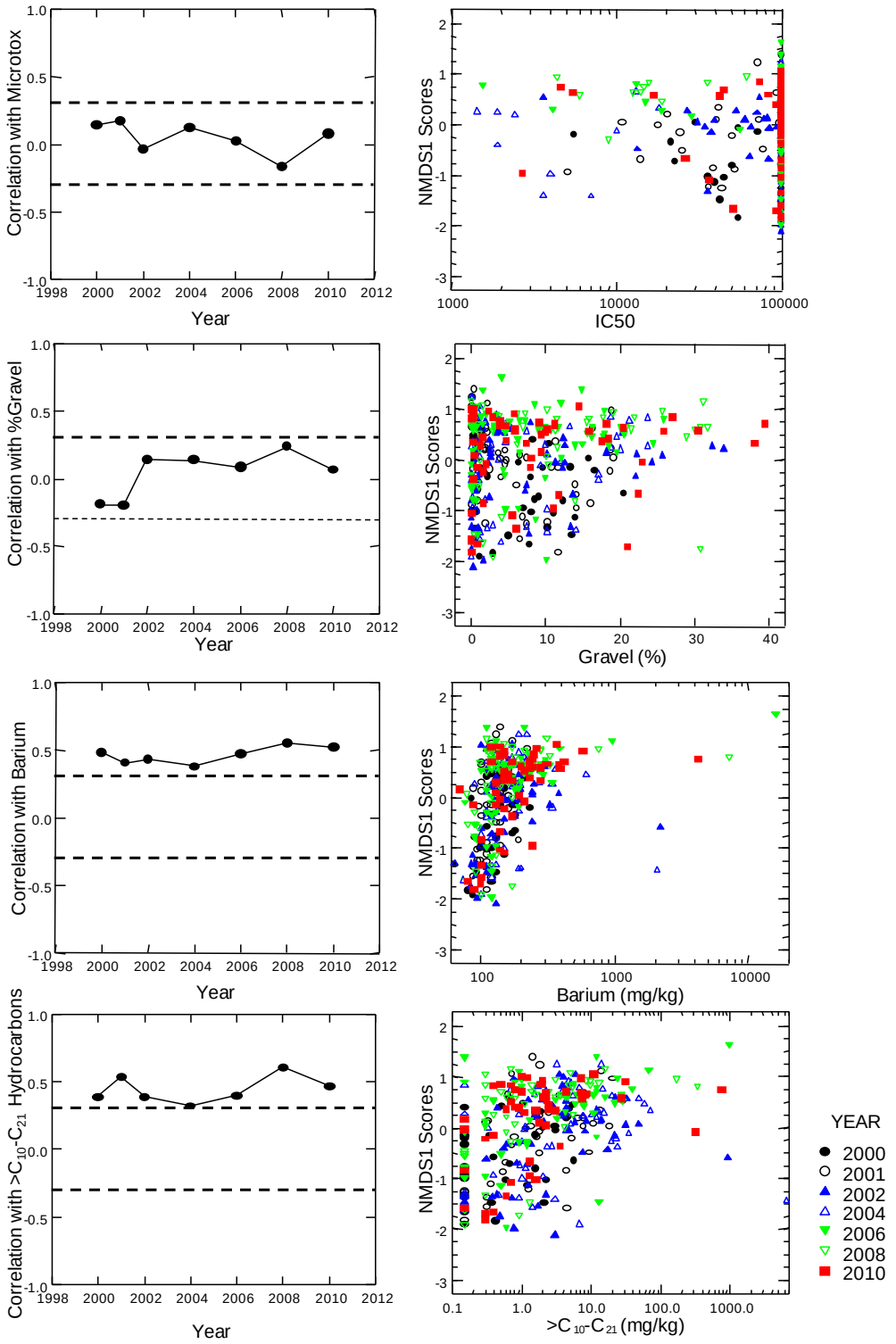


Figure 5-49 Correlations (r_s) Over Time and Scatterplots of NMDS1 Scores in Relation to Microtox, % Gravel, Barium and >C_{10}-C_{21} Hydrocarbons

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

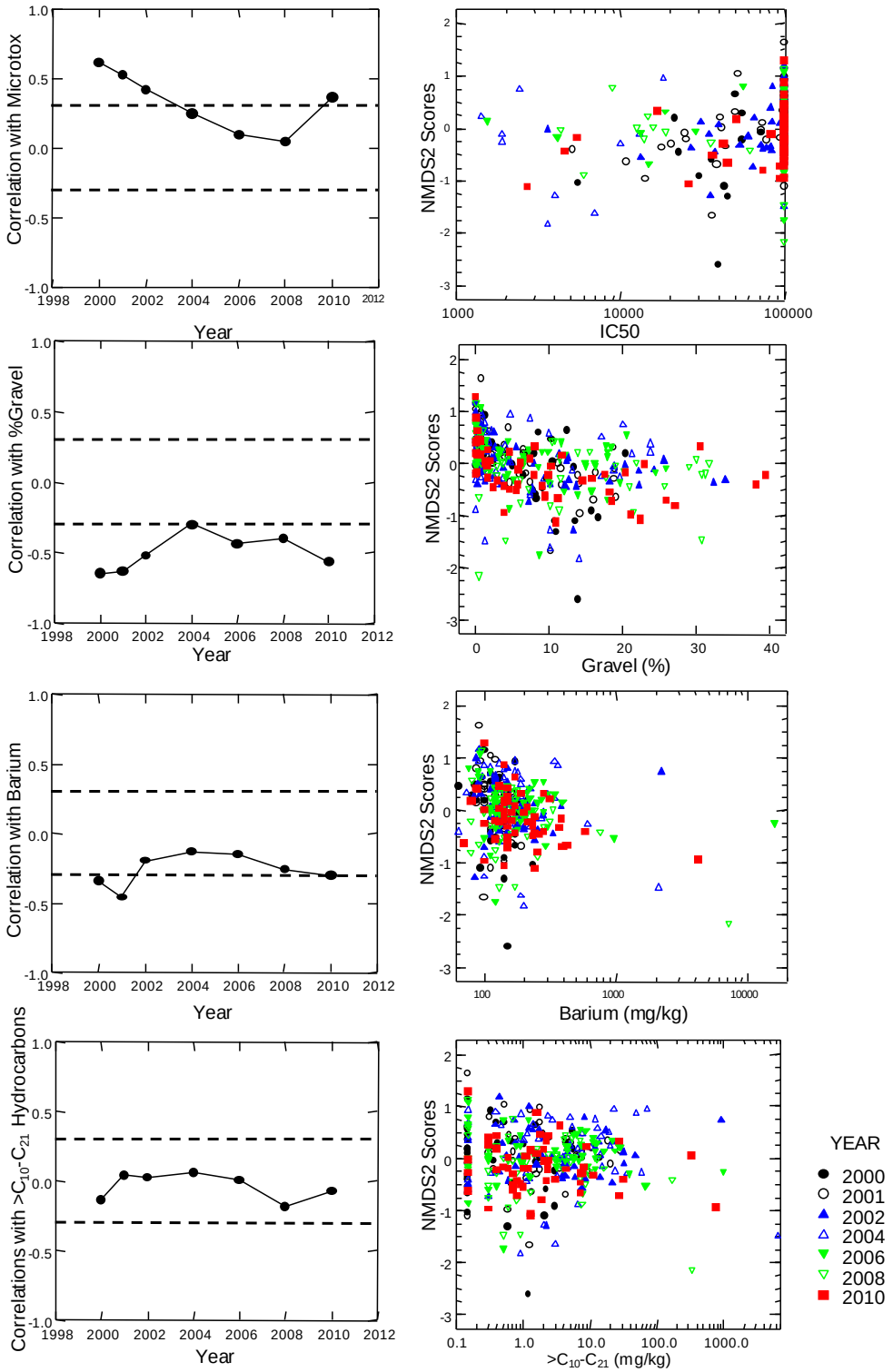


Figure 5-50 Correlations (r_s) Over Time and Scatterplots of NMDS2 Scores in Relation to Microtox, % Gravel, Barium and >C_{10}-C_{21} Hydrocarbons

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

5.5 SUMMARY OF FINDINGS

5.5.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

In 2010, as in previous years, $>C_{10}$-C_{21} hydrocarbons and barium concentrations decreased significantly with distance from drill centres. In 2010, concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to levels near laboratory detection limit (0.3 mg/kg) within 3 km of drill centres. Concentrations of barium decreased to background levels (less than 190 mg/kg) within 2 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 3 km in 2008 and 2010. Estimated threshold distances for barium have remained relatively constant at 1 to 2 km since 2002. 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 have generally increased since 2000 but have decreased in recent years from levels observed in 2004 and 2006. Median $>C_{10}$-C_{21} hydrocarbon concentrations across all stations 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. 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 2010, maximum $>C_{10}$-C_{21} hydrocarbon concentrations (760 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 2010. Median concentrations in EEM years have been below the 90th percentile concentration (190 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 (4,200 mg/kg) at station 30(FE) in 2010.

In 2010, 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 (0.05 to 0.08%) 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 and 2006. In 2010, the highest sulphur concentration (0.23%) occurred at station 30(FE), 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% and was noted at station 30(FE) in 2006. Median levels were highest in 2008 and 2010 (0.05 and 0.04%, respectively) but near the laboratory detection limit of 0.02% in all years when sulphur was measured (2001 to 2010).

Fines content in 2010 ranged from 0.5 to 2.7% (median = 1.0%). Fines content during baseline (1997) ranged from 0.7 to 3.4% (median = 1.0%). The highest fines content (2.2, 2.5 and 2.7%) in 2010 occurred at three stations within 1 km of drill centres (stations 30(FE), 44(FEZ) and 11(SE), respectively). 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.

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.

5.5.2 TOXICITY

There has been little evidence for project effects on laboratory amphipods in previous EEM years and there was no evidence for effects in 2010. Only one sample from a Reference station located 19 km from the nearest drill centre was toxic in 2010.

Microtox IC50s from laboratory toxicity tests were unrelated to distance from drill centres and to $>C_{10}$-C_{21} hydrocarbon concentrations in 2010 and most other EEM years. Negative Microtox responses were correlated with barium concentration in 2010, but these correlations were weaker than correlations with other variables such as strontium concentrations and sediment fines content. 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 2010, based on Environment Canada (2002) interpretive guidelines.

5.5.3 BENTHIC COMMUNITY STRUCTURE

Benthic invertebrate communities in the vicinity of the Terra Nova development in 2010 contained an assortment of organisms typical of an offshore marine environment. The community was numerically dominated by polychaete worms (82% or more), and sub-dominated by amphipods (4%), bivalves (3%) and gastropods (2%). In 2010, total abundance varied by more than 10-fold (range of values was 165 to 1984 individuals per station) among stations. Biomass varied almost 25-fold (approximately 20 to 500 g wet/station).

Total abundance and taxa richness were positively correlated in 2010, as in previous years. Stations with high total number of organisms tended to be dominated numerically by Spionidae and Phyllodocidae polychaetes, and were more diverse. Stations with lower total number of organisms tended to be numerically dominated by Syllidae polychaetes, and were generally less diverse. Spionidae, Syllidae, Cirratulidae and Phyllodocidae polychaetes were found at every station.

Total abundance, richness and NMDS2 scores and abundances of the dominant polychaete taxa Spionidae were uncorrelated with distances to drill centres. Biomass, NMDS1 scores and abundances of Syllidae, Orbiniidae, Paraonidae, Phyllodocidae, Tellinidae and, to a lesser extent, adjusted richness and the abundances of Cirratulidae, Amphipoda and Echinodermata, did vary in relation to distance from drill centres. Distance to the nearest FEZ drill centres generally produced stronger distance relationships (i.e., stronger partial *r* values), indicating that the FEZ drill centres had a greater influence on benthos community variables than did the FE drill centre.

Abundance, biomass, richness and NMDS2 were relatively low at station 30(FE), and NMDS1 and adjusted richness were relatively high, but values at station 30(FE), (i.e., the station nearest to a drill centre) were within the range of values noted at other stations (i.e., values were not extremes). Among the individual taxa examined in this analysis, only Syllidae abundances were lower at station 30(FE) than elsewhere.

Across years, total abundance increased from 2000 to 2010. Approximately 200 to 1,000 organisms per station were noted in 2000; between 200 and 2,000 organisms per station were noted in 2010. Overall, biomass has remained relatively consistent since year 2000, ranging between approximately 50 and 400 g wet/station. However, biomass values were slightly lower in 2002 than in other years. Richness varied

between 20 and 50 taxa per station in year 2000, and between about 15 and 55 in 2010, with median richness values slightly higher since 2006 (32 to 37 taxa in 2006, 2008, 2010) than in previous years (30 taxa in 2002 and 26 in 2004). Adjusted richness values were generally higher in 2000, 2001 and 2002 than in subsequent years. NMDS1 scores have increased from 2000 to 2010.

When extreme values at stations 30(FE) and 31(FE), within 0.37 km of the FE drill centre, were removed from multi-year analyses, the relationship between total abundance, adjusted richness, biomass and NMDS1 scores relative to distance from drill centres (i.e., slopes of relationships with distance from drill centres) varied among years. Distance relationships for total abundance and adjusted richness varied more in relation to the FEZ drill centres. Distance relationships for biomass and NMDS1 scores varied more in relation to distance from the FE drill centre.

For abundance, slopes (decreases in abundance with distance) were steepest in 2000, 2004, 2006 and 2008. The strength of the distance slopes from the FEZ drill centres for total abundance was weakest and approximately equivalent (i.e., approximately -0.1) in 2001 and 2010.

Adjusted richness values generally increased with distance from the FEZ drill centres, and decreased with distance from the FE drill centre from 2006 to 2010. That observation was robust to the inclusion of data from stations 30(FE) and 31(FE).

Distance slopes from the FE drill centre for biomass increased in strength from approximately 0 in 2002 and 2004, were stronger in 2004 and 2006 and decreased in strength from 2008 to 2010.

The distance slopes from the FE drill centre for NMDS1 scores, in this case increases in NMDS scores with distance, generally decreased in strength since 2004; slopes were steeper from 2000 to 2004 than in subsequent years.

5.5.3.1 Integrated Assessment

Across all years, total benthic abundances and richness were correlated positively with barium and % gravel. Total abundances and richness were also negatively correlated with Microtox IC50s in 2010, as well as most EEM years, with higher abundances occurring at stations with lower IC50s (more toxic). Biomass decreased significantly in relation to % gravel in 2002 and to barium concentration in 2004. In 2010, there were no significant relationships between biomass and core variables

(toxicity, % gravel, $>C_{10}$-C_{21} hydrocarbon and barium concentrations) examined in the integrated assessment.

Adjusted taxa richness was significantly negatively correlated with $>C_{10}$-C_{21} hydrocarbon concentrations in 2004 through 2008, an observation that was a potential artefact of low adjusted richness values and high $>C_{10}$-C_{21} hydrocarbon concentrations at station 30(FE) (i.e., the relationship might have been driven by coincidence at that one station). In 2010, $>C_{10}$-C_{21} hydrocarbon concentrations were high at station 30(FE) but adjusted richness values were not reduced, and the relationship between adjusted richness and $>C_{10}$-C_{21} hydrocarbons was not significant.

NMDS1 scores were significantly positively associated with both barium and $>C_{10}$-C_{21} hydrocarbon concentrations in all EEM years.

NMDS2 scores were significantly positively associated with % gravel in sediments in every year.

6.0 WATER COMPONENT

6.1 FIELD COLLECTION

The water component of the 2010 EEM Program was conducted in conjunction with the sediment component of the program. Details on collections dates are provided in Section 5.1. Water collection stations for the 2010 program are shown in Figure 1-8 (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 and 40 m and 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, oil and grease, mercury, trace metals, total suspended solids (TSS), TPH, 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 and Storage Temperature
PAHs	2 - 250 mL glass bottles (4°C)
Oil and Grease	2 - 100 mL Amber glass bottles (4°C)
Mercury	1 -100 mL Amber glass bottle with $K_2Cr_2O_7$ in 17% HNO_3 (4°C)
Trace Metals	2 - 500 mL plastic bottles with nitric acid (10 drops per bottle) (4°C)
TSS	1 - 1 L plastic bottle (4°C)
TPH	2 - 250 mL glass bottles; 3 - 40 mL vials (BTEX) (4°C)
Chlorophyll and phaeophytin	GF/F filters (1 L samples) stored in petri dish wrapped in tin foil (-20°C)

Field blanks for PAHs, oil and grease, mercury, trace metals and TPHs made up of distilled water were collected at stations W7 (Bottom), W9 (Surface), W14 (Bottom) and W23 (Bottom). 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 W6 (Surface), W9 (Bottom), W16 (Bottom), W24 (Surface) and W24 (Middle).

A Conductivity Temperature Depth (CTD) recorder cast was performed at all water and sediment stations (see Figure 1-8, Section 1, for station locations) to obtain depth, pH, temperature, conductivity, salinity, dissolved oxygen and chlorophyll profiles. Data from CTD casts for stations W1 to W4 in the SW Reference Area were irretrievable because of a CTD communication error. Therefore, no CTD data were available for the SW Reference Area in 2010.

QA/QC protocols were followed for collection of samples to ensure sample integrity and prevent onboard contamination. Niskin bottles were brought to a clean working area. Sampling personnel were supplied with new latex gloves for each station. The laboratory facility and sampling tools were washed with isopropanol, then rinsed with distilled water between each station to prevent cross-contamination between stations. Processed samples were transferred to cold storage within one hour of collection.

6.2 LABORATORY ANALYSIS

Water samples were processed by Maxxam Analytics for constituents listed in Table 6-2. Details on analytical methods are provided in Appendix C-2.

Table 6-2 Water Chemistry Analytes (1997 to 2010)

Parameters	Method	RDL							Units
		1997	2000	2001	2002	2004	2006&08	2010	
Benzene	P&T	NA	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Toluene	P&T	NA	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Ethylbenzene	P&T	NA	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Xylenes	P&T	NA	0.002	0.002	0.002	0.002	0.002	0.002	mg/L
C_6-C_{10} HC (Less BTEX)	Calculated	NA	0.25	0.25	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	mg/L
>C_{10}-C_{13}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	mg/L
>C_{13}-C_{21}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	mg/L
>C_{21}-C_{32}	GC/FID	NA	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	mg/L
Oil & Grease	IR, FTIR	1	0.1	0.2	0.2	0.5	0.5	2	mg/L
Vegetable Oil & Grease	IR	1	NA	NA	NA	NA	NA	NA	mg/L
Mineral Oil & Grease	IR	1	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	µg/L
2-Chloronaphthalene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.05	0.05	µg/L
1-Methylnaphthalene	GC/FID	0.01	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	µg/L
Acenaphthene	GC/FID	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	µg/L
Anthracene	GC/FID	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	µg/L
Benzo[*a*]pyrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[*b*]fluoranthene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[*ghi*]perylene	GC/FID	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	µg/L
Chrysene	GC/FID	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	µg/L
Fluoranthene	GC/FID	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	µg/L
Indeno[1,2,3-*cd*]pyrene	GC/FID	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	µg/L
Perylene	GC/FID	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	µg/L
Pyrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Arsenic	ICP-MS-SW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Barium	USEPA200.7	NA	NA	50	NA	NA	NA	NA	µg/L
Cadmium	ICP-MS-SW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Chromium	ICP-MS-SW	0.5	0.5	0.5	0.5	0.5	0.5	0.5	µg/L
Cobalt	ICP-MS-SW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Copper	ICP-MS-SW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Iron	ICP-MS-SW	1	1	1	1	1	1	1	µg/L
Lead	ICP-MS-SW	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Manganese	ICP-MS-SW	1	1	1	1	1	1	1	µg/L
Mercury	CVAA	0.05	0.05	0.05	0.05	0.05	0.01	0.013	µg/L
Nickel	ICP-MS-SW	0.5	0.5	0.5	0.5	0.5	0.5	0.5	µg/L
Zinc	ICP-MS-SW	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	µg/L
Chlorophyll *a*	Fluorescence	NA	0.1	0.1	0.1	0.1	0.01	0.01	µg/L
TSS	Grav.	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/L

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 by Maxxam Analytics as part of QA/QC procedures.
- The Estimated Quantification Limit was used in previous years instead of laboratory detection limit. The two terms are interchangeable and relate solely to the merger between Phillip Analytics and Maxxam Analytics and the various terminologies used by these two laboratories.
- NA = Not Analyzed.
- Phaeophytin and chlorophyll laboratory detection limits are for Niskin bottle samples.

6.3 DATA ANALYSIS

6.3.1 PHYSICAL AND CHEMICAL CHARACTERISTICS FROM NISKIN BOTTLES

Analysis of 2010 physical and chemical characteristics from Niskin bottle samples included qualitative analysis of iron and mercury and more quantitative analysis of TSS, arsenic and copper.

Iron was not detected at a detection limit of 1 μg/L in 38 of 72 samples. Mercury was not detected at a detection limit of 0.013 μg/L in 59 samples. For these two metals, frequencies of concentrations below and above detection limits were calculated for each depth for Reference and Study Area stations.

TSS was not detected at a laboratory detection limit of 0.5 mg/L in 13 of 72 samples, and was not detected at a detection limit of 1 mg/L in another four samples[16]. Fisher's Exact Test was used to compare frequencies of TSS concentrations below and above 1 mg/L between the pooled Reference Areas and the Study Area. A log-likelihood (*G*) Test was used to compare concentrations below and above 1 mg/L among depths (surface, mid-depth and bottom).

Arsenic was detected in all 72 samples. Copper was detected in 62 samples. Concentrations of these substances in 2010 were compared among the 24 stations and three depths in a two-way analysis of variance (ANOVA) with Station and Depth as factors. The analysis assumed that Station × Depth interactions were negligible[17]. Contrasts were used to subdivide differences among stations and depths (Table 6-3). These contrasts are orthogonal or independent tests that collectively account for the variance among stations and depths. The Vertical Gradient depth contrast tested for a progressive increase or decrease in concentration from Surface to Bottom. The Remainder contrast tested for deviations from any gradient. Copper concentrations were rank-transformed for the ANOVA. Rank transformation will treat all concentrations less than detection limit as tied for the lowest value (rank).

[16] Detection limits may vary among samples because of matrix interference.

[17] Horizontal (station) differences were assumed to be similar at all depths, and vertical (depth) differences were assumed to be similar at all stations.

Table 6-3 ANOVA Model and Contrasts Used for Analysis of Arsenic and Copper Concentrations

Source/Term	Degrees of Freedom (*df*)
Among Stations	
Overall	23
Reference versus Study Area	(1)
Between Reference Areas	(1)
Within Reference Areas	(6)
Within Study Area	(15)
Among Depths	
Overall	2
Vertical Gradient	(1)
Remainder	(1)

Note: - A "bottom-up" approach, with lower-level differences inspected before higher-level differences, should be used to interpret results of the Station × Depth ANOVA. For example, if differences among stations within Areas are significant, differences between Areas (i.e., Between Reference Areas and Between Reference versus Study Areas) should be interpreted with caution unless the differences between Areas are much more significant (lower *p*) than differences within Areas. Similarly, if differences between Reference Areas are significant, differences between those Reference Areas and the Study Area should be interpreted with caution. Results for the depth Vertical Gradient contrast should also be interpreted with caution if the Remainder contrast is significant.

Median arsenic and copper concentrations, and results (*p* values) of Station × Depth ANOVA, were qualitatively compared among sample years (1997, 2000, 2001, 2002, 2004, 2006, 2008 and 2010). Median TSS concentrations were also qualitatively compared among sample years.

6.3.2 PIGMENTS AND CTD PROFILES

6.3.2.1 Niskin Bottle Samples

Log-transformed chlorophyll *a* and untransformed phaeophytin *a* concentrations in Niskin bottle samples from 2010 were compared among stations and depths in Station × Depth ANOVA, with the same contrasts used for analysis of arsenic and copper (Section 6.3.1).

6.3.2.2 CTD Profiles

Water column temperature, pH, salinity, oxygen and chlorophyll *a* values from CTD casts from water and sediment quality stations sampled in 2010 were plotted against depth for each station. Summary statistics were generated from each station.

Temperature and chlorophyll *a* concentrations from CTD casts were also plotted against depth for each water quality sampling area (SE Reference and Study Areas) and for all sediment quality stations combined.

Mean chlorophyll *a* concentrations were calculated for each of the 73 water and sediment quality stations at three depth intervals: 1 to 30 m, 31 to 60 m and 61 to 85 m[18]. Means for each depth interval were regressed on:

- distance to the nearest drill centre (Min *d*) (single *X* variable);
- distance to the nearest of the four drill centres surrounding the FEZ (FEZ *d*) and distance to the FE drill centre (FE *d*) (two *X* variables); and
- distance from the FPSO (single *X* variable).

Chlorophyll *a* concentrations and distances were rank-transformed. The partial regression approach described in Appendix B-4 was used to separate the effects of distance from the FEZ and FE drill centres. The effects of distance from the FEZ drill centres versus the FPSO are more difficult to separate because the two distance measures are strongly correlated (Spearman rank correlation r_s = 0.727 for the 73 water and sediment quality stations analyzed in 2010). Both measures could be considered measures of distance from the centre of the development, and results were usually similar for both measures (Section 6.4).

Distance regressions for chlorophyll based on CTD data from water and sediment quality stations were qualitatively compared among years (1997, 2000, 2001, 2002, 2004, 2006, 2008 and 2010).

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 2010 are provided in Appendix C-2. Results for 2010 are summarized in Sections 6.4.1.1 and 6.4.1.2. Multi-year comparisons are provided in Section 6.4.1.3.

[18] CTD data are missing for the four stations from the SW Reference Area because of an instrument communication error.

6.4.1.1 Infrequently Detected Compounds

$>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon concentrations were detected in 3 of 48 Study Area samples, at mid-depth. Examination of chromatograms showed that these hydrocarbons bore no resemblance to hydrocarbons found in produced water or to those found in the synthetic-based drilling fluid used at Terra Nova (J. Kiceniuk, 2011 pers. comm.).

Fluorene and phenanthrene were the only PAHs detected in the Niskin bottle samples. Fluorene was detected in 1 of 12 SW Reference Area samples. Phenanthrene was detected at concentrations near laboratory detection limits (0.01 to 0.02 μg/L) in 8 of 48 Study Area samples. Five of these eight detectable concentrations occurred in bottom samples.

Chromium was detected in one SW Reference Area surface sample. Lead was detected in two bottom samples and one mid-depth sample from the Study Area. Zinc was detected in seven Study Area samples, five from the bottom depth. Iron was detected in 21 of 24 Reference Area samples and 13 of 48 Study Area samples, with frequencies of detection similar among depths. Mercury was detected in five Reference Area and eight Study Area samples (Table 6-4).

Table 6-4 Frequencies of Values Below and Above Laboratory Detection Limit for Iron and Mercury (2010)

Metal	Depth	Area					
		References		Study		Both	
		No. <RDL	No. ≥RDL	No. <RDL	No. ≥RDL	No. <RDL	No. ≥RDL
Iron	Surface	1	7	12	4	13	11
	Mid-depth	2	6	11	5	13	11
	Bottom	0	8	12	4	12	12
	All	3	21	35	13	38	34
Mercury	Surface	8	0	15	1	23	1
	Mid-depth	6	2	12	4	18	6
	Bottom	5	3	13	3	18	6
	All	19	5	40	8	59	13

Note - RDL = Reportable Detection Limit

6.4.1.2 TSS and Frequently Detected Metals

TSS concentrations in Niskin bottle water samples collected in 2010 were generally higher in Reference Area samples than in Study Area samples (Figure 6-2). Concentrations at or above 1 mg/L (the highest detection limit for TSS in 2010) occurred in 15 (63%) of 24 Reference samples but in only 17 (35%) of 48 Study Area samples (Table 6-5). The difference in frequencies of concentrations below and

above 1 mg/L between Reference and Study Area stations was significant (p = 0.044; Fisher Exact Test). Differences in TSS concentrations among depths were limited. Concentrations below detection limit occurred at all three depths (Figure 6-3), and differences in frequencies of concentrations below and above 1 mg/L among depths were not significant (p = 0.168; G Test).

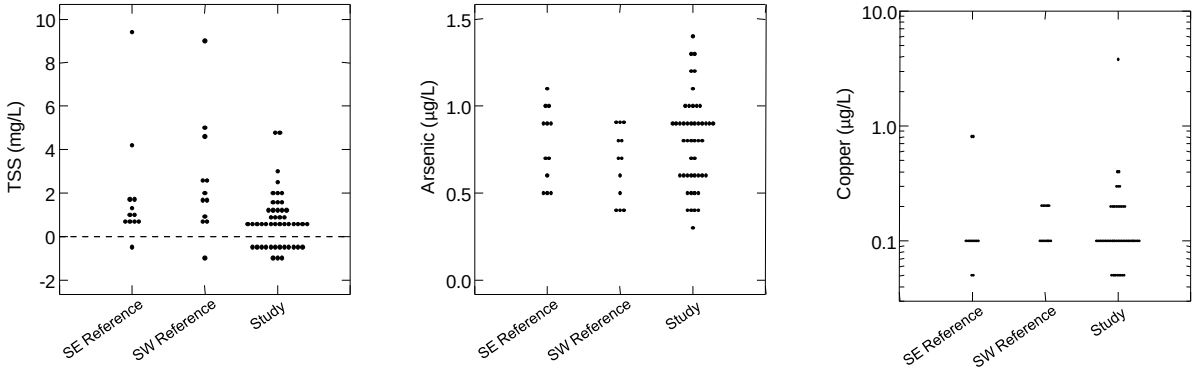


Figure 6-2 TSS, Arsenic and Copper Concentrations in Niskin Bottle Water Samples from Each Area (2010)

Notes: Detection limits for TSS varied between 0.5 and 1 mg/L in 2010. Concentrations less than detection limits are plotted as negative values

Copper concentrations less than the detection limit of 0.1 µg/L are plotted as ½ detection limit (0.05 µg/L)

Table 6-5 Frequencies of TSS Concentrations Less than and Above 1 mg/L (2010)

Depth	Area					
	References		Study		Both	
	No. <1 mg/L	No. ≥1 mg/L	No. <1 mg/L	No. ≥1 mg/L	No. <1 mg/L	No. ≥1 mg/L
Surface	4	4	8	8	12	12
Mid-depth	4	4	13	3	17	7
Bottom	1	7	10	6	11	13
All	9	15	31	17	40	32

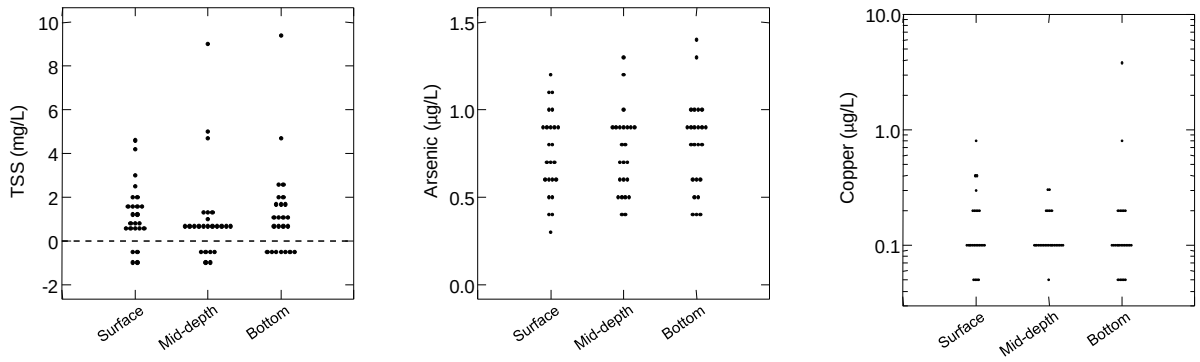


Figure 6-3 TSS, Arsenic and Copper Concentrations in Niskin Bottle Water Samples at Each Depth (2010)

Notes: Detection limits for TSS varied between 0.5 and 1 mg/L in 2010. Concentrations less than detection limit are plotted as negative values

Copper concentrations less than the detection limit of 0.1 µg/L are plotted as ½ detection limit (0.05 µg/L)

In 2010, arsenic concentrations in Niskin bottle samples ranged from 0.3 to 1.4 µg/L (Figure 6-2). Arsenic concentrations were significantly higher at Study Area stations (mean = 0.80 µg/L) than at Reference Area stations (mean = 0.72 µg/L) (Table 6-6). Arsenic concentrations also differed significantly between the two Reference Areas, with the SE Reference mean (0.78 µg/L) comparable to the Study Area mean and greater than the SW Reference Area mean (0.67 µg/L). Most of the variance in arsenic concentrations occurred at smaller spatial scales; differences among stations within Areas were highly significant (Table 6-6). Therefore, with differences between Reference Areas and differences within Areas significant, the difference between the Reference versus Study Areas, although significant, should be interpreted with caution. There was a wide range of arsenic concentrations within Areas, and the Study Area included concentrations both above and below the Reference Area range (Figure 6-2). Differences in arsenic concentrations among depths were not significant (Table 6-6; Figure 6-3).

Copper concentrations did not differ significantly between the Reference and Study Areas, or among stations or depths (i.e., none of the terms in Table 6-6 was significant). Most concentrations were near or below the laboratory detection limit of 0.1 µg/L (Figure 6-3), and the overall median and medians for each of the three Areas were 0.1 µg/L. One SE Reference concentration was 0.8 µg/L and one Study Area concentration was 3.8 µg/L.

Table 6-6 Results of Two-way ANOVA and Contrasts Comparing Arsenic and Copper Concentrations Among Stations and Depths (2010)

Source/Term	*p* Values	
	Arsenic (Log_{10})	Copper (Rank)
Among Stations		
Overall	**<0.001**	0.093
Reference versus Study Area	0.011	0.766
Between Reference Areas	0.024	0.227
Within Reference Areas	**<0.001**	0.141
Within Study Area	**<0.001**	0.102
Among Depths		
Overall	0.223	0.730
Vertical Gradient	0.134	0.438
Remainder	0.383	0.887

Note: - $p \leq 0.001$ in **bold.**

- A "bottom-up" approach, with lower-level differences inspected before higher-level differences, should be used to interpret results of the Station × Depth ANOVA. For example, if differences among stations within Areas are significant, differences between Areas (i.e., Between Reference Areas and Between Reference versus Study Areas) should be interpreted with caution unless the differences between Areas are much more significant (lower *p*) than differences within Areas. Similarly, if differences between Reference Areas are significant, differences between those Reference Areas and the Study Area should be interpreted with caution. Results for the depth Vertical Gradient contrast should also be interpreted with caution if the Remainder contrast is significant.

6.4.1.3 Comparison Among Years

Ten stations were sampled in baseline (1997) and there was no clear distinction between Study and Reference Areas. For plotting and summary purposes, eight of the baseline stations were considered Study Area stations, although some were further from the centre of the development than more recent Study Area stations (see Section 1). The two 1997 Reference stations were located within the SE and SW Reference Areas. From 2000 to 2010, 16 Study Area stations located around the FEZ, and four stations in each of the SE and SW Reference Areas, have been sampled.

Most TSS concentrations at the 10 stations sampled in 1997 were less than the laboratory detection limit of 1 mg/L (Figure 6-4). Therefore, no statistical comparisons were conducted. Most concentrations in 2001 were also less than the detection limit of 0.5 mg/L used in that year. In other EEM years prior to 2010, TSS did not differ significantly between Reference Area and Study Area stations, nor did it differ among depths (Suncor Energy 2009). In 2010, TSS concentrations were higher in the Reference Areas than in the Study Area (Section 6.4.1.2), but most concentrations in all Areas were near or below the laboratory detection limits (see medians in Figure 6-4).

Differences in arsenic concentrations between Reference and Study Area stations were significant in five of the seven EEM sample years (2004 and 2008 were the exceptions) (Table 6-7). However, median Study Area concentrations have not been consistently higher or lower than median Reference Area concentrations (Figure 6-4). Further, as in 2010, significant differences in past years often occurred between the two Reference Areas, and among stations within the Reference Areas and/or within the Study Area. Significant depth differences in arsenic concentrations have not occurred since 2000. Arsenic concentrations at both Reference and Study Area stations have decreased over time (Figure 6-4).

Table 6-7 Results of Two-way ANOVA Comparing Arsenic and Copper Concentrations Among Stations and Depths (1997 to 2010)

Variable	Year	p Values		
		Among Stations		Among Depths
		Overall	Reference vs. Study	
Arsenic	1997	**<0.001**	Not Tested	**<0.001**
	2000	**<0.001**	**<0.001**	**0.001**
	2001	**<0.001**	**<0.001**	0.247
	2002	0.002	**<0.001**	0.322
	2004	**<0.001**	0.242	0.835
	2006	**0.001**	0.003	0.489
	2008	0.106	0.130	0.152
	2010	**<0.001**	0.011	0.223
Copper	1997	0.180	Not Tested	0.009
	2000	0.491	0.472	0.003
	2001	0.215	0.037	**<0.001**
	2002	0.253	0.618	0.009
	2004	0.130	0.942	0.031
	2006	0.908	0.820	0.028
	2008	0.554	0.026	**<0.001**
	2010	0.093	0.766	0.730

Notes: - $p \leq 0.001$ in **bold.**
- TSS concentrations were not analyzed in ANOVA in years when many concentrations were below laboratory detection limits (e.g., 2010). Results for years when TSS was analyzed can be found in Suncor Energy (2010).
- If Overall differences among stations are more significant (lower *p*) than the difference between Reference vs. Study Areas, then there may also be differences between the Reference Areas and/or among stations within Areas.

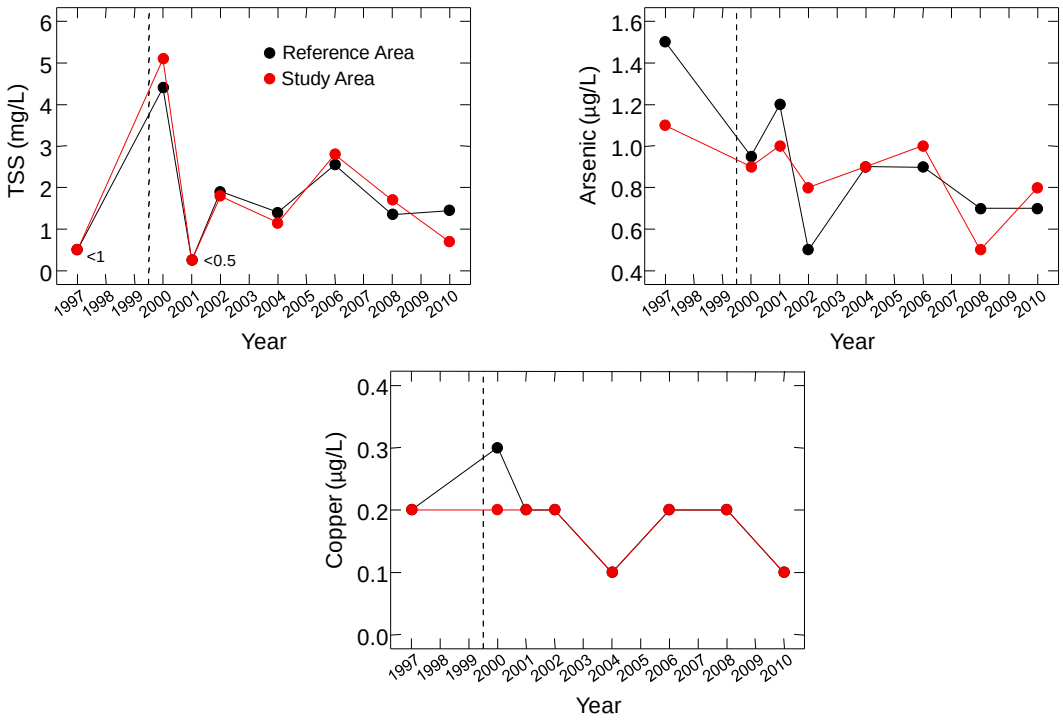


Figure 6-4 Median TSS, Arsenic and Copper Concentrations in Niskin Bottle Water Samples from the Reference and Study Areas (1997 to 2010)

Notes: When the Study Area and Reference values and lines completely overlap (i.e., are identical), only the Study Area values and lines (red) appear in the plots

Copper concentrations differed significantly among depths in every year except 2010 (Table 6-7), with concentrations usually higher in surface samples. Copper concentrations have only differed significantly between Reference and Study Area stations in 2001 and 2008 (Table 6-7). In both of those years, most concentrations ranged from 0.1 to 0.3 µg/L, and all Area medians were 0.2 µg/L (Figure 6-4). In general, differences in copper concentrations between the Reference and Study Areas, and other differences among stations, were small, and most of the limited variance for copper occurred among depths (compare *p* values in Table 6-7).

6.4.2 PIGMENTS AND CTD PROFILES

6.4.2.1 Niskin Bottle Samples

Summary statistics for pigment analysis from Niskin bottles are provided in Appendix C-2. In 2010, chlorophyll *a* concentrations did not differ significantly between the Reference Areas and the Study Area, nor did they vary between the two Reference Areas (Table 6-8). Concentrations differed significantly among stations within the Study Area but not among stations within the Reference Areas.

Chlorophyll *a* concentrations varied significantly among depths ($p < 0.001$). In Figure 6-5, each cluster of four points within the Reference Areas represents a different depth; there was no overlap in concentrations among depths in the Reference Areas. Depth clusters were less evident within the Study Area because of the significant variance in concentrations among stations as well as among depths within that Area. Chlorophyll *a* concentrations decreased significantly with increasing depth (Figure 6-6; note the highly significant Vertical Gradient in Table 6-8).

Phaeophytin *a* concentrations differed significantly between Reference and Study Area stations, and also between the two Reference Areas (Table 6-8). Mean and median concentrations were lowest (approximately 0.24 μg/L) in the SW Reference Area, and similar (approximately 0.29 μg/L) in the SE Reference and Study Areas (Figure 6-5). Depth differences in phaeophytin *a* concentrations were highly significant (Table 6-8), with concentrations increasing with increasing depth (Figure 6-6).

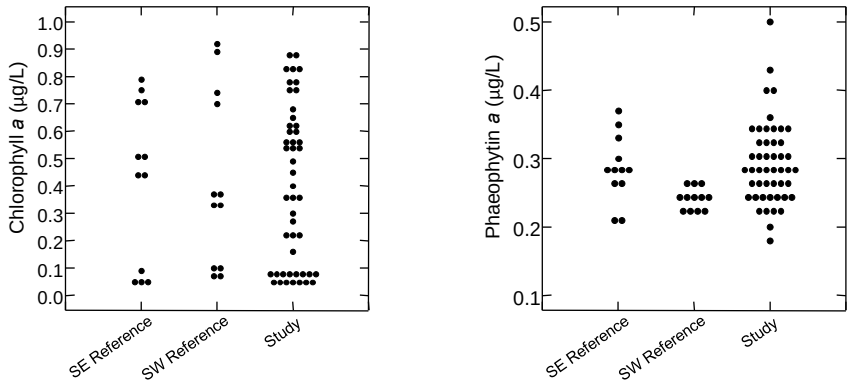


Figure 6-5 Chlorophyll a and Phaeophytin a Concentrations in Niskin Bottle Water Samples from Each Area (2010)

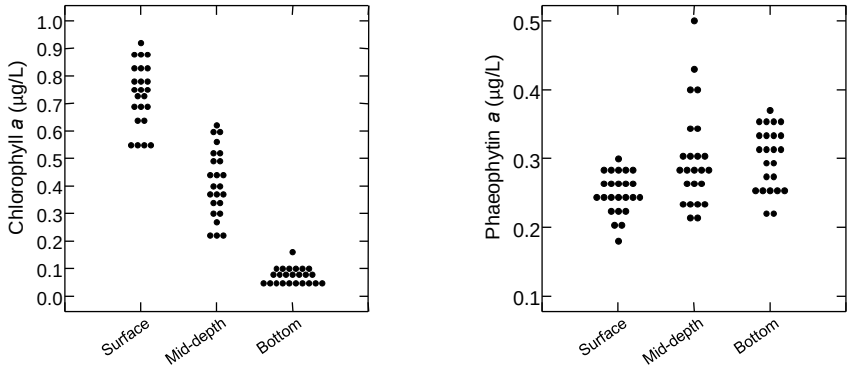


Figure 6-6 Chlorophyll a and Phaeophytin a Concentrations in Niskin Bottle Water Samples at Each Depth (2010)

Table 6-8 Results of Two-way ANOVA and Contrasts Comparing Pigment Concentrations Among Stations and Depths (2010)

Source/Term	p Values	
	Chlorophyll *a* (log_{10})	**Phaeophytin *a***
Among Stations		
Overall	0.005	0.292
Reference versus Study Area	0.144	0.023
Between Reference Areas	0.658	0.037
Within Reference Areas	0.771	0.989
Within Study Area	**<0.001**	0.380
Among Depths		
Overall	**<0.001**	**0.001**
Vertical Gradient	**<0.001**	**0.001**
Remainder	**<0.001**	0.061

Note: - $p \leq 0.001$ in **bold.**

- A "bottom-up" approach, with lower-level differences inspected before higher-level differences, should be used to interpret results of the Station × Depth ANOVA. For example, if differences among stations within Areas are significant, differences between Areas (i.e., Between Reference Areas and Between Reference versus Study Areas) should be interpreted with caution unless the differences between Areas are much more significant (lower *p*) than differences within Areas. Similarly, if differences between Reference Areas are significant, differences between those Reference Areas and the Study Area should be interpreted with caution. Results for the depth Vertical Gradient contrast should also be interpreted with caution if the Remainder contrast is significant.

6.4.2.2 CTD Profiles

Summary statistics for water column temperature, pH, salinity, oxygen and chlorophyll from CTD readings for 1997 to 2010, and depth profiles for individual water and sediment quality stations in 2010, are provided in Appendix C-3. Analyses of temperatures and chlorophyll concentrations are provided below.

Temperature Profiles

Temperatures at the 20 water quality stations[19] sampled in 2010 ranged from approximately 0°C near the bottom to approximately 10°C near the surface (Figure 6-7). Thermoclines for the SE Reference Area and the Study Area extended from approximately 30 to 60 m. Thermoclines at the 53 sediment quality stations were also generally located between 30 to 60 m (Figure 6-8).

[19] CTD data are missing for the four stations from the SW Reference Area because of an instrument communication error.

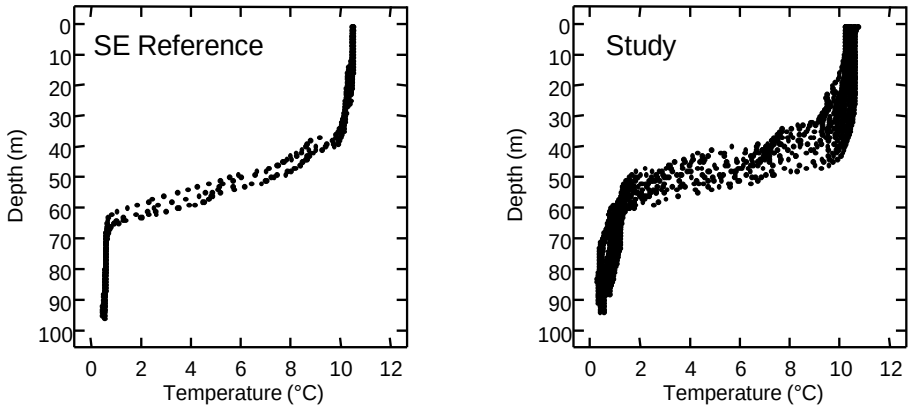


Figure 6-7 Temperature versus Depth for Each Area (2010 Water Quality Stations)

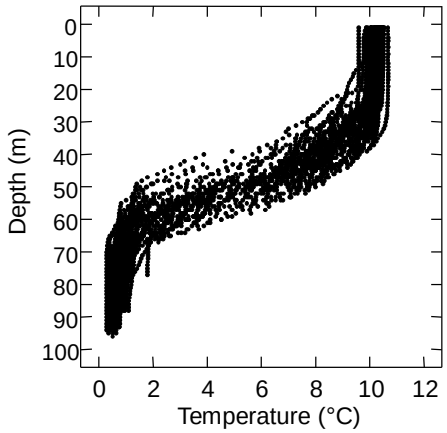


Figure 6-8 Temperature versus Depth (2010 Sediment Quality Stations)

Chlorophyll *a* Profiles

In 2010, chlorophyll ***a*** concentrations at water quality stations varied considerably among stations at any depth, especially in the Study Area (Figure 6-9). Concentrations at the four SE Reference stations never exceeded 5 μg/L, but concentrations at some Study Area stations approached 10 μg/L. Chlorophyll ***a*** concentrations generally decreased with depth, although there were some low concentrations within the first few metres of the surface. Depth gradients and, specifically, any decreases with depth for chlorophyll ***a*** for the water quality stations (and also the sediment quality stations; see below) were much weaker for the CTD data than for the Niskin bottle samples (Section 6.4.2.1).

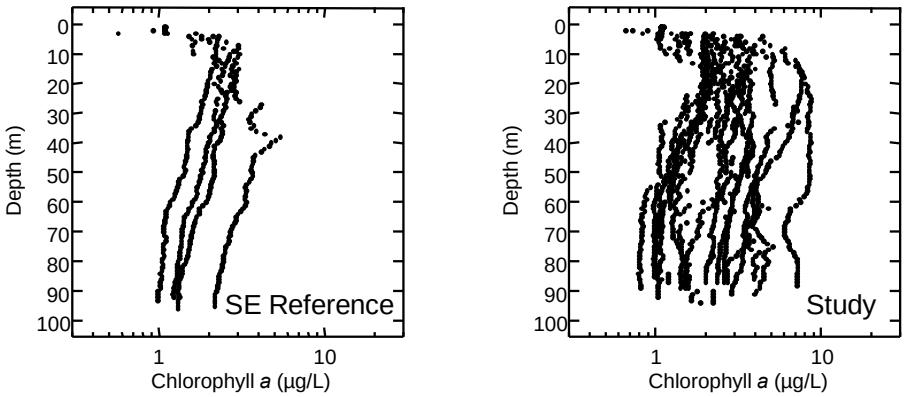


Figure 6-9 Chlorophyll a Concentrations versus Depth for Each Area (2010 Water Quality Stations)

At sediment quality stations, concentrations also varied among stations at any depth (Figure 6-10). Concentrations never exceeded 10 µg/L except at station 37(FEZ) (extreme right values in Figure 6-10). Depth gradients were weak, although concentrations generally decreased with depth below the first few metres.

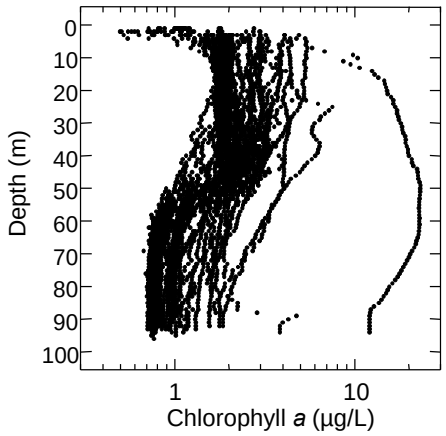


Figure 6-10 Chlorophyll a Concentrations versus Depth (2010 Sediment Quality Stations)

Table 6-9 provides results of rank-rank regressions of mean chlorophyll *a* concentrations at 1 to 30 m, 31 to 60 m and 61 to 85 m depth on distances from drill centres and distance from the FPSO. As noted previously (Section 6.3.2.2), both distance from the FEZ drill centres and distance from the FPSO can be considered measures of distance from the centre of the development because these two measures were highly correlated.

Table 6-9 Results of Rank-Rank Regressions of Mean Chlorophyll a Concentrations on Distance Variables (2010)

X Variables	Statistic/Result	Depth Interval		
		1 to 30 m	**31 to 60 m**	**61 to 85 m**
Min *d*	r (=r_s)	0.073	0.085	–0.056
FEZ *d*, FE *d*	Multiple *R*	0.090	0.167	0.105
	Partial *r* FEZ *d*	0.050	0.150	–0.105
	Partial *r* FE *d*	–0.085	–0.111	0.032
FPSO *d*	r (=r_s)	–0.104	–0.076	–0.196

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; $p \leq 0.001$ in **bold.**
- *n* = 73 water and sediment quality stations.
- Min *d* = distance from the nearest drill centre; FEZ *d* = distance from the nearest drill centre surrounding the FEZ; FE *d* = distance from FE drill centre; FPSO *d* = distance from FPSO.

None of the distance relationships was significant at $p \leq 0.05$ and all distance correlations were weak (|*r* or *R*| $\leq$ 0.2). There was a general tendency for chlorophyll ***a*** concentrations to be more variable near the FEZ drill centres and FPSO than at more remote stations (Figure 6-11). Consequently, the highest concentrations occurred at a few stations near the centre of the development despite the absence of any overall distance relationships.

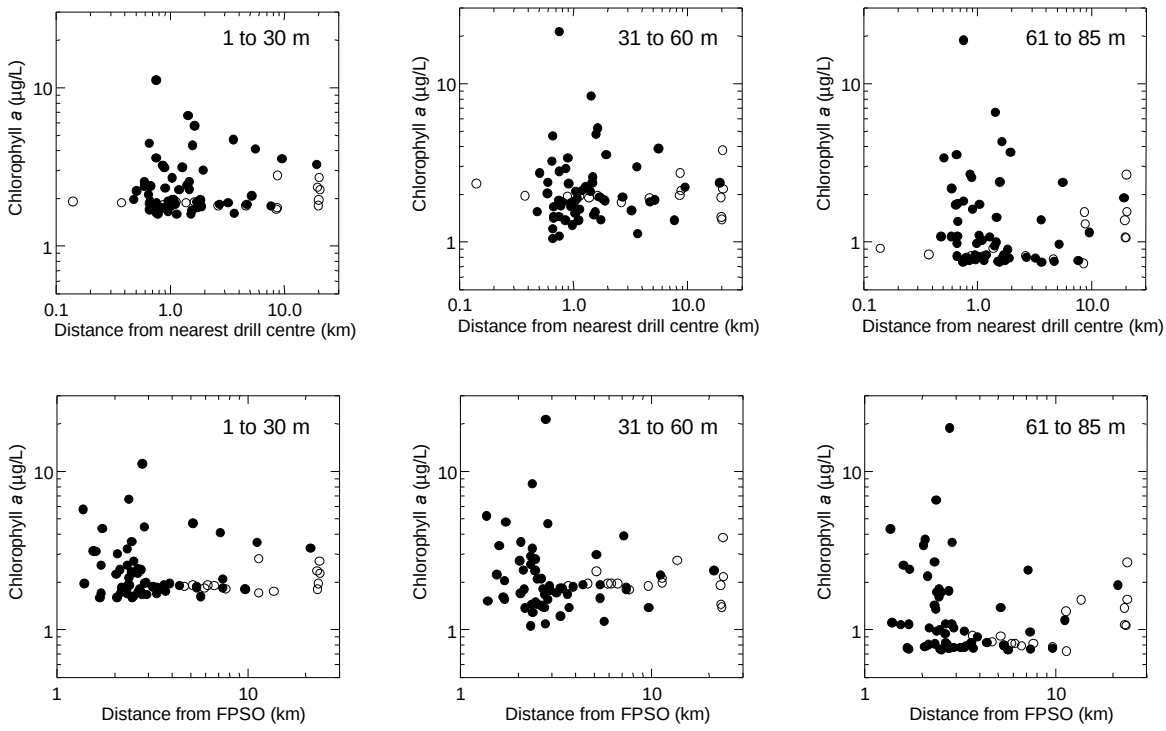


Figure 6-11 Distance Gradients for Mean Chlorophyll a Concentrations for Three Depth Intervals (2010 Water and Sediment Quality Stations)

Notes: Open circles indicate stations nearest to the FE drill centre; closed circles indicate stations nearest one of the four FEZ drill centres.

Comparison Among Years

Table 6-10 summarizes results of chlorophyll distance rank-rank regressions for all sample years based on CTD data from water and sediment quality stations. In 1997, data were available for only 32 sediment quality stations and no water quality stations. Data were available from 2000 to 2010 for most of the 77 water and sediment quality stations. The depth intervals analyzed differed by a few metres among years, but the middle interval (mid-depth) always included most of the thermocline (generally 30 to 60 m), the surface interval (30 m or less) was mostly above the thermocline and the bottom interval was mostly below the thermocline (greater than 60 m).

Table 6-10 Results of Rank-Rank Regressions for Mean Chlorophyll a Concentrations (1997 to 2010)

Depth Interval	Year	No. Stations	Multiple Regression on Distance from FEZ and FE Drill Centres			Distance from Nearest Active Drill Centre
			Multiple *R*	Partial *r*		
				FEZ *d*	FE *d*	r/r_s
Surface	1997	32	0.255	NS	NS	0.387*
	2000	62	0.351*	–**	NS	–0.274**
	2001	70	0.312*	NS	+*	0.114
	2002	68	**0.808*** **	**–*** **	+**	**–0.624*** **
	2004	74	0.174	NS	NS	–0.77
	2006	70	**0.413*** **	NS	**–*** **	–0.327**
	2008	77	0.383**	–*	+**	0.032
	2010	73	0.090	NS	NS	0.073
Mid-Depth	1997	32	**0.624*** **	–**	+**	–0.327**
	2000	64	0.133	NS	NS	0.012
	2001	70	0.343*	NS	–**	0.098
	2002	68	0.255	–*	NS	–0.127
	2004	74	0.343*	+*	NS	0.297*
	2006	70	0.350*	–*	NS	–0.266*
	2008	77	**0.478*** **	–***	NS	–0.357**
	2010	73	0.167	NS	NS	0.085
Bottom	1997	32	0.542**	+**	NS	0.507**
	2000	64	**0.464*** **	NS	**+** **	0.282*
	2001	71	0.011	NS	NS	–0.010
	2002	68	0.058	NS	NS	0.057
	2004	74	0.128	NS	NS	0.110
	2006	70	0.305	NS	–*	–0.036
	2008	77	**0.519*** **	**–*** **	**+*** **	–0.032
	2010	73	0.105	NS	NS	–0.056

Notes: - NS = Not Significant ($p > 0.05$); *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$; $p \leq 0.001$ in **bold.**
+ = positive correlation; **– = negative correlation**.
NE and SW drill centres were active in 2000; all four FEZ drill centres were active in 2001 and subsequent years; the FE drill centre was active in 2002 and subsequent years; the NE and SW drill centres were assumed active in baseline (1997). Produced water started being released at Terra Nova in 2003.
FEZ *d* = distance from the nearest drill centre surrounding the FEZ; FE *d* = distance from FE drill centre.

Suncor Energy (2010) provides a more extended discussion of chlorophyll *a* distance relationships prior to 2010[20]. In brief, in baseline (1997), surface and bottom chlorophyll concentrations increased significantly with distance from the nearest 'active' drill centre (r/r_s term in Table 6-10) (the NE and SW drill centres were considered "active" in 1997 because they were the first two drill centres to become active in 2000). At mid-depth (i.e., within the thermocline), chlorophyll concentrations were not significantly correlated with distance from the nearest 'active' drill centre but significantly decreased with distance from the nearest of the four FEZ drill centres and significantly increased with distance from the FE drill centre. Thus, in the absence of any drilling activity or produced water discharge in 1997, significant distance correlations occurred, but differed among depth intervals and among drill centres.

In the six EEM years prior to 2010, there was little or no evidence for any consistent and generalized project-related distance effects on chlorophyll concentrations. There were significant correlations between chlorophyll concentrations and various distance measures in EEM years (Table 6-10). However, few EEM distance correlations were stronger than baseline distance correlations. Furthermore, the EEM distance correlations varied in significance, strength or direction (sign) among years, depth intervals and between distances from the FEZ versus FE drill centres, with no apparent relationship with the onset of drilling activity at the FEZ drill centres in 2000 and the FE drill centre in 2002, or produced water discharges in 2003. In 2010, there were no significant distance relationships for chlorophyll *a*.

6.5 SUMMARY OF FINDINGS

In 2010, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were not detected in any of 24 Reference Area water column (Niskin bottle) samples, but were detected in three (3) of 48 Study Area samples, all from mid-depth. These hydrocarbons bore no resemblance to those found in produced water or in the synthetic-based drilling fluid used at Terra Nova.

Phenanthrene was detected in eight Study Area samples, mostly from the bottom. Fluorene was detected in one Reference Area sample.

[20] In the present report and for greater consistency, results were re-analyzed using rank-rank regression for all years instead of log-log for 1997 to 2002 and rank-rank for subsequent years. Using rank-rank regression did not substantially alter results for 1997 to 2002.

TSS was detected in 55 Niskin bottle samples. Arsenic was detected in all 72 samples and copper was detected in 62 samples. Iron was detected in 34 samples, mercury was detected in 13 samples, zinc was detected in seven samples, lead was detected in three samples and chromium was detected in one sample.

In 2010, frequencies of concentrations greater than or equal to 1 mg/L (the highest laboratory detection limit used) were significantly greater in Reference Area samples than in Study Area samples. Arsenic concentrations were significantly higher in the Study Area (mean = 0.80 μg/L) than in the Reference Areas (combined mean = 0.72 μg/L) but were also significantly higher in the SE Reference Area (mean = 0.78 μg/L) than in the SW Reference Area (mean = 0.67 μg/L). Smaller-scale variance of arsenic concentrations among stations within Areas was highly significant ($p < 0.001$). Copper concentrations did not differ significantly between Areas or among stations within Areas. TSS, arsenic and copper concentrations also did not differ significantly among depths (surface, mid-depth, bottom).

From 1997 to 2010, TSS concentrations varied mostly among years, rather than among Area and stations, or among depth. Arsenic concentrations have not been consistently higher or lower in the Study Area than in the Reference Areas, and significant differences have often occurred between Reference Areas, or among stations within Areas. Arsenic concentrations have not differed significantly among depths since 2000. Copper concentrations have differed mostly among depths rather than among Areas or among stations, with concentrations usually higher at the surface.

In 2010, chlorophyll *a* concentrations in Niskin bottle samples did not differ significantly among Areas, but differed significantly among stations within the Study Area. Chlorophyll *a* concentrations decreased significantly with increasing depth in both the Study and Reference Areas. Phaeophytin *a* concentrations in the SE Reference Area and the Study Area were similar (means = 0.29 μg/L) and higher than concentrations in the SW Reference Area (mean = 0.24 μg/L). Phaeophytin *a* concentrations increased significantly with increasing depth.

In 2010, CTD casts were conducted at the 4 SE Reference Area and 16 Study Area water quality stations, and at the 53 sediment quality stations. Thermoclines at most stations occurred between 30 to 60 m. Chlorophyll *a* concentrations measured in the CTD casts decreased with increasing depth, but that depth gradient was much weaker than the depth gradient observed for chlorophyll in the Niskin bottle samples.

Chlorophyll *a* concentrations at the surface, mid-depth and bottom were not correlated with distances from the drill centres or FPSO.

In the seven EEM years (2000, 2001, 2002, 2004, 2006, 2008, 2010), with sample sizes of 64 to 77 stations, there was no evidence for any consistent and generalized project-related distance effects on chlorophyll concentrations. In some EEM years, there were significant correlations between chlorophyll concentrations and distance from either the FEZ and FE drill centres. However, few EEM distance correlations were stronger than baseline distance correlations. Furthermore, the EEM distance correlations varied in significance, strength and direction among years, among depth intervals, and between distances from the FEZ versus FE drill centres, with no apparent relationship with the onset of drilling activity or produced water discharges.

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* between June 29 and July 2, 2010. 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

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). Sampling for the 2010 program was conducted under experimental fishing license issued by Fisheries and Oceans Canada (DFO). A total of 50 plaice and 569 scallop were collected in the Terra Nova Study Area in 2010. A total of 50 plaice and 390 scallop were collected in the Reference Area. Location of sampling transects are provided in Figures 1-19 and 1-20 (Section 1) and in Appendix D-1. Plaice were collected using a commercial fishing trawl towed at 3 knots for 15 minutes per transect. Scallop were collected by towing an 8-foot dredge at 3 knots for 15 minutes.

Preliminary processing of samples was done on board 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 Dietrich's fixative 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 top deck of the survey vessel was washed with degreaser then flushed with seawater. The fishing deck and chute leading to the processing facilities were flushed continuously during the survey. Sampling personnel wore new latex gloves and all sampling and measuring instruments were washed with mild soap and water then rinsed with distilled water before each 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, plus one additional transect (TN-03), were used in taste analyses (Table 7-2). TN-03 was used exclusively for taste tests to provide better representation for the North East corner of the FEZ (20 of the 27 scallop collected in TN-07, the other transect at the North East corner of the FEZ, were required for chemistry, leaving only

seven scallop for taste analyses). 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 (2010)

Transect	Area	No. of Scallop	Body Burden Composites	Taste (Wt. g. of Scallop)
TN-01	Study (NW corner of FEZ)	71	Composite 1 (20 scallop)	294
TN-03	Study (NE corner of FEZ)	35	None	205
TN-04	Study (SE side of FEZ)	66	Composite 2 (20 scallop)	238
TN-05	Study (SW corner of FEZ)	290	Composite 3 (20 scallop)	846
TN-06	Study (NW corner of FEZ)	80	Composite 4 (20 scallop)	333
TN-07	Study (NE corner of FEZ)	27	Composite 5 (20 scallop)	43
Total	**Study**	**569**	**5**	**1,959**
TN-08	Reference	144	Composite 6 (20 scallop)	749
TN-09	Reference	120	Composite 7 (20 scallop)	613
TN-10	Reference	43	Composite 8 (20 scallop)	159
TN-11	Reference	28	Composite 9 (20 scallop)	48
TN-12	Reference	55	Composite 10 (20 scallop)	206
Total	**Reference**	**390**	**5**	**1,775**

Note: - Study Area tissue for taste analyses was selected to generate relatively equal weights 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 (2010)

Transect	Area	Total No. Fish	Body Burden Composites	Taste (Wt. g. of Top Fillets)	Health (No. of Fish)
TN-18	Study (SW corner of FEZ)	10	Composite 1 (10 fish)	295	10
TN-19	Study (NW corner of FEZ)	10	Composite 2 (10 fish)	623	10
TN-20	Study (NE corner of FEZ)	10	Composite 3 (10 fish)	618	10
TN-21	Study (SE corner of FEZ)	10	Composite 4 (10 fish)	614	10
TN-22	Study (SW corner of FEZ)	10	Composite 5 (10 fish)	310	10
Total	**Study**	**50**	**5**	**2,460**	**50**
TN-13	Reference	10	Composite 6 (10 fish)	467	10
TN-14	Reference	10	Composite 7 (10 fish)	441	10
TN-15	Reference	10	Composite 8 (10 fish)	458	10
TN-16	Reference	10	Composite 9 (10 fish)	466	10
TN-17	Reference	10	Composite 10 (10 fish)	447	10
Total	**Reference**	**50**	**5**	**2,279**	**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 2010)

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

Variables	Method	Laboratory Detection Limit						Units
		1997	2000	2001	2002	2004-06	2008-10	
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[*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	Grav.	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[21].

- NA = Not Analyzed.

[21] Typically, Maxxam Analytics sets the laboratory detection limit at 2 to 10 times the Method Detection Limit calculated using the USEPA (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 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).

Size, shape and degree of haemoglobinization of red blood cells were examined and recorded.

Differential blood cell counts were performed on lymphocytes, neutrophils and thrombocytes and expressed as a percentage of each type of cell on 200 white blood cells counted. Cells were counted under 400x magnification in fields along a row starting from the front edge of the smear and continuing parallel to the slide edge until the total number of cells were counted.

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 Pohl and Fouts (1980), as modified by Porter et al. (1989).

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 four weeks of storage of S9 fractions.

EROD Assay

The reaction mixture, final volume of 1 ml, contained 50 mM Tris buffer, pH 7.5, 2 µM ethoxyresorufin (Sigma) dissolved in dimethyl sulphoxide, 0.15 mM NADPH and 20 µl of S9 protein (diluted five times). After a 15-minute incubation at 27°C, the reaction was stopped with 2 mL of methanol (High Performance Liquid Chromatography grade) and samples were centrifuged (3,600 g for five minutes) in order to remove the protein precipitate. The fluorescence of resorufin formed in the supernatant was measured at an excitation wavelength of 550 nm and an emission wavelength of 580 nm using a Perkin-Elmer LS-5 fluorescence spectrophotometer. Blanks were performed as above, with methanol added at the beginning of the incubation. All the samples were run in duplicate. Protein concentration 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 against standard concentrations of resorufin. Two external positive controls (pools of liver homogenates from uninduced cunners and cunners induced with petroleum) were run with each batch of samples to assure consistency of measurements.

7.2.4.3 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

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

Lesions (except macrophage aggregates) 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).

The percentage of fish affected by each type of lesions or prevalence of lesion 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).

A semi-quantitative examination was carried out where the total number of secondary lamellae as well as the lamellae presenting the lesions were 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.

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 for two purposes. The analyses provide basic descriptive information on the biology of the two species at Terra Nova. For the EEM program, differences in biological characteristics of the two species in the Study and the Reference Areas might also affect results for body burden, taste and health analyses.

7.3.1.1 Scallop

Quantitative analyses of biological characteristics for scallop were performed on 2010 samples. Summary statistics from previous years are provided in Appendix D-4 for qualitative comparisons with 2010 data. Analyses of scallop biological characteristics in 2010 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 959 scallop from the 11 transects sampled in 2010.

Sex ratios (frequencies of the two sexes) were compared among transects within Areas and between Areas, using log-likelihood ratio or *G* tests[22] (Sokal and Rohlf 1981).

Size variables included shell length, width and height (one-dimensional measures), tissue weight (adductor muscle weight + viscera weight + gonad weight) and shell weight (total weight – tissue weight) (three-dimensional measures). PCA[23] was used to derive summary size and shape measures from these five size variables.

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

[23] 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).

Size and shape PC1 and PC2 scores were compared among transects within Areas and between Areas in nested ANOVA[24]. The nested ANOVA were conducted on each sex separately.

The above comparisons of sex ratios, size and shape were repeated for the subset of 200 scallop (approximately 20% of all scallop collected) used for analysis of body burdens to determine if that subset was representative of all scallop collected. Scallop from Transect TN-03 (Study Area) were not used for analyses of body burdens. Otherwise, each of the 10 body burden composites included scallop from a single transect (i.e., there was a direct match between composites and transects).

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 was 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 and gutted 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.

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

- Fulton's condition factor: 100 x body weight/(length cubed) based on gutted weight;

[24] 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.

- hepato-somatic index (HSI): 100 x liver weight/gutted weight; and
- gonado-somatic index (GSI): 100 x gonad weight/gutted 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 gutted weight (which is not always the case), log-log regressions of body gutted weight on length, and liver and gonad weight on body gutted 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*-value 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 and 2010). The PCA for muscle included six metals detected in all 80 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 eight sample years and between the two Areas in two-way Year $\times$ Area ANOVA. Three time (Year) contrasts were tested. The Before-After (BA) contrast compared baseline (Before project activity) values to EEM (After onset of project activity) values. The EEM Linear contrast tested for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over the seven EEM years. The EEM Quadratic contrast tested for a parabolic (U-shaped) relationship between body burden variables after drilling began, which is effectively a reversal of monotonic trends (i.e., an increase followed by a decrease, or vice versa).

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 × Area interaction, the contrasts provide tests of potential project effects and other changes in differences between the two Areas over time. The BA × 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 × 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. Similarly, the EEM Quadratic × Area contrast tests for a difference in quadratic relationships between Areas. Quadratic relationships are of interest in long-term monitoring programs because they may indicate recovery from earlier project effects. For example, body burdens in the Study Area might initially increase relative to background (Reference Area) levels after initiation and intensification of drilling in earlier EEM years but then subsequently decrease to background levels as drilling activity is reduced[25].

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%. In 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 laboratory detection limit, especially in adductor muscle.

[25] A "bottom-up" approach should be used to interpret the results of the Year × Area ANOVA. If the overall Year × 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. Similarly, if Quadratic contrasts are significant, Linear contrasts should be interpreted with caution.

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 and 2010. In 2000, fillet and liver samples from individual fish, rather than composite samples, were analyzed. In 1997, no plaice samples were collected for body burden analysis.

Three metals (arsenic, mercury and zinc) were detected in all fillet samples. Fat content and concentrations of these three metals were compared among years and between Areas in two-way ANOVA. The Year BA and Year × Area BACI contrasts could not be tested because there were no baseline data. One fat concentration in 2010 was less than recent laboratory detection limit of 0.5% and 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 2010, 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. 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 and arcsine square-root transformed percentages of blood cells and 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*-value 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 2010, a total of 959 scallop were collected in five Reference Area transects and six 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 (2010)

Sex	Area	Statistic	Dimensions (mm)			Weights (g)					
			Length	Width	Height	Total	Tissue	Shell	Adductor	Viscera	Gonad
Female	Reference	*n*	217	217	217	217	217	217	217	217	217
		Mean	73.8	69.5	23.0	52.2	20.4	31.8	5.3	13.0	2.1
		SD	4.7	4.9	2.1	11.7	5.6	8.4	0.8	5.0	0.5
	Study	*n*	360	360	360	360	360	360	360	360	360
		Mean	73.6	68.5	23.4	47.9	15.6	32.3	3.8	9.6	2.1
		SD	5.6	5.6	2.6	12.4	5.4	9.5	1.2	4.5	0.7
Male	Reference	*n*	173	173	173	173	173	173	173	173	173
		Mean	72.7	68.2	22.5	49.9	19.2	30.8	5.1	12.0	2.2
		SD	5.2	5.1	2.1	11.4	5.2	8.3	0.9	4.4	0.6
	Study	*n*	209	209	209	209	209	209	209	209	209
		Mean	72.4	67.3	22.6	45.4	15.0	30.4	3.8	9.1	2.1
		SD	5.3	5.6	2.6	12.2	5.1	8.9	1.2	4.2	0.6

Sex Ratios

In 2010, female scallop outnumbered males in catches from both the Reference and Study Areas, with an overall female:male sex ratio of 60:40 (Table 7-6). Females also outnumbered males in all but one of the 11 transects. Therefore, sex ratios were skewed towards females even at small spatial scales (i.e., within transects). Female:male ratios were significantly higher in the Study Area (63:37) than in the Reference Area (56:44) and varied less among Study Area transects than among Reference Area transects (Tables 7-6 and 7-7).

Table 7-6 Sex Ratios of Scallop in Transects (2010)

Area	Transect	Females		Males		Total
		No.	%	No.	%	No.
Reference	TN-08	69	48	75	52	144
	TN-09	77	64	43	36	120
	TN-10	22	51	21	49	43
	TN-11	17	61	11	39	28
	TN-12	32	58	23	42	55
	Total	**217**	**56**	**173**	**44**	**390**
Study	TN-01	40	56	31	44	71
	TN-03	23	66	12	34	35
	TN-04	41	62	25	38	66
	TN-05	192	66	98	34	290
	TN-06	49	61	31	39	80
	TN-07	15	56	12	44	27
	Total	**360**	**63**	**209**	**37**	**569**
Both	**Total**	**577**	**60**	**382**	**40**	**959**

Table 7-7 Results of G Tests Comparing Scallop Sex Ratios Among Transects (2010)

Source	df	*G*	*p*
Among all Transects	10	16.910	0.076
Between Areas	1	5.602	0.018
Among Transects within Areas	9	11.307	0.255
Among Reference Area Transects	4	7.840	0.098
Among Study Area Transects	5	3.467	0.628

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 (2010)

Size Variable	Correlation (*r*) with:		
	PC1	PC2	PC3
One-dimensional (shell)			
Length	**0.917**	–0.030	0.299
Width	**0.926**	0.041	0.265
Height	**0.807**	–0.199	**–0.517**
Three-dimensional (weight)			
Tissue weight	**0.682**	**0.697**	–0.150
Shell weight	**0.838**	–0.389	0.006
% variance	70.3	13.6	9.0

Notes: - $|r| \geq 0.5$ in bold.
- n = 959 scallop.

PC2 was positively correlated with tissue weight and negatively correlated with shell weight (Table 7-8). Higher PC2 scores therefore indicate greater tissue:shell weights. PC3 was negatively correlated with shell height and weakly correlated with shell length and width. Lower PC3 scores indicate scallop with "flatter" shells.

For both sexes, PC1 scores and overall size differed significantly among transects within Areas but not between Areas (Table 7-9). Within the Study Area, scallop collected at the Southwest corner of the FEZ (Transect TN-05) were smaller than scallop in other transects (Figure 7-3).

Table 7-9 Results of Nested ANOVA Comparing Scallop Size and Shape Principal Components (PCs) Among Transects Within Areas and Between Areas (2010)

Variable	Source	Females		Males	
		df	*p*	df	*p*
PC1	Area	1	0.942	1	0.836
	Transects within Areas	9	**<0.001**	9	**<0.001**
	Within Transects (Error)	566		371	
PC2	Area	1	0.022	1	0.012
	Transects within Areas	9	**<0.001**	9	**<0.001**
	Within Transects (Error)	566		371	
PC3	Area	1	0.272	1	0.503
	Transects within Areas	9	**<0.001**	9	**<0.001**
	Within Transects (Error)	566		371	

Note: - $p \leq 0.001$ in **bold.**

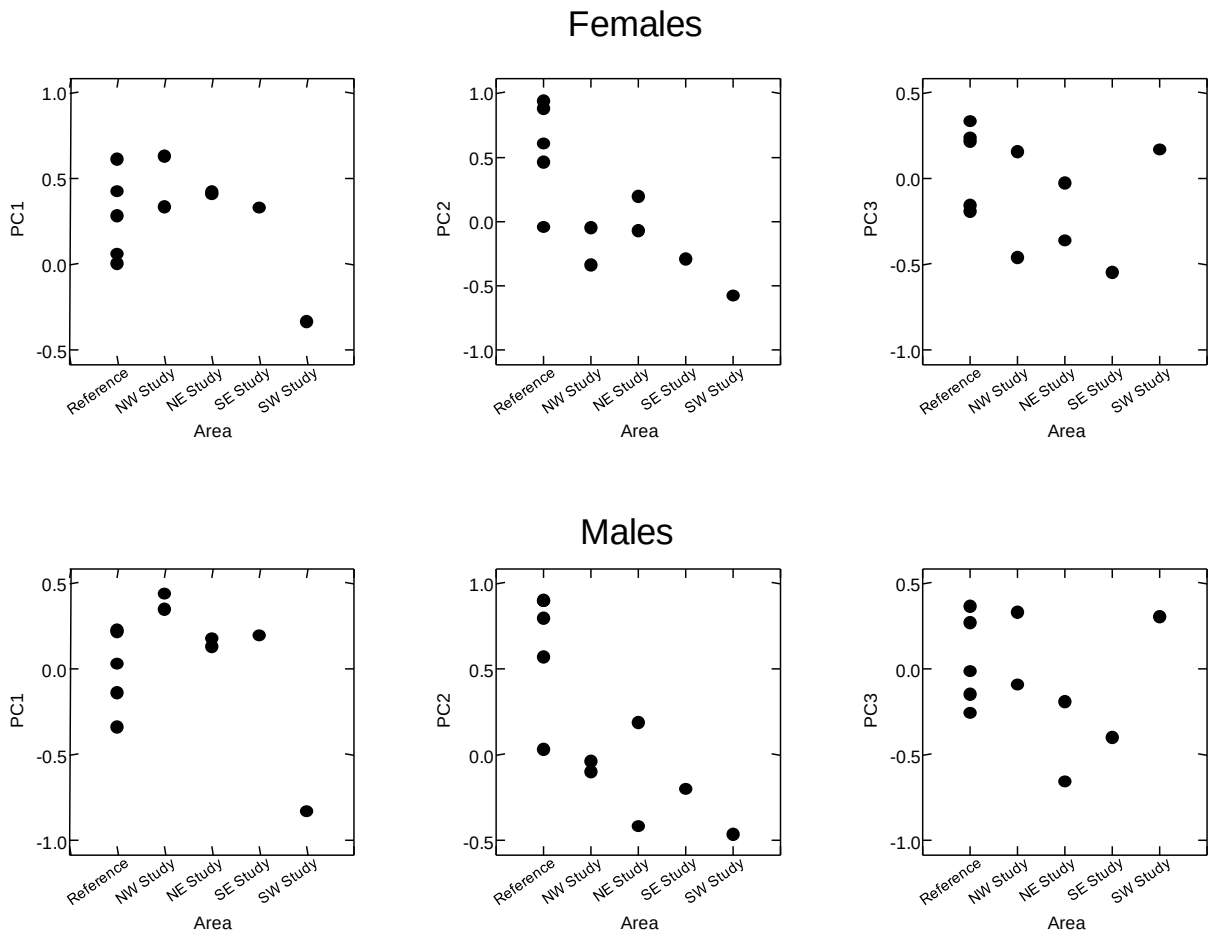


Figure 7-3 Mean Scallop Size and Shape Principal Component (PC) Scores (2010)

Size PC2 (tissue:shell weight) differed significantly between Areas for both sexes (Table 7-9), with PC2 scores higher in Reference Area scallop (Figure 7-3). PC2 scores also varied significantly among transects within Area. PC3 scores (shell flatness) differed significantly among transects within Areas but did not vary between the Study and Reference Areas.

Males were smaller than females in most transects (i.e., below the diagonal line for PC1 in Figure 7-4; see also Table 7-5). PC2 and PC3 scores did not differ systematically between the sexes.

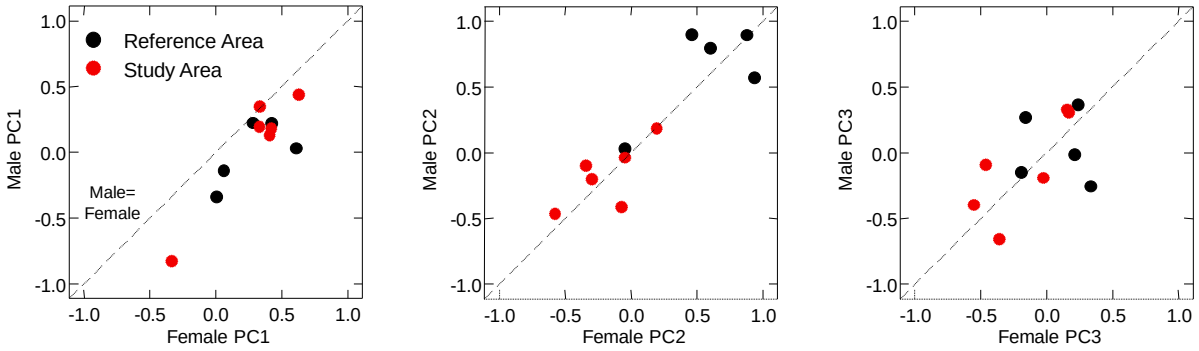


Figure 7-4 Transect Mean Male versus Female Scallop Size and Shape Principal Component (PC) Scores (2010)

The body burden samples in 2010 also generally reproduced broad differences (or their absence) in biological characteristics evident in the total catch. As in the total catch, females outnumbered males in the body burden samples, PC1 scores did not differ significantly between Areas, and PC2 scores were significantly higher for Reference Area scallop than for Study Area scallop.

7.4.1.2 Plaice

Sex Ratios and Maturity Stages

Thirty-five females and 15 males were collected in the Study Area, while 37 females and 13 males were collected in the Reference Area. Female:male sex ratios were not significantly different between the two Areas (p = 0.824; Fisher Exact Test).

No significant differences in frequencies of maturity stages for males were observed between the two Areas (Table 7-10).

Table 7-10 Frequencies (%) of Maturity Stages of Male Plaice (2010)

	n	Immature M-100 [a]	Maturing to spawn this year M-140 [a]	Partly spent M-150 [a]	Spent this year M-160+M-170 [a]	Maturing for next year M-180 [a]
Reference Area	13	0	0	3	10	0
Study Area	15	0	0	0	15	0
p [b]		1.000	1.000	0.242	0.356	1.000

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

Most of the female fish sampled were mature (Table 7-11), and no significant difference in frequencies of maturity stages were observed.

Table 7-11 Frequencies (%) of Maturity Stages of Female Plaice (2010)

	n	Immature F-500 [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]	Maturing for next year F-580 [a]
Reference Area	37	0	1	0	36	0
Study Area	35	0	1	0	34	0
p [b]		1.000	1.000	1.00	0.828	1.000

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

Size, Age and Condition

Males

Information on size, age and condition indices of male fish (all maturity stages pooled) from the Reference and Study Areas are summarized in Table 7-12. Data are expressed as mean ± standard deviations. The complete data set is provided in Appendix D-3, Annex B.

There were no significant differences between the two Areas in any of the parameters measured in male fish.

Similarly, gutted weight for males relative to the covariate length, liver weight relative to the covariate gutted weight and gonad weight relative to the covariate gutted weight were not significantly different between Areas (Table 7-13).

Table 7-12 Size, Age and Condition Indices of Male Plaice (all Maturity Stages Pooled) (2010)

	Reference Area	Study Area	*p* [d]
Fish number	13	15	
Length (cm)	33.5 ± 3.4	34.9 ± 2.4	0.234
Total body weight (g)	349.9 ± 91.8	387.2 ± 89.8	0.288
Gutted body weight (g)	305.4 ± 83.3	345.1 ± 80.0	0.210
Liver weight (g)	4.4 ± 1.5	4.8 ± 2.2	0.576
Gonad weight (g)	3.5 ± 3.0	3.3 ± 1.4	0.371
Age (year)	7.4 ± 1.1	8.1 ± 1.7	0.193
Fulton's condition factor [a]	0.793 ± 0.057	0.800 ± 0.069	0.779
HSI [b]	1.439 ± 0.347	1.397 ± 0.606	0.818
GSI [c]	1.224 ± 1.001	0.962 ± 0.329	0.580

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

Table 7-13 Adjusted Means of Male Plaice (all Maturity Stages Pooled) (2010)

Variable	Covariate	Adjusted Means		p [a]
		Reference Area	Study Area	
Gutted weight	Length	314.4	317.3	0.777
Liver weight	-	4.41	4.00	0.537
Gonad weight	Gutted weight	2.90	2.96	0.927

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

Females

Information on size, age 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 Size, Age and Condition Indices of Female Plaice (All Maturity Stages Pooled) (2010)

	Reference Area	Study Area	*p* [d]
Fish number	37	35	
Length (cm)	42.0 ± 4.9	42.8 ± 5.1	0.516
Total body weight (g)	721.3 ± 264.3	787.4 ± 270.3	0.298
Gutted body weight (g)	586.1 ± 224.6	662.3 ± 225.0	0.155
Liver weight (g)	10.0 ± 5.2	9.8 ± 5.1	0.927
Gonad weight (g)	23.7 ± 24.9	24.1 ± 10.3	0.229
Age (year)	9.9 ± 1.8	10.3 ± 1.8	0.413
Fulton's condition factor [a]	0.758 ± 0.116	0.884 ± 0.621	0.411
HSI [b]	1.928 ± 1.937	1.494 ± 0.622	0.089
GSI [c]	3.699 ± 3.199	3.597 ± 1.149	0.358

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

No significant differences in fish size, liver and gonad weight, age, Fulton's condition factor and GSI were found between Reference and Study Areas. However, the HSI was marginally lower in fish from the Study Area (p = 0.089).

Gutted weight relative to the covariate length and gonad weight relative to the covariate gutted weight did not differ significantly between the two Areas (Table 7-15). In spite of the indication of a difference in HSI between Areas, the adjusted means of liver weight on gutted weight were not significantly different between Areas.

Table 7-15 Adjusted Means of Female Plaice (all Maturity Stages Pooled) (2010)

Variable	Covariate	Adjusted Means		*p* [a]
		Reference Area	Study Area	
Gutted weight	Length	550.1	611.1	0.106
Liver weight	Gutted weight	9.34	8.21	0.165
Gonad weight	Gutted weight	17.0	18.9	0.434

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

7.4.2 BODY BURDEN

7.4.2.1 Scallop

In 2010 and in previous years, arsenic, boron, cadmium, mercury, strontium and zinc were detected in every scallop adductor muscle sample (Appendix D-2). Mercury was not detected in one 2010 viscera sample; otherwise, the six metals detected in all adductor muscle samples plus aluminum, copper, iron, manganese, nickel, selenium and uranium were detected in every scallop viscera sample (Appendix D-2). Other metals were rarely or never detected in the body burden samples and were excluded from quantitative analyses.

Fat content in most muscle samples was near or below the recent laboratory detection limit of 0.5%. Fat content in viscera was 1 to 2%, and greater than the laboratory detection limit in all samples.

>C_{10}-C_{21} hydrocarbons were detected relatively frequently in Study Area body burden samples but not in Reference Area samples (see below and Appendix D-2). >C_{21}-C_{32} hydrocarbons were rarely detected in samples and individual PAHs were never detected.

Metals and Fat

In adductor muscle and viscera samples collected from 1997 to 2010, concentrations of metals, except boron in muscle and aluminum in viscera, were positively correlated with the first Principal Component (metals PC1) derived from those concentrations (Table 7-16). Therefore, PC1 for both tissues can be considered a summary measure of total metal concentrations.

Table 7-16 Correlations (r) Between Concentrations of Metals in Scallop Tissue and Principal Components Derived from those Concentrations (1997 to 2010)

Metal	Adductor Muscle		Viscera	
	Correlation (*r*) with:		Correlation (*r*) with:	
	PC1	PC2	PC1	PC2
Aluminum			–0.066	**0.929**
Arsenic	0.485	**0.557**	**0.759**	0.055
Boron	–0.031	**0.685**	0.287	–0.052
Cadmium	**0.765**	0.128	**0.591**	–0.016
Copper			**0.673**	–0.244
Iron			0.203	**0.916**
Manganese			0.385	0.424
Mercury	0.271	**–0.509**	0.418	–0.253
Nickel			0.247	–0.305
Selenium			**0.818**	–0.040
Strontium	**0.587**	–0.435	0.143	**0.655**
Uranium			**0.681**	0.294
Zinc	**0.827**	0.057	**0.739**	–0.299
% variance	32.1	20.8	27.6	20.9

Notes: - $|r| \geq 0.5$ in **bold.**
- $n = 80$ composite samples for each tissue.

PC2 for muscle samples was positively correlated with concentrations of arsenic and boron and negatively correlated with concentrations of mercury and strontium (Table 7-16). Therefore, arsenic and boron "behaved" similarly to each other but differently from mercury and strontium, beyond the overall tendency for concentrations of all metals to be positively correlated. Higher PC2 scores in muscle indicate enrichment of arsenic and boron relative to mercury and strontium.

PC2 for viscera samples was positively correlated with aluminum, iron, manganese and strontium concentrations (Table 7-16). These metals occur at relatively high background levels in Terra Nova sediments (Section 5). Therefore, PC2 could be considered a measure of natural metal concentrations in ingested sediments. Aluminum, iron and manganese were presumably egested (eliminated) rather than incorporated into muscle tissue, since they were not detected in muscle.

Concentrations of metals in adductor muscles and Metals PC1 scores differed significantly over time but not between Areas (the Area and Year × Area terms were not significant for Metals PC1; Table 7-17). In most years, including baseline (1997), differences in Metals PC1 scores between the Study and Reference Areas were small and variances within Areas low (see narrow error bars in Figure 7-5). In both Areas, PC1 scores were lower in baseline than in most EEM years (the Year BA contrast was highly significant ($p < 0.001$); Table 7-17). There was also significant variance among EEM years, with Metals PC1 scores decreasing from early EEM

years to baseline levels by 2008, but then increasing again in 2010 in both Areas (note the significant EEM Quadratic contrast in Table 7-17).

Table 7-17 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Adductor Muscle Among Years and Between Areas (1997 to 2010)

Source	df	*p*		
		Metals PC1	**Metals PC2**	**Fat (%)**
Year	7	**<0.001**	**<0.001**	**<0.001**
BA	(1)	**<0.001**	0.081	0.657
EEM Linear	(1)	0.747	0.001	0.662
EEM Quadratic	(1)	0.008	0.020	0.009
Area (CI)	1	0.193	**<0.001**	0.197
Year × Area	7	0.670	0.259	**<0.001**
BACI	(1)	0.783	0.727	0.029
EEM Linear × Area	(1)	0.101	0.775	0.592
EEM Quadratic × Area	(1)	0.672	0.517	0.943

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

Metals PC2 scores for adductor muscle also varied significantly ($p < 0.001$) among years (Table 7-17). PC2 scores were greater in the Reference Area than in the Study Area in every year including baseline (Figure 7-5; note the highly significant Area differences in Table 7-17). Higher PC2 scores in Reference Areas reflect greater concentrations of arsenic and/or boron relative to mercury and/or strontium. Arsenic concentrations were greater in the Reference Area than in the Study Area in every year (including baseline), and mercury concentrations were greater in the Study Area than in the Reference Area in every year except 2004 (Figure 7-5).

In 2002, mean fat concentrations in Reference Area samples were approximately 0.8% (Figure 7-5). The Year × Area interaction and BACI contrast were significant (Table 7-11) because the 2002 Reference Area mean was greater than all other means, which were near or below the recent laboratory detection limit of 0.5% (i.e., there was almost no other variance among samples).

Viscera Metals PC1 scores, a measure of total metal concentrations, differed significantly between the Reference and Study Areas (Table 7-18). Metals PC1 scores were greater in the Study Area than in the Reference Area in every year including baseline, except 2008 (Figure 7-6). Annual Reference Area means were relatively constant over time, whereas Study Area means were more variable (note the significant Year × Area interaction in Table 7-18). Differences between the two Areas decreased over time in EEM years, with Study Area PC1 scores similar to Reference Area scores in 2008 and 2010 (Figure 7-6; note the significant EEM Linear × Area contrast in Table 7-18).

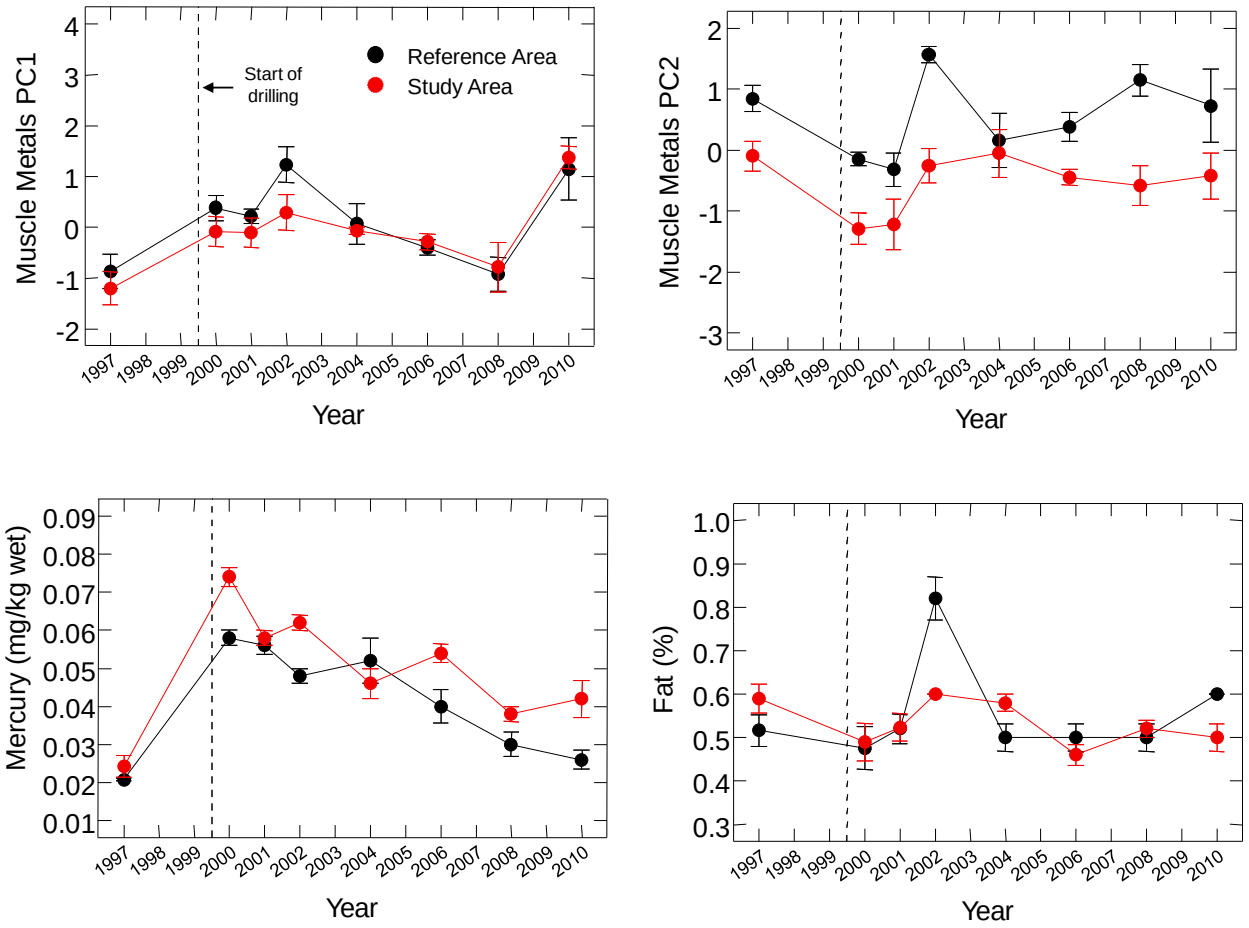


Figure 7-5 Area Mean (±1 Standard Error (SE)) Metal and Fat Concentrations in Scallop Adductor Muscle (1997 to 2010)

Table 7-18 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Viscera among Years and Between Areas (1997 to 2010)

Source	df	*p*		
		Metals PC1	Metals PC2	Fat (%)
Year	7	0.036	**<0.001**	**<0.001**
BA	(1)	0.230	0.893	**<0.001**
EEM Linear	(1)	0.073	**<0.001**	0.331
EEM Quadratic	(1)	0.033	**<0.001**	**<0.001**
Area (CI)	1	**<0.001**	0.010	0.074
Year × Area	7	0.003	0.026	**<0.001**
BACI	(1)	0.138	0.033	0.953
EEM Linear × Area	(1)	0.009	0.900	0.001
EEM Quadratic × Area	(1)	0.223	0.012	0.409

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

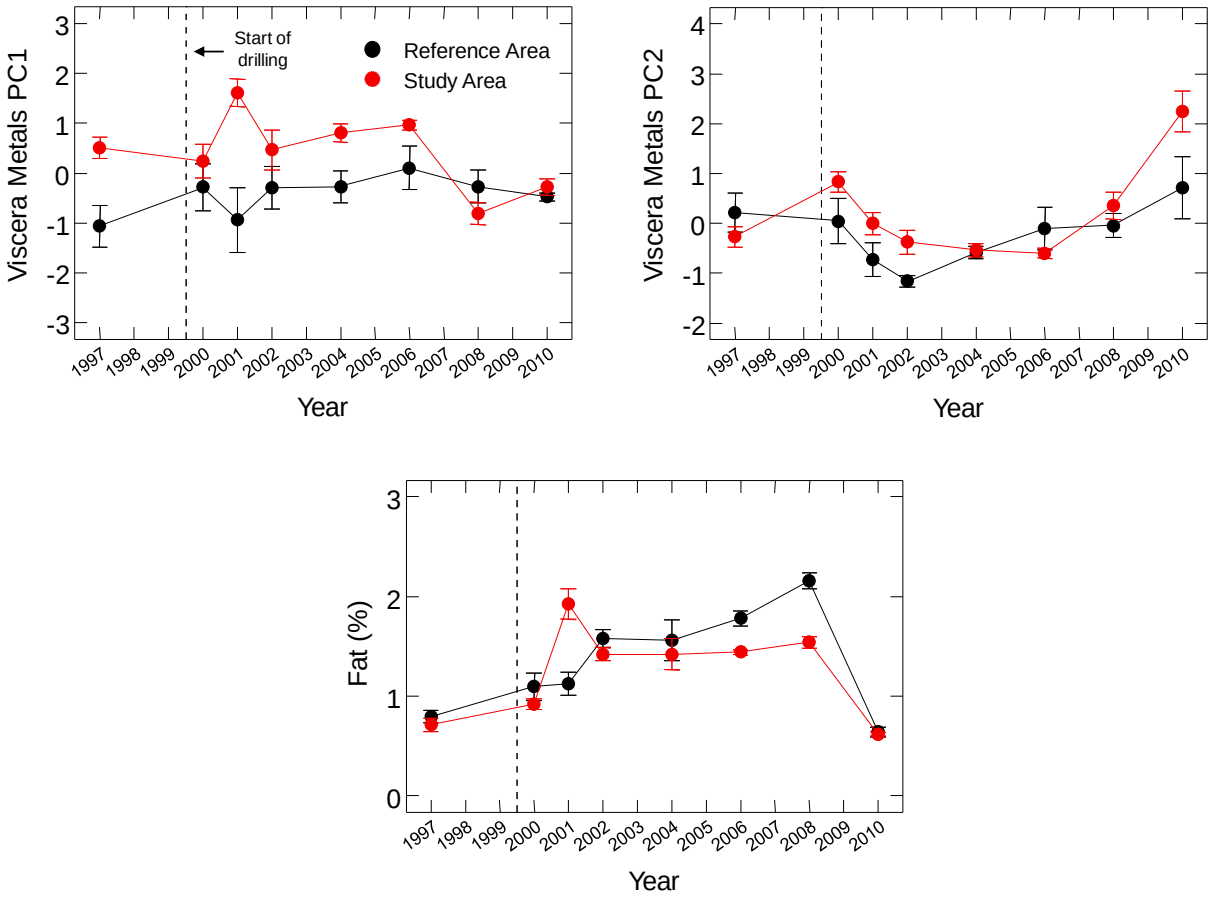


Figure 7-6 Area Mean (±1 SE) Metal and Fat Concentrations in Scallop Viscera (1997 to 2010)

Viscera Metals PC2 scores (positively correlated with concentrations of several metals occurring at relatively high concentrations in sediments) differed significantly ($p < 0.001$) over time (Table 7-18). In both Areas, Metals PC2 scores in EEM years first decreased, then increased (a quadratic relationship) (Figure 7-6; the Year EEM Quadratic contrast was significant at $p < 0.001$ in Table 7-18). The EEM quadratic time relationship was somewhat stronger for the Study Area than for the Reference Area (note the significant EEM Quadratic × Area contrast in Table 7-18). Metals PC2 scores were greater in the Reference Area than in the Study Area in 1997, but greater in the Study Area than in the Reference Area in most EEM years (note the significant BACI contrast in Table 7-18). Overall, year-to-year changes and, specifically, the decrease then increase in PC2 scores (quadratic time relationship) during EEM years accounted for a substantial portion of the total variance. Those changes (both increases and decreases) and differences between baseline and EEM years were generally greater for the Study Area than for the Reference Area.

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 7-6). The Year × Area interaction was highly significant ($p < 0.001$; Table 7-18), partly because of the high value in the Study Area in 2001 versus other years. However, differences between the Areas also varied in other years, from approximately 0 in 2010 to approximately 50% in 2008. In both Areas, fat content was lowest in 1997 and 2010. Otherwise, fat content increased from 2000 to 2008, although any linear trend for those years in the Study Area was obscured by the high 2001 value.

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 and were not detected in any 1997 (baseline) Study Area samples (Figure 7-7; concentrations less than laboratory detection limit were set at ½ detection limit for plotting medians). 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 fluid used at Terra Nova. In 2006 and 2010, $>C_{10}$-C_{21} hydrocarbons were not detected in any Study Area muscle sample. In 2008, $>C_{10}$-C_{21} hydrocarbons were detected in one sample at 15 mg/kg, but this result was assigned to integration error (Suncor Energy 2009). Therefore, it is reasonable to conclude that project-related hydrocarbon contamination of adductor muscle occurred in the first few EEM years but decreased after 2004. Overall, any hydrocarbon contamination of Study Area scallop muscle was limited. Study Area medians from 2000 to 2004 were at or barely above the laboratory detection limit of 15 mg/kg and the maximum concentration over the four years was 24 mg/kg.

Barium, a constituent of both synthetic- and water-based drill fluids, was detected (laboratory detection limit of 1.5 mg/kg) in two adductor muscles samples from the Reference Area in 2000 and 2004, and in three samples from the Study Area in 2010. The Reference Area maximum was 2 mg/kg and the Study Area maximum was 5.8 mg/kg.

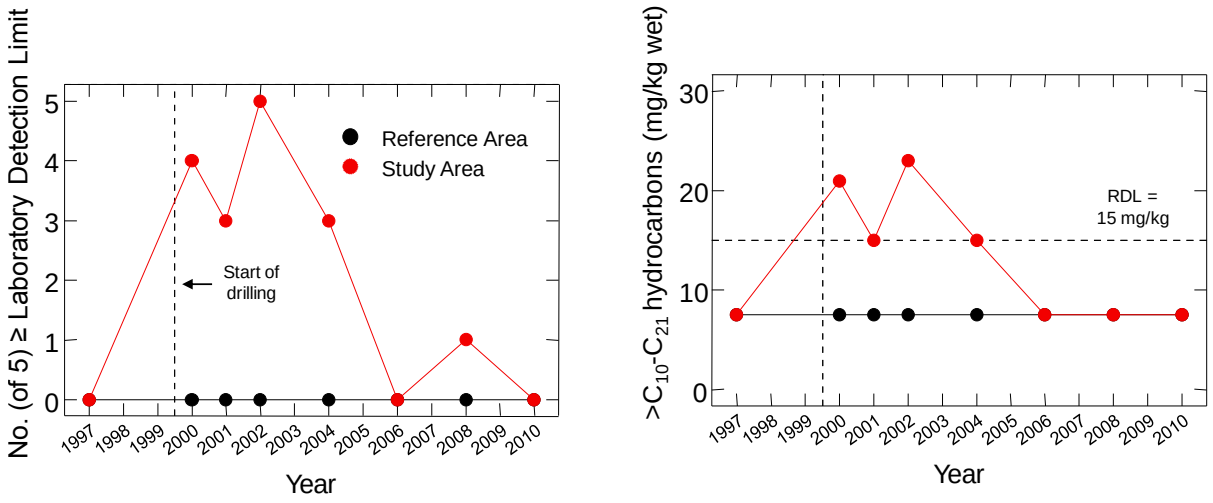


Figure 7-7 Frequencies of Detection and Area Median for >C_{10}-C_{21} Hydrocarbon Concentrations in Scallop Adductor Muscle (1997 to 2010)

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

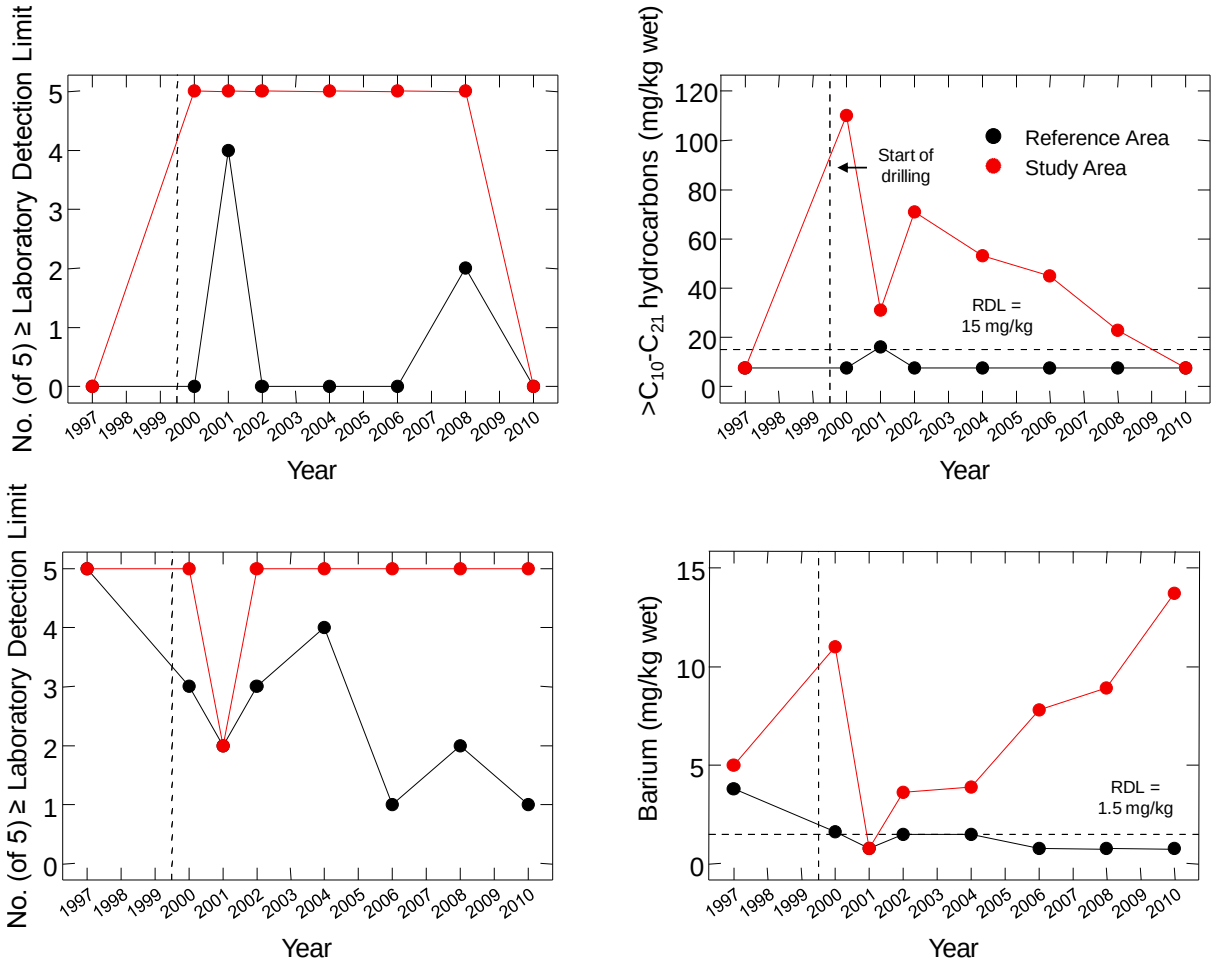


Figure 7-8 Frequencies of Detection and Area Median >C_{10}-C_{21} Hydrocarbon and Barium Concentrations in Scallop Viscera (1997 to 2010)

Barium has been detected more frequently and at higher concentrations in Study Area viscera samples than in Reference Area samples in EEM years (Figure 7-8). In 1997, barium was detected in all five Reference Area samples. Frequencies of detection and median concentrations subsequently decreased (medians less than the laboratory detection limit of 1.5 mg/kg are plotted as ½ detection limit in Figure 7-8). Barium was detected in every Study Area sample in every year except 2001. From 2001 to 2010, median barium concentrations in viscera of Study Area scallop progressively increased. 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 2010 (Appendix D-2).

Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in all 40 plaice liver composite samples from 2001 to 2006[26], and in all 10 samples from 2010. 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. Manganese was also not detected in two of five Study Area liver samples in 2000, when samples from individual fish were analyzed and sample volumes were smaller and laboratory detection limits higher.

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 2010 was approximately 1 to 2% and always greater than the laboratory detection limit (Appendix D-2). Fat content in composite liver samples was higher (approximately 10%).

$>C_{10}$-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 2010 (see below for further discussion). PAHs have never been detected in plaice fillet or liver samples.

Metals and Fat

Concentrations of arsenic and zinc in plaice fillets varied significantly among EEM years (Table 7-19). Differences between Areas and the Year $\times$ Area interaction were not significant. There was a net increase in arsenic concentrations in both Areas over time in EEM years (significant Linear contrast), and zinc concentrations increased in early EEM years, then later decreased (significant Quadratic contrast) (Table 7-19; Figure 7-9). Those relationships spanned a narrow range of concentrations and were significant primarily because variance was minimal. Differences in mercury concentrations between Areas were small, and changed and

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

sometimes reversed from year to year ($p \approx 0.05$ for the Year × Area and Quadratic × Area interactions; Table 7-19). However, any quadratic time relationships and especially differences in those relationships between Areas are not visually apparent in Figure 7-9.

Table 7-19 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Plaice Fillets among Years and Between Areas (2001 to 2010)

Source	df	*p*			
		Arsenic	Mercury	Zinc	Fat (%)
Year	5	**<0.001**	0.055	**<0.001**	**<0.001**
EEM Linear	(1)	**<0.001**	0.070	0.074	**<0.001**
EEM Quadratic	(1)	0.227	0.988	0.004	**<0.001**
Area	1	0.635	0.501	0.955	0.474
Year × Area	5	0.230	0.047	0.974	0.051
EEM Linear × Area	(1)	0.303	0.393	0.926	0.133
EEM Quadratic × Area	(1)	0.144	0.057	0.436	0.937

Notes: - $p \leq 0.001$ in **bold.**
- n = 60 composite samples.

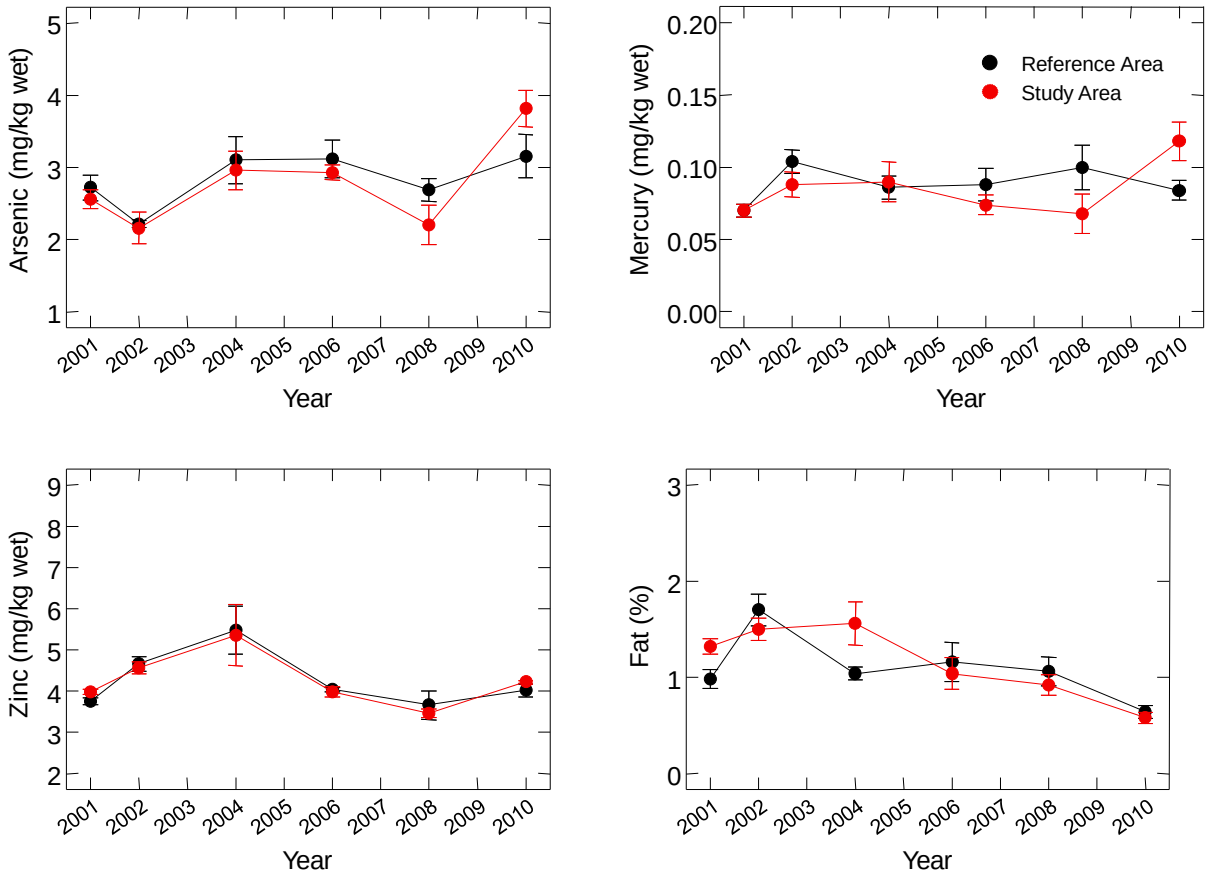


Figure 7-9 Area Mean (± 1 SE) Metal and Fat Concentrations in Plaice Fillets (2001 to 2010)

Fat content differed significantly among years ($p < 0.001$; Table 7-19). Both the Year Linear and Quadratic contrasts were highly significant ($p < 0.001$). However, it is difficult to see any trend or pattern in the time profiles in Figure 7-9 beyond a small decrease in fat content in both Areas from 2002 to 2010. Differences between Areas were not significant but there were some changes in the small, albeit not significant, Area differences from year to year ($p \approx 0.05$ for the Year $\times$ Area interaction; Table 7-19).

Mean concentrations of arsenic, mercury and zinc in fillet samples from individual plaice in 2000 were similar to or lower than the lowest means in subsequent years and did not differ substantially between Areas (Table 7-20). Fat content was not measured in 2000 fillet samples.

Table 7-20 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

Except for manganese, concentrations of the eight metals detected in all 59 plaice liver composites included in data analyses were positively correlated with each other and with the first Principal Component (PC1) derived from those concentrations (Table 7-21). Therefore, PC1 was a summary measure of total metal concentrations. PC1 accounted for more than 50% of the covariance among metals and the variance among samples. PC2 was positively correlated with manganese concentrations and negatively correlated with mercury concentrations, suggesting that these two metals behaved differently from each other. However, both metals were negatively correlated with PC3, which accounted for almost as much variance as PC2. Therefore, the two axes were difficult to interpret, and were included in data analyses primarily to determine if there were any differences in metal concentrations over space or time that were not evident from analyses of the dominant PC1.

Liver Metals PC1 scores differed significantly ($p < 0.001$) among years but not between Areas (Table 7-22). In both Areas, PC1 scores decreased in earlier years and then increased (Figure 7-10); the quadratic or U-shaped relationship was highly significant and is perhaps the most convincing quadratic relationship for any body burden variable. Results for Metals PC2 and PC3 were qualitatively similar to results for PC1. Most of the variance occurred among years, with no significant difference between Areas, although quadratic relationships were not as evident as for PC1.

Table 7-21 Correlations (r) Between Concentrations of Metals in Plaice Liver and Principal Components Derived from those Concentrations (2001 to 2010)

Metal	Correlation (*r*) with:		
	PC1	**PC2**	**PC3**
Arsenic	**0.892**	–0.010	0.093
Cadmium	**0.777**	0.275	–0.122
Copper	**0.831**	0.046	0.022
Iron	**0.871**	–0.183	–0.167
Manganese	–0.053	**0.841**	–0.489
Mercury	**0.522**	**–0.538**	**–0.625**
Selenium	**0.671**	0.041	0.319
Zinc	**0.864**	0.274	0.261
% variance	54.0	14.6	10.6

Notes: - $|r| \geq 0.5$ in **bold.**
- n = 59 composite samples.

Table 7-22 Results of Two-Way ANOVA Comparing Metal Concentrations in Plaice Liver among Years and Between Areas (2001 to 2010)

Source	df	Metals			Fat	
		p			df	*p*
		PC1	**PC2**	**PC3**		
Year	5	**<0.001**	0.003	**<0.001**	3	0.004
EEM Linear	(1)	0.051	0.252	0.611	(1)	0.094
EEM Quadratic	(1)	**<0.001**	0.044	0.880	(1)	**0.001**
Area	1	0.310	0.242	0.093	1	0.548
Year × Area	5	0.369	0.124	0.273	3	0.691
EEM Linear × Area	(1)	0.125	0.405	0.073	(1)	0.322
EEM Quadratic × Area	(1)	0.112	0.266	0.214	(1)	0.860

Notes: - $p \leq 0$ .001 in **bold.**
- n = 59 composite samples from 2001 to 2010 for metals.
- n = 40 composite samples from 2004 to 2010 for fat.

Fat content also varied significantly among years but not between Areas (Table 7-22). Fat content increased from 2004 to 2006 and 2008, then decreased in 2010 (Figure 7-10; $p < 0.001$ for the Year Quadratic contrast; Table 7-22). Annual means for both Areas from 2004 to 2010 were approximately 10 to 15%, similar to or greater than values for the single Area composites analyzed in 2001 and 2002 (Table 7-23).

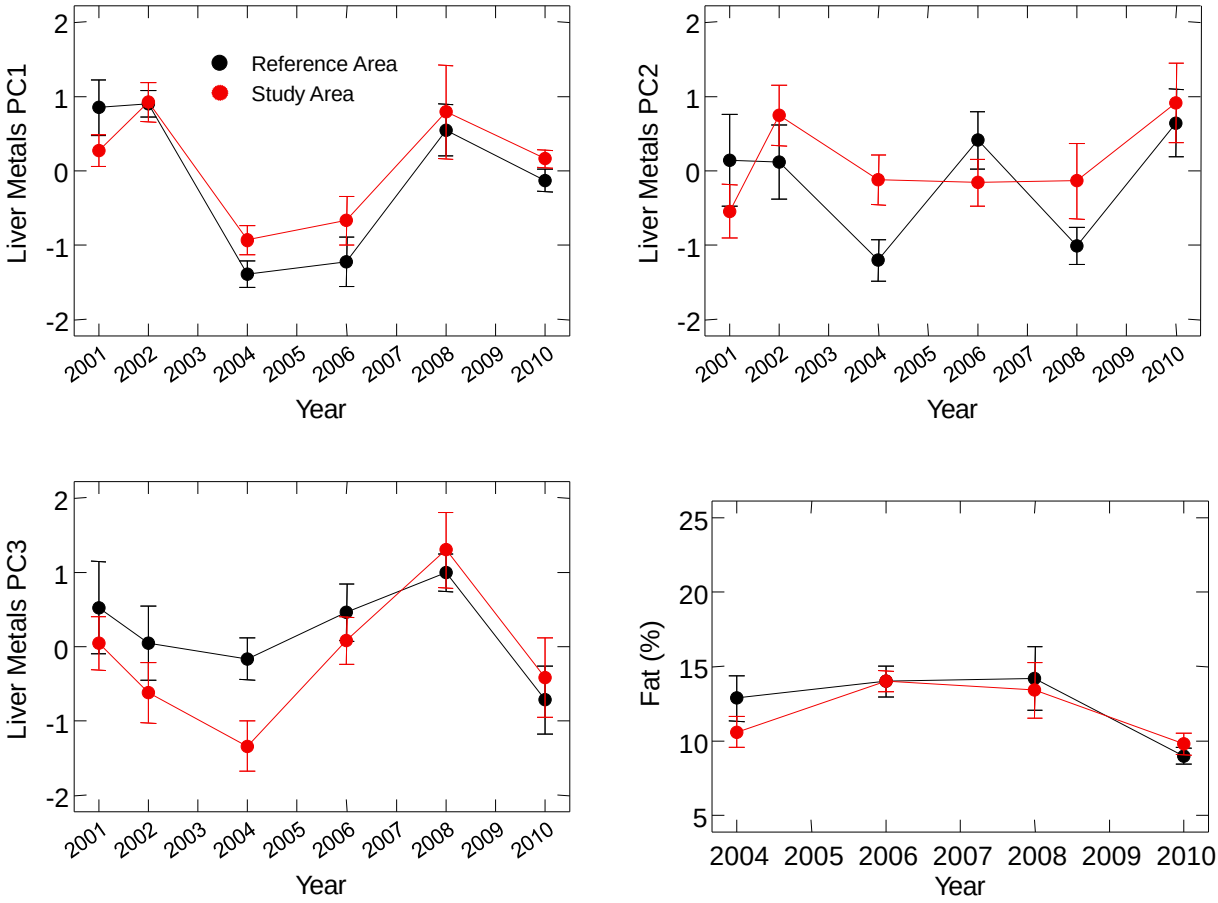


Figure 7-10 Area Mean (± 1 SE) Metal (2001 to 2010) and Fat (2004 to 2010) Concentrations in Plaice Livers

Table 7-23 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, respectively. 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 78 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 7-24). In 2006, 2008 and 2010, $>C_{10}$-C_{21} hydrocarbons were detected in every liver composite from both Areas. $>C_{21}$-C_{32} hydrocarbons were detected in every liver composite sample in both Areas from 2002 to 2010. Median and maximum hydrocarbon concentrations were generally similar in the Reference and Study Areas.

In all years, hydrocarbons showed no resemblance to drill mud hydrocarbons. Only one sample in 2008, from a Reference Area composite, showed potential $>C_{21}$-C_{32} contamination (J. Kiceniuk, 2011 pers. comm.). Most of the hydrocarbon peaks observed on chromatograms for liver (Appendix D-2; also see Suncor Energy 2003, 2005, 2007 and 2009 for chromatograms for 2002, 2004, 2006 and 2008 samples, respectively) were consistent with those expected for natural compounds (J. Kiceniuk, 2011 pers. comm.) and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2009). In 2010, all samples from Terra Nova were analyzed further by mass spectroscopy. These additional results are provided in Appendix D-2 (Chromatograms Section). Based on these additional analyses, Maxxam Analytics reports that there was no indication of petrogenic hydrocarbons in any of the samples.

Table 7-24 Hydrocarbon Concentrations in Plaice Liver (2002 to 2010)

Carbon range	Year	Reference Area			Study Area		
		No. (of 5) >RDL	Median (mg/kg)	Maximum (mg/kg)	No. (of 5) >RDL	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
>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

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.

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

ANOVA statistics for hedonic scaling are provided in Table 7-25 and a frequency histogram of results is provided in Figure 7-11. These results show no significant taste difference between Areas.

Table 7-25 Analysis of Variance for 2010 Taste Evaluation by Hedonic Scaling of Scallop

Source of Variation	SS	df	MS	F	*p*	F crit
Between Groups	1.69	1	1.69	1.39	0.24	4.05
Within Groups	55.79	46	1.21			
Total	57.48	47				

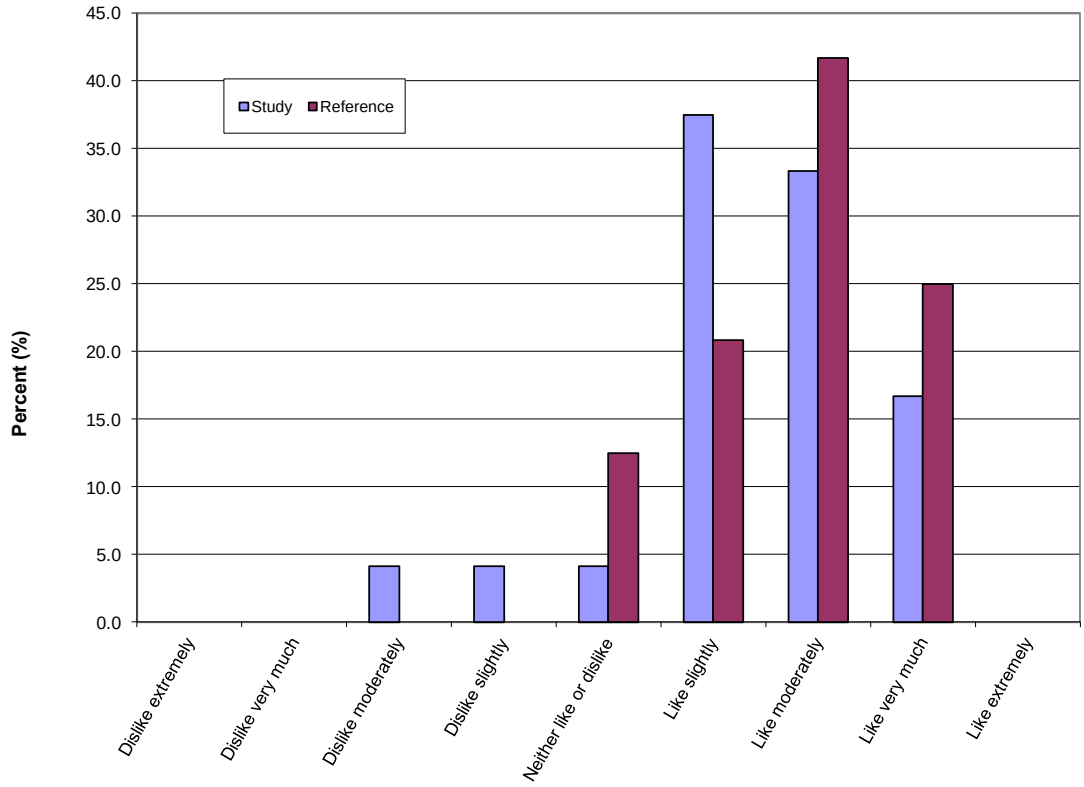


Figure 7-11 Scallops Frequency Histogram for Hedonic Scaling Taste Evaluation (2010)

From ancillary comments (Tables 7-26 and 7-27; Appendix D-5), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 7-26 Summary of Comments from the Triangle Test for Scallop (2010)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
192 (RA) is sweeter in taste.	679 (SA) had a sweeter taste.
192 (RA) less flavourful.	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
Couldn't really tell much difference. Maybe a little less taste on sample 123 (RA).	269 (SA) not quite so pleasant as 192 (RA) or 688 (SA).
776 (RA) has an odd taste.	Not much difference in the samples.
123 (RA) has better taste and less odour.	688 (SA) had a sweeter flavour than the other samples; odour of all samples was acceptable.
Very little difference but 660 (RA) seems a little sweeter.	Would not order either sample.
Not sure.	859 (SA) not as fishy tasting as 609 (RA). Liked 859 (SA).
Both 660 (RA) and 679 (SA) very flavourful showing distinct difference from 708 (RA) which I choose as the odd sample.	609 (RA) pleasant scent, faint flavour. 382 (SA) pleasant scent, faint flavour. 859 (SA) moderate scent, flavour a bit fishier than others.

Table 7-27 Summary of Comments from the Hedonic Scaling Test for Scallop (2010)

Preferred Reference Area	Preferred Study Area
516 (SA) not so sweet and flavourful as 437 (RA).	516 (SA) had stronger flavour. 437 (RA) more bland.
574 (SA) had an off flavour (perfume).	516 (SA) had a more pleasant smell, taste is similar.
574 (SA) slight bitter taste, moderate smell. 161 (RA) next to no smell, lovely flavour.	161 (RA) had a much sweeter flavour than 574 (SA). 161 (RA) also had a stronger odour, more pungent.
Very little difference in taste.	Not much different in either sample.
Could not identify any difference.	Very little difference in taste.
572 (RA) is preferred based on taste and odour.	Could not identify any difference.
No difference in taste.	No difference in taste.
555 (SA) was crunchy.	
572 (RA) tastes more like scallops I've had before.	
There is no difference between the two samples. However, 572 (RA) is slightly preferred.	
More flavour on 572 (RA). Odour may have seemed a little better on 555 (SA), but flavour overruled.	

7.4.3.2 Plaice

Panellists for the triangle test were successful in discriminating 17 out of 24 samples. These results were significant at $\alpha = 0.05$ (Appendix D-5).

ANOVA statistics for hedonic scaling are provided in Table 7-28. The results were significant and the frequency histogram (Figure 7-12) indicates a preference for Study Area plaice.

Table 7-28 Analysis of Variance for 2010 Taste Evaluation by Hedonic Scaling of Plaice

Source of Variation	SS	df	MS	F	*p*	F crit
Between Groups	12	1	12.00	5.92	0.02	4.05
Within Groups	93.25	46	2.03			
Total	**105.25**	**47**				

Ancillary comments from panellists for both tests are summarized in Tables 7-29 and 7-30 and presented in full in Appendix D-5. There were no consistent comments identifying abnormal or foreign odour or taste.

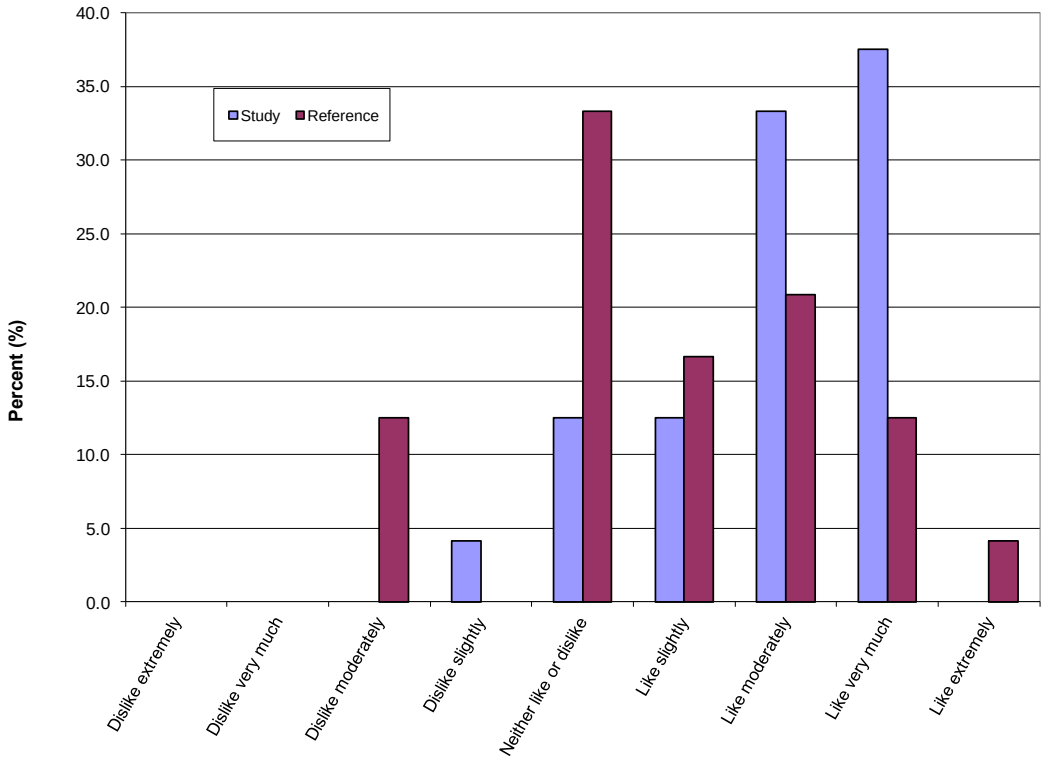


Figure 7-12 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2010)

Table 7-29 Summary of Comments from the Triangle Test for Plaice (2010)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
Little difference in odour on 349 (RA).	822 (SA) is more pleasant flavour and preferred as compared with others.
No difference in odour. 349 (RA) had a stronger taste.	Very little difference in taste.
Very hard to distinguish, all three tasted the same. 923 (RA) smelled a little different.	822 (SA) had no or little flavour compared to the others.
Odour and taste on 923 (RA) did not seem as strong as the other two. Flavour on 923 (RA) was more bland.	822 (SA) has very little taste relative to 333 (RA) and 445 (RA).
	No obvious difference in smell.
	No distinguishable difference in odour or taste.
	522 (RA) and 235 (RA) were very bland. 663 (SA) seemed somewhat metallic in taste. Overall all samples were OK.
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
All very similar in taste and odour. 235 (RA) had a slightly stronger fish taste.	414 (SA) was the best sample; the other two had a slight odour and did not taste as good.
522 (RA) had a little saltier taste, but a less fishier taste than the other two samples.	370 (SA) didn't taste as fishy.
	370 (SA) seems to have less of a smell than the other two, but the difference is very minimal. Couldn't taste much difference, 658 (SA) was a little less flavourful.

Table 7-30 Summary of Comments from Hedonic Scaling Tests for Plaice (2010)

Preferred Reference Area	Preferred Study Area
491 (RA) seems to have a slightly preferred flavour.	Sample 491 (RA) very bland. Little taste or odour.
405 (SA) is somewhat bland; 491 (RA) slightly sweeter.	Sample 491 (RA) has very little odour compared to 405 (SA), and is lacking in taste, very bland.
Very similar in taste, cannot tell the difference.	Not much of a taste on 491 (RA). 405 (SA) tastes more fishy.
Taste and smell no difference.	Very similar in taste, cannot tell the difference.
Unable to tell the difference, I like both samples.	492 (RA) had a bland after taste.
I like both evenly for flavour as well as odour.	Taste and smell no difference.
699 (SA) seemed to have a slight bitterness.	Preferred 571 (SA), as it did not have an odour.
	812 (SA) very low odour. 535 (RA) slight odour.
	Unable to tell the difference, I like both samples.
	812 (SA) had a little sweet flavouring and less odour than 535 (RA). Sample 535 (RA) was fishy and had a less desirable taste.
	812 (SA) tasted saltier. 535 (RA) had a fishy, fresh odour, similar to a fish shop. It was less salty which otherwise hurt its flavour.
	Liked both evenly for flavour as well as odour.
	812 (SA) lovely but faint scent. Flavour is smoother and much more favourable. 535 (RA) stronger scent, less favourable aroma. Stronger fishy taste that might be favourable under some circumstances.
	699 (SA) was very tasty, maybe a little sweeter or salty compared to 789 (RA).
	789 (RA) was very bland tasting.
	789 (RA) has a stronger taste which I did not approve of.
	699 (SA) had a slightly stronger odour.
	699 (SA) had slightly more flavour. Not much difference, both good.

7.4.4 FISH HEALTH INDICATORS

7.4.4.1 Gross Pathology

No visible parasites or other abnormalities were observed upon necropsy on the skin or fins of fish or on the external surface of the gill, gonad, liver, digestive tract, body cavity or spleen (Appendix D-3, Annex C).

7.4.4.2 Haematology

The red blood cells of all fish appeared to be normal in size and shape. Colouration was also similar, indicating a similar degree of haemoglobinization.

A differential cell count of lymphocytes, neutrophils and thrombocytes was carried out on a total of 100 fish. Two hundred cells were counted per fish and the results were expressed as mean frequency ± standard deviation of each cell type for each Area (Table 7-31). The complete data set on the different cells examined is provided in Appendix D-3, Annex D.

Table 7-31 Frequencies (%) of Blood Cell Types in Plaice (2010)

	Reference Area n = 50	Study Area n = 50	p [a]
Lymphocytes	82.3 ± 0.04.3	83.9 ± 0.03.2	0.020
Neutrophils	0.9 ± 0.00.9	0.7 ± 0.00.8	0.376
Thrombocytes	16.9 ± 0.04.0	15.4 ± 0.03.2	0.045

Notes: - All data are expressed as mean percentage ± standard deviation of each type of cell on 200 blood cells counted.
- [a] *p* obtained with Unpaired t-test or Mann-Whitney Rank Sum test after arcsin square root transformation of percentages.

There was no significant difference in the frequency of neutrophils between fish from the two Areas. A slight but significant difference was observed for the two other cell types. A very small increase of lymphocyte and a very small decrease of thrombocytes were observed in fish from the Study Area (see Table 7-31).

7.4.4.3 Mixed Function Oxygenase Activity

Results on MFO enzyme activity, measured as EROD, in the liver of male and female plaice (all maturity stages pooled) from the Reference and Study Areas are summarized in Figures 7-13 and 7-14, respectively. The complete data set is provided in Appendix D-3, Annex D.

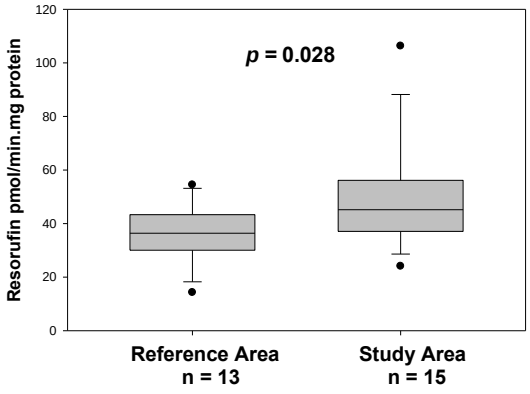


Figure 7-13 MFO Activity in the Liver of Male Plaice (all maturity stages combined)

Note: Data plotted are median (horizontal line in middle of box), 10th, 25th, 75th and 90th percentiles as vertical boxes with error bars. Data points beyond the 5th and 95th percentiles are also displayed. p was obtained with the Unpaired t- test on log-transformed data.

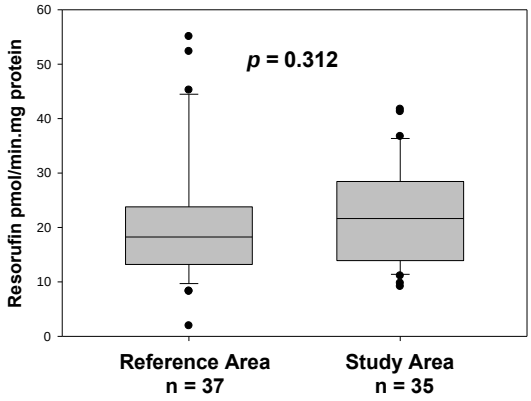


Figure 7-14 MFO Activity in the Liver of Female Plaice (all maturity stages combined)

Note: Data plotted are median (horizontal line in middle of box), 10th, 25th, 75th and 90th percentiles as vertical boxes with error bars. Data points beyond the 5th and 95th percentiles are also displayed. p was obtained with the Unpaired t- test on log-transformed data.

Enzyme activity in male fish at the Study Area was 1.4-fold higher compared to enzyme activity in fish from the Reference Area (p = 0.028; Unpaired t-test). There was no significant difference in enzyme levels in females between the two Areas (p = 0.312; Unpaired t-test).

7.4.4.4 Histopathology

Liver Histopathology

Percentages of fish affected by each type of lesion/observation (or prevalence of lesion) in the Reference and Study Areas are presented in Table 7-32. The complete data set is provided in Appendix D-3, Annex E and a representative photograph is included in Appendix D-3, Annex G, with Photo 1 representing a normal liver structure.

No lesions that have been commonly associated with chemical toxicity were detected.

Frequencies of macrophage aggregates in livers of fish from the various Areas were low (0-1 rating on a relative scale from 0-7) and no cases of moderate to high aggregation (4 or higher on the relative scale) that are considered as a proliferation of macrophage aggregates were observed.

Table 7-32 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2010)

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
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
Peri-biliary inflammatory response	1	2	0	0
Hepatocellular vacuolation	3	6	2	4
Parasitic infestation of biliary system	15	30	9	18

Notes: - [a] Percentage of fish affected.
- [b] Defined as scores greater than 3 on a 0-7 relative scale.

With respect to other observations, the following were detected:

- a mild peri-biliary inflammatory response was observed in a fish from the Reference Area (Annex G, Photo 2).
- a patchy distribution of hepatocellular vacuolation, not associated with degenerative changes, was observed in 6% of fish from the Reference Area and in 4% of fish from the Study Area. However, no significant difference in prevalence of hepatocellular vacuolation was found (p = 1.000; Fisher exact Test).
- an infestation of the biliary system with a myxosporean parasite, possibly Myxidium sp., was observed in 30% of fish from the Reference Area and in 18% of fish from the Study Area. The infestation did not appear to result in any other pathological changes in hepatic tissues, and no significant difference between the Study and Reference Areas was found (p = 0.241; Fisher exact Test).

The observations on inflammatory response, hepatocellular vacuolation and parasitism are of general interest but the absence of liver lesions that have been commonly associated with chemical toxicity are more relevant from an EEM perspective.

Gill Histopathology

Gill histopathology data are provided in full in Appendix D-3, Annex F. In all gill samples (Reference and Study Areas), minor epithelial lifting was found. However, this was an artifact of tissue fixation, unrelated to exposure to xenobiotic substances and thus was not counted. The percentages of lamellae affected by other lesions were very low, all less than 3.1% per fish (Appendix D-3, Annex F), except for two fish from the Reference Area, one with approximately 8% of lamellae exhibiting basal hyperplasia and the other with approximately 8% of lamellae fused.

Means and standard deviations of percentages of lamellae presenting each type of lesion per Area are provided in Table 7-33.

There were no significant differences between Reference and Study Areas in the percentages of lamellae presenting each type of lesion (Mann-Whitney Sum Rank test; $p > 0.05$).

Table 7-33 Percentages of Secondary Lamellae Affected by Lesions in the Gill Tissues of Plaice (2010)

	Reference Area ***n* = 50**	**Study Area** ***n* = 46**	***p*** [e]
Basal hyperplasia 1 [a]	0.22 ± 1.18	0.04 ± 0.16	0.690
Basal hyperplasia 2 [b]	0.01 ± 0.10	0	0.348
Distal hyperplasia [c]	0.12 ± 0.40	0.06 ± 0.23	0.407
Tip hyperplasia [d]	0.26 ± 0.59	0.07 ± 0.18	0.114
Fusion	0.25 ± 1.24	0.06 ± 0.28	0.696
Telangiectasis	0	0.003 ± 0.020	0.307

Notes:
- All data are mean percentage of lamellae presenting the lesion ± standard deviation.
- [a] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
- [b] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.
- [c] Distal hyperplasia was recorded when there were more than two cell layers all around the two sides of the secondary lamellae.
- [d] Tip hyperplasia was recorded when there were more than three cell layers at least 2/3 around the secondary lamellae tip.
- [e] *p* was obtained with the Mann-Whitney Sum Rank test on arcsine square root-transformed percentages of the lesions.

7.5 SUMMARY OF FINDINGS

7.5.1 BIOLOGICAL CHARACTERISTICS

In 2010, a total of 959 scallop were collected in five Reference Area transects and six Study Area transects. Overall female:male ratios were approximately 60:40 and females outnumbered males in all but one transect. Female:male ratios were significantly higher in the Study Area than in the Reference Area. Females were

larger than males. The only significant biological difference between Areas was that Reference Area scallop of both sexes had higher tissue weights relative to shell weights than Study Area scallop. Size and shape of both sexes differed significantly among transects within Areas. Scallop used in body burden analysis (approximately 20% of scallop caught) had higher tissue weights relative to shell weights than other scallop, but were otherwise representative of the larger set of scallop caught.

Thirty-five female and 15 male plaice were collected in the Study Area; 37 female and 13 male plaice were collected in the Reference Area. Sex ratios did not differ between Areas. All males and most females were mature, with again no differences in maturity between Areas. Size, age and fish condition for both males and females were similar between Areas, except for a marginally significant (p = 0.089) difference in HSI between Areas for female fish (with a lower index in the Study Area). Since the HSI assumes that liver weight is linearly related to gutted weight (which is not always the case), a log-log regression of liver weight on body gutted weight was also tested in ANCOVA. This test revealed no significant difference between Areas.

7.5.2 BODY BURDEN

7.5.2.1 Scallop

Arsenic, boron, cadmium, mercury, strontium and zinc were detected in all 80 scallop adductor muscle composite samples analyzed from 1997 to 2010. Except for mercury, these metals and aluminum, copper, iron, manganese, nickel, selenium and uranium were detected in all 80 scallop viscera composite samples analyzed. Mercury was not detected in one Study Area sample in 2010.

Overall metal concentrations in scallop adductor muscle differed significantly among years but not between Areas (Reference and Study). In both Areas, concentrations of most metals were greater in EEM sample years than in baseline (1997). Metal concentrations decreased from 2000 to 2008, and then increased in 2010. In all years including baseline, arsenic concentrations were lower in Study Area scallop muscle than in Reference Area muscle. In all years including baseline, except 2004, mercury concentrations were higher in Study Area muscle than in Reference Area muscle. Viscera Metals PC1 scores, a summary measure of total metal concentrations, were higher for Study Area scallop than for Reference Area scallop in all years (including baseline) except 2008. Metal concentrations in Study Area scallop viscera were also more variable over time than Reference Area concentrations.

Fat content was high in Reference Area scallop adductor muscle samples in 2002 and in Study Area viscera samples in 2001. Otherwise, differences between Areas for both tissues were minimal. Except for the 2002 Reference Area samples, mean annual muscle fat content in both Areas was similar and near the recent laboratory detection limit of 0.5%. Fat content in viscera increased from 2000 to 2008, particularly in the Reference Area, and was lowest in both Areas in 1997 and 2010.

$>C_{10}$-C_{21} hydrocarbons, important constituents of synthetic-based drill fluids, were detected more frequently in Study Area scallop adductor muscle and viscera samples than in Reference Area samples after drilling started in 2000. However, hydrocarbon concentrations in Study Area muscle and tissue decreased to near or below the laboratory detection limit in recent years. In 2010, all hydrocarbon concentrations in muscle and viscera samples were less than detection limits. Chromatogram profiles of hydrocarbons in Study Area scallop tissue have been similar to profiles for the drilling mud PureDrill IA35-LV.

Barium, a constituent of drilling muds, was detected in two adductor muscle samples from the Reference Area (in 2000 and 2004) and in three samples from the Study Area (in 2010). Barium was detected relatively frequently in Study Area viscera samples and less frequently in Reference Area viscera samples. Median barium concentrations in viscera were also higher in the Study Area than in the Reference Area, with the greatest differences occurring in EEM years.

7.5.2.2 Plaice

Arsenic, mercury and zinc were detected in all 81 individual and composite plaice fillet samples analyzed since 2000. Fillet samples were not analyzed in 1997. These three metals and cadmium, copper and iron were detected in all 60 plaice liver composites analyzed from 2001 to 2010. Manganese and selenium were detected in all composites from 2001 to 2010 at a laboratory detection limit of 0.5 mg/kg, with the exception of one 2008 Reference Area sample where manganese and selenium were not detected due to an elevated detection limit (5 mg/kg).

From 2001 to 2010, concentrations of arsenic, zinc and fat in plaice fillets differed significantly among years but not between Areas. Differences in mercury concentrations between Areas were small, and differences in concentrations changed significantly, sometimes even reversing, from year to year. In livers, concentrations of metals again differed significantly among years but not between

Areas. Metal concentrations in liver in both Areas decreased from 2001 to 2004, but then increased from 2006 to 2010.

$>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were detected in one Study Area plaice fillet in 2000 and $>C_{21}$-C_{32} hydrocarbons were detected in one Study Area plaice fillet composite in 2008, but the hydrocarbon profiles for these samples did not match that of the synthetic-based drill mud used at Terra Nova or petroleum compounds. $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were not detected in any other Reference or Study Area samples from 2000 to 2010.

$>C_{10}$-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} range were detected in most liver samples from both the Study and the Reference Areas from 2002 to 2010, but none of these compounds had profiles that matched that of PureDrill IA35-LV. Additional mass spectroscopy tests on liver tissues revealed that compounds were not petrogenic in origin.

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

7.5.3 TASTE TESTS

No difference in taste was noted between the Study and the Reference Areas for scallop. Panellists were able to differentiate between Study and Reference Area plaice in the triangle test and preferred Study Area plaice in the hedonic scaling test. There were no consistent comments from panellists identifying abnormal or foreign odour or taste for either tissue type.

7.5.4 FISH HEALTH INDICATORS

No visible parasites or other abnormalities were observed upon necropsy on the skin or fins of fish or on the external surface of the gill, gonad, liver, digestive tract, body cavity or spleen.

There were slight inter-area differences (less than 2%) in percentage of lymphocytes and thrombocytes in the blood of fish.

A higher level of MFO enzyme activity (1.4-fold increase) was observed in the liver of male fish from the Study Area. No difference between Areas was observed for females.

No liver lesions that have been commonly associated with chemical toxicity were detected.

Microstructural changes in gill histopathology that have been associated with chemical toxicity were absent or found at very low frequencies in both Areas and no significant differences were observed between 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 2010 and all previous years. Gravel content varied from 0% to approximately 40% in 2010 and previous years. Fines (silt + clay) content was low (median and maximum fines content were 1% and 2.7% in 2010, respectively) and there were no depositional areas dominated by fines such as one might find in harbours and other nearshore areas. Sediment total organic carbon content was also low (0.04 to 0.31%). 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 is a major constituent of synthetic-based drill muds. There was clear evidence of sediment contamination by both substances. $>C_{10}$-C_{21} hydrocarbons in synthetic-based muds are synthetic organic compounds and background concentrations for these compounds can be considered near or below the reportable 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 natural variance.

In 2010, 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.

For $>C_{10}$-C_{21} hydrocarbons, the threshold distance at which concentrations approached background levels (i.e., the estimated zone of influence) in 2010 was approximately 3 km, similar to the threshold distance noted in 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 (100 to 200 mg/kg) within 2 km of drill centres in 2010. Estimated barium threshold distances have been relatively constant in EEM years.

The strength of distance gradients for $>C_{10}$-C_{21} hydrocarbons and barium and overall concentrations were also reduced from 2002-2006 to 2008-2010. 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 2010, maximum $>C_{10}$-C_{21} hydrocarbon and barium concentrations were 760 and 4,200 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 2010 were 1.3 mg/kg and 150 mg/kg. Decreases in sediment $>C_{10}$-C_{21} hydrocarbon and barium concentrations in 2008 and 2010 coincided with a decrease in drilling activity at Terra Nova.

Petroleum hydrocarbons and barium levels at Terra Nova remain within the range observed at other sites (Table 8-1). Table 8-1 also shows a rapid decrease of hydrocarbon and barium concentrations with distance at a number of offshore oil development sites. Steep distance gradients have also been observed at the nearby White Rose development.

Table 8-1 Hydrocarbon and Barium Concentration at Terra Nova and at Other Development Sites

Well Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Terra Nova	2010	140 to 750	<3 to 767	130 to 4,200
		750 to 2,500	<3 to 339**	87 to 420
		2500 to 5,000	<3	69 to 160
	2008	140 to 750	<3 to 343	130 to 7,200
		750 to 2,500	<3 to 11	89 to 280
		2,500 to 5,000	<3	78 to 210
	2006	140 to 750	8 to 986	240 to 16,000
		750 to 2,500	<3 to 30	110 to 340
		2,500 to 5,000	<3	89 to 230
	2004	140 to 750	8 to 6,580	140 to 2,100
		750 to 2,500	3 to 72	100 to 340
		2,500 to 5,000	<3 to 4	63 to 190

Well Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Terra Nova	2002	140 to 750 750 to 2,500 2,500 to 5,000	<3 to 931 <3 to 49 <3 to 5	110 to 2,200 84 to 330 83 to 200
	2001	750 to 2,500 2,500 to 5,000	<3 to 30 <3 to 8	100 to 190 87 to 180
	2000	750 to 2,500 2,500 to 5,000	<3 to 14 <3 to 6	92 to 210 80 to 230
	1997	750 to 2,500 2,500 to 5,000	<3 <3	87 to 190 79 to 280
White Rose	2010	300 to 750 750 to 2,500 2,500 to 5,000	9.9 to 819 0.5 to 11.40 0.4 to 1.40	250 to 2,700 160 to 480 160 to 200
	2008	300 to 750 750 to 2,500 2,500 to 5,000	<3 to 1,615 <3 to 56 <3 to 4	170 to 3,400 160 to 600 160 to 210
	2006	300 to 750 750 to 2,500 2,500 to 5,000	<3 to 576 <3 to 53 <3	200 to 3,100 150 to 770 140 to 250
	2005	300 to 750 750 to 2,500 2,500 to 5,000	<3 to 262 <3 to 55 <3	210 to 810 140 to 380 150 to 220
	2004	300 to 750 750 to 2,500 2,500 to 5,000	9 to 276 <3 to 22 <3 to 7	190 to 1400 120 to 470 140 to 230
	2000	300 to 750 750 to 2,500 2,500 to 5,000	<3 <3 <3	140 to 180 140 to 190 140 to 210
Gulf of Mexico (NPO-895) (Candler et al. 1995)	1993	50 200 2,000	134,428 80 to 11,460 24	47,437 542 to 5,641
Gulf of Mexico (MAI-686) (Kennicutt et al. 1996)	1993	200 500 3,000	40 43 49	1,625 1,134 1,072
Gulf of Mexico (MU-A85) (Kennicutt et al. 1996)	1993	200 500 3,000	42.3 31.7 27.1	3,706 1,817 1,094
Gulf of Mexico (HI-A389) (Kennicutt et al. 1996)	1993	200 500 3,000	65 33 32	13,756 3,993 1,293
North Sea (Beatrice) (Addy et al. 1984)	1982	250 750 3,000	8 to 759 5 to 105 3 to 73	-
Dutch Continental Shelf (K14-13) (Daan and Mulder 1996)		200	54 to 161	-
Norway (Valhall) (Hartley 1996)	1985	250 500 3,000	-	19,000 to 96,000 3,700 to 9,300 280 to 430
North Sea (Brent) (Massie et al. 1985)	1981	800 3,200	41 to 61 33 to 43	-
North Sea (Forties) (Massie et al. 1985)	1980	800 3,200	9 to 78 16 to 55	-
Gulf of Mexico (Matagorda 622) (Chapman et al. 1991, Brooks et al. 1990)	1987	25 150 750 3,000	757 ±1,818	6,233 12,333 980
Santa Maria Basin (Hidalgo) (Phillips et al. 1998)	1991	125 500 1,000	-	1,250 975 1,050

Well Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Norway (Ekofisk) (Ellis and Schneider 1997)	1996	750 2,000 5,000	-	3,650 2,214 667
Norway (Gyda 2/1-9) (Bakke et al. 1995)	1994	100 to 200	236	-
Norway (Tordis) (Gjøs et al. 1991)	1990	500	8,920	-
Norway (U/a 2/7-29) (Vik et al. 1996)		200	1,000 to 2,368	-
North Sea (UK) (UKOOA 2001)	1975 to 1995	0 to 500 >500 to 2,000 >2,000 to 5,000	124 to 11,983 3 to 164 3 to 76	84 to 2,040 7 to 1595 8 to 729

Notes:
- Distance to drill centres for Terra Nova is distance to the nearest of the FEZ drill centres in 1997, 2000 and 2001; and distance to the nearest active drill centre (including the FE drill centre) in 2002, 2004, 2006, 2008 and 2010.
- TPH at Terra Nova was calculated as the sum of concentrations over the ranges $>C_6$-C_{10}, $>C_{10}$-C_{21} and $>C_{21}$-C_{32}. Values below laboratory detection limit in any of these ranges were assumed to be zero for additions. Sums less than 3 mg/kg (the detection limit for $>C_6$-C_{10}) are reported as <3 mg/kg.
- Absolute barium levels should not be compared across projects because of potential differences in measurement techniques (Hartley 1996) and differences in background levels.
- ** One relatively high value for TPH (339 mg/kg) was noted at station 43(FEZ). With that station excluded, the range for the 25 stations remaining in the 750 to 2,500 m distance class was < 3 to 31 mg/kg.

There was evidence of project effects on sulphur and fines levels in EEM years, with elevated levels near drill centres. In 2010, 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 0.08%) 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 and 2006. In 2010, the highest sulphur concentration (0.23%) 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) but near the laboratory detection limit of 0.02%.

Sulphur (barium sulphate) is an important component of drill muds, especially water-based 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%[27]. Therefore,

[27] 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.

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 weak. Fines content decreased with distance from drill centres in all years including baseline but distance gradients were stronger in EEM years. Fines content in 2010 ranged from 0.5 to 2.7% (median = 1.0%). Fines content during baseline (1997) ranged from 0.7 to 3.4% (median = 1.0%). The highest fines content (2.2, 2.5 and 2.7%) in 2010 occurred at three stations within 1 km of drill centres (stations 30(FE), 44(FEZ) and 11(SE), respectively). The highest fines content (7.0%) over all EEM years occurred at station 44(FEZ) in 2008. Therefore, sediment contamination with fines appears to be limited to a few stations in the vicinity of drill centres. However, in most cases, sediment fines content has not exceeded the maximum noted in baseline (1997).

Metals PC1 scores (a summary measure of the concentration of metals other than barium) were elevated at station 30(FE) in 2010 and metals concentrations at that station and, to a lesser extent, at 31(FE)[28] increased after drilling began at the FE drill centre in 2002 – potential evidence of localize drilling effects on metals other than barium from the FE drill centre. High metals PC1 scores reflected higher concentrations of a suite of metals including aluminum, chromium, iron, lead, manganese, strontium and vanadium. There was also a general, though weak, decrease in scores with distance from the nearest drill centre in all years. However, this gradient was also noted in baseline (1997). Therefore, other than elevated metals PC1 scores in the immediate vicinity of the FE drill centre, there was little evidence of project effects on metals other than barium.

Evidence of sulphide contamination has always been weak and that evidence was weaker in 2010 than in 2008. In 2010, distance gradients for sulphide were not significant and levels at stations 30(FE) were intermediate compared to levels at other stations.

To date, there has been little evidence of project effects on ammonia. In 2010, ammonia concentration decreased with distance from drill centres. A significant decrease in concentration with distance from drill centres for ammonia had not been noted in previous years. The maximum ammonia concentration over all EEM years (53 mgN/kg) was noted in 2008 at station 9(SE), located more than 2.5 km from a drill centre. The highest concentration in 2010 was 25 mgN/kg and occurred at

[28] Station 31(FE) is the next closest station (0.37 km) to the FE drill centre.

station 23(NW), located 0.8 km from the NW drill centre. However, concentrations were not elevated at station 30(FE) in 2010 or in previous years. The highest median concentration (8.6 mgN/kg) was noted in 2001. Median concentration in 2010 was 4.7 mgN/kg.

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 (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 (percent fines, total organic carbon and metal concentrations) 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 versus 10 to 20 of approximately 50 stations in EEM years. Thirteen (13) of 53 samples were toxic in 2010. 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 from drill centres. Microtox responses were correlated with barium concentration in 2010, 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) and 31(FE), the two stations within 0.5 km of the FE drill centre. Adverse Microtox responses were not associated with adverse effects on *in situ* benthic invertebrate communities. Instead, adverse Microtox response were greater in sediments with higher overall numbers and variety of organisms (sediments with higher abundance and richness).

The strongest correlations with Microtox responses were with strontium and sediment fines content. Strontium and fines effects were probably natural because sediment metals and fine content were only marginally affected by project activity (Section 8.1.1). Fines effects on Microtox have been observed in other studies but usually at higher levels (i.e., more than 5% fines (Environment Canada 2002)) than in Terra Nova EEM sediments (less than 3% fines). 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 previous EEM years and there was no evidence for effects in 2010. One sample, from station 1(SW) (a Reference station located 19 km from the nearest drill centre) was toxic to laboratory amphipods in 2010 based on Environment Canada (1998) interpretive guidelines. Amphipod survival was not significantly correlated with distances from drill centres or any sediment physical or chemical characteristic. The two survival values less than 70% occurred at stations more than 3 km from drill centres.

8.1.3 BENTHIC INVERTEBRATE COMMUNITY STRUCTURE

Benthic macro-invertebrate communities in the Terra Nova area are dominated by three polychaete families: Spionidae; Cirratulidae; and Syllidae. These three families accounted for 60% or more of the invertebrates collected, and were found in all EEM samples in every year. More generally, polychaetes accounted for more than 80% of the invertebrates collected. Amphipods (Crustacea) accounted for 4% of the organisms collected, with Phoxocephalidae, Oedicerotidae and Stenothoidae the most abundant families. Balanidae (barnacles) and Tanaidacea were the only other crustacean taxa accounting for more than 1% of total abundance in EEM samples. Tellinidae (mostly *Macoma*) was the dominant bivalve taxon. Ophiuroidea (mostly juveniles) and Echinarachniidae (sea spiders) were the dominant echinoderm taxa.

Total abundance decreased with increasing distance from the FEZ drill centres and the centre of development in all seven EEM years as well as in baseline (1997)[29].

[29] 1997 baseline data are not directly comparable to EEM data for many taxa because of differences in the methods used to recover invertebrates. However, the baseline data were useful for indicating that natural distance gradients could occur for abundances of some taxa and community summary measures.

These distance gradients were weak and relatively consistent over time, and the distance gradient was significant in 2004 only. The relatively stable relationship between total abundance and distance reflects a mixture of natural and project-related negative and positive relationships with distance by individual taxa, as detailed below. Total abundance has increased since 2004. This increase in total abundance was likely largely natural because it occurred for many taxa or at most stations.

Over all sampling years, the relationships between abundance and sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations were linear and positive through most of the concentration ranges, but in excess of 700 mg/kg for barium and 300 mg/kg for $>C_{10}$-C_{21} hydrocarbons, abundance was depressed. Below these upper limits, the relationship between total abundance and drill mud indicators (barium and $>C_{10}$-C_{21} hydrocarbons) may have been driven in part by a common relationship between each of these three variables and percent gravel content in sediment; because the relationship between total abundance and percent gravel (increases in abundance with increasing gravel content) was stronger than those between total abundance and drill mud indicators.

For individual taxa, abundances of Spionidae (the most abundant taxon), Cirratulidae and several sub-dominant taxa (e.g., Phyllodocidae and Tellinidae) have decreased with distance from the centre of development (i.e., abundances were higher near the centre of the development)[30]. Median abundances for Spionidae and Phyllodocidae increased approximately 3-fold from 2000 to 2010. Conversely, abundances of several other sub-dominant taxa (e.g., amphipods and the polychaete families Orbiniidae and Paraonidae) increased with increasing distance (i.e., were lower near the centre of the development), with relationships gaining strength over time for Orbiniidae and Paraonidae. Median abundances also decreased approximately 2-fold for these two taxa since 2000. Most of the decreases occurred between 2000 and 2004, when median Orbiniidae abundance approached 0. Orbinidae and Paraonidae abundances have increased slightly since 2004.

Spionidae, Cirritulidae, Phyllodocidae and Tellinidae abundances were significantly positively correlated with sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations. Abundances of Orbinidae and Paraonidae were significantly

[30] A multivariate community composition measure (NMDS1, reflecting Spionidae dominance) also increased with distance from drill centres in EEM years.

negatively correlated with barium and >C_{10}-C_{21} hydrocarbon concentrations. Abundance of the dominant taxon Spionidae and, to a lesser extent, Cirratulidae, Phyllodocidae and Tellinidae were correlated (increased) with sediment gravel content, potentially explaining the relationship between total abundance and sediment texture. Conversely, abundances of Orbinidae and Paraonidae were not correlated to gravel content in sediment, or any to other measure of sediment texture (i.e., percent fines).

In 2004, biomass increased significantly with distance from drill centres and the relationship between biomass and barium was significant and negative. In remaining years (including 2010), biomass was unrelated to distance from the nearest drill centre or drill mud indicators. Over all years, there is weak evidence to suggest that biomass may have been reduced at barium concentrations in excess of 700 mg/kg. Otherwise, there has been no consistent evidence of project effects on biomass.

Richness (number of taxa per station) was positively correlated with total abundance in Terra Nova sediments, reflecting the general tendency for more taxa to be collected where more organisms are collected. Correlations between richness versus distance from drill centres were generally weak and not significant. Adjusted richness**,** which expresses richness relative to abundance and provides a measure of diversity, increased significantly with distance from drill centres from 2004 to 2008, but was not significantly related to distance from drill centres from 2000 to 2002, or in 2010.

Across all years, richness was strongly and positively correlated (increased) with sediment gravel content, more weakly positively correlated with sediment barium concentration and uncorrelated with sediment >C_{10}-C_{21} hydrocarbon concentration. As was the case for abundance, the correlation between richness and barium concentration could have been driven by a common relationship between each of these two variables and percent gravel.

Adjusted richness, or diversity, was significantly negatively correlated with >C_{10}-C_{21} hydrocarbon concentrations from 2004 through 2008, an observation that may have been an artefact of low adjusted richness values and high >C_{10}-C_{21} hydrocarbon concentrations at station 30(FE) in those years. In 2010, adjusted richness at station 30(FE) was intermediate relative to other values, in spite of high >C_{10}-C_{21} hydrocarbon concentrations, and there was no significant relationship between adjusted richness and >C_{10}-C_{21} hydrocarbons.

In 2010, abundance and biomass were relatively low at station 30(FE) (the station nearest to a drill centre) and diversity was relatively high, but values at station 30(FE) were within the range of values noted at other stations (i.e., values were not extremes). Among the individual taxa, Syllidae abundances were lower at station 30(FE) than elsewhere.

In summary, evidence of effects on total abundance, biomass, richness and diversity at Terra Nova was 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. Distance gradients for affected taxa were too weak to provide robust estimates of the spatial extent of effects. In 2010, when Orbinidae and Paraonidae were not found in samples, these samples were collected within 2 km of drill centres. These results, and results from previous years, suggest that effects on affected taxa were greatest within 2 km of drill centres. The 2010 data generally confirmed project-related effects (or their absence) evident in previous years.

Effects on benthic invertebrates in response to offshore oil and gas activities have been noted elsewhere (e.g., Daan et al. 1994; Daan and Mulder 1996; Olsgård and Gray 1995; 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, primarily because of increases in abundances of several dominant and sub-dominant polychaete taxa (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. 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 (e.g., Kilgour et al. 2005). In the Terra Nova EEM program, a multivariate community composition measure (NMDS1, reflecting Spionidae dominance) was relatively strongly correlated with distance and sediment concentrations of drill mud indicators and effects on total benthic abundance, diversity and biomass were subtle or absent.

The multivariate measure and analyses was useful for identifying individual taxa that responded strongly to distance and drill mud indicators.

In spite of the noted correlations with barium, elevated barium concentrations in Terra Nova sediments may not be the direct cause of effects on benthic invertebrates. 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 metals 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 (usually less than 5 mg/L) observed in Terra Nova water column samples (Section 6), any effects should be restricted to plankton and filter-feeding bivalves (Smit et al. 2008). However, abundances of Tellinidae (*Macoma*; a deposit and filter feeder), the dominant bivalve at Terra Nova, increased rather than decreased near drill centres and at higher sediment barium concentration. 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.

Natural or anthropogenic hydrocarbons can 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). Based on the laboratory effects threshold of 1,900 mg/kg for amphipods in Payne et al. (2001), $>C_{10}$-C_{21} hydrocarbons should not be toxic to amphipods in the field at most if not all stations. However, in the field, reductions in abundances were correlated with much lower $>C_{10}$-C_{21} hydrocarbon concentrations in the Terra Nova area and also in the nearby White Rose area (Husky Energy 2011). The laboratory tests in Payne et al. (2001) measured lethal effects on survival over a relatively short (acute) exposure (10 days) on a single species (*R. abronius*). In contrast, field surveys assess longer-term (i.e., chronic)

exposures on multiple species, which could be the result of sublethal effects on reproduction or growth over one or more generations.

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.

8.2 WATER COMPONENT

8.2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Since 2002, PAHs have been detected more frequently, although sporadically and in trace amounts, in water column samples from the Study Area and than in samples from the Reference Areas. In 2010, trace levels of phenanthrene were detected in 8 of 48 (17%) Study Area samples. Fluorene was detected in 1 of 12 samples (8%) from the SW Reference Area. No PAHs were detected in the SE Reference Area. 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. Conversely, PAHS were detected in 38% of Reference Area samples and 10% of Study Area samples in 2000. In 2010, low levels of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon (maximum 0.25 mg/L and 0.13 mg/L, respectively) were detected 3 of 48 samples (6%) from the Study Area. Chromatograms for these three samples bore no resemblance to drill mud hydrocarbons or hydrocarbons found in produced water (J. Kiceniuk, 2011 pers. comm.).

Arsenic and copper have been the most frequently detected metals in water samples, with arsenic detected in every sample collected from 1997 to 2010. Total suspended solids (TSS) was detected in most samples.

In 2010, arsenic concentrations were significantly greater at Study Area stations than at Reference Area stations, although average differences were slight (mean = 0.80 μg/L versus 0.72 μg/L). Differences among stations within Areas and

differences between the two Reference Areas were also significant. Arsenic concentration did not differ among depths sampled.

Copper concentrations did not differ significantly between the Reference and Study Areas, or among station or depths. TSS concentrations were generally higher in the Reference Area samples than in Study Area samples and TSS was more frequently detected above the laboratory detection limit (1 mg/L) in Reference Area samples.

In EEM years, there have been significant differences in arsenic and copper concentrations between the two Reference Areas and the Study Area, but with no consistent pattern (i.e., concentrations of the two metals were sometimes higher and sometimes lower in the Study Area). TSS concentrations varied mostly among years, rather than between Areas. There was also no progressive increase in arsenic, copper and TSS concentrations over time in the Study Area.

8.2.2 PHYTOPLANKTON PIGMENTS

Chlorophyll *a* and other pigments in the water column from Niskin Bottle samples and CTD casts have been used as indicators of algal biomass in the Terra Nova EEM program. In 2010, chlorophyll *a* concentrations from Niskin Bottle samples did not differ significantly between the Reference Areas and the Study Area, nor did they differ between the two Reference Areas. Chlorophyll *a* concentrations in Niskin Bottles were usually greatest in samples collected at the surface in 2010. In previous years, maximum chlorophyll *a* concentration sometimes occurred at mid-depth (e.g., Suncor Energy 2009).

Phaeophytin *a* concentrations differed significantly between Reference and Study Area stations, and also between the two Reference Areas. Mean and median concentrations were lowest (approximately 0.24 μg/L) in the SW Reference Area, and similar (approximately 0.29 μg/L) in the SE Reference and Study Areas. Pheophytin *a* concentrations in Niskin Bottles were usually greatest in samples collected at the bottom.

In 2010, chlorophyll *a* concentration from CTD casts had a tendency to be more variable toward the centre of the development – an observation that could be related to the greater sample sizes near the FEZ. Beyond this, chlorophyll *a* concentrations in CTD casts in 2010 did not vary in relation to distance from the FEZ drill centre or distance from the FPSO (note that given the proximity of the FEZ drill centres and the FPSO, both distance variables generally represent distance from the centre of

the development). In baseline (1997), in the absence of any drilling activity or produced water discharge, significant distance correlations from the centre of the development occurred. There were also significant correlations between chlorophyll concentrations and various distance measures in EEM years prior to 2010. However, few EEM distance correlations were stronger than baseline distance correlations. Furthermore, the EEM distance correlations varied in significance, strength or direction (sign) among years, depth intervals with no apparent relationship with the onset of drilling activity at the FEZ drill centres in 2000 and the FE drill centre in 2002, or produced water discharges in 2003.

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 male scallop in Terra Nova EEM samples. In 2010, overall female:male sex ratios were approximately 60:40, comparable to sex ratios in 2006 and 2008 and more skewed towards females than from 1997 to 2004. In 2010, scallop tissue weight relative to shell weight (i.e., PC2 scores, see Section 7) was higher in the Reference Area than in the Study Area. No other size or shape differences among the two Areas were noted. In past years, there have often been large and significant small-scale differences in scallop size and/or shape among transects within Areas (i.e., within the Study Area or within the Reference Area), with few or no consistent differences between Areas.

Scallop selected for body burden analysis in 2010 were generally representative of the larger set of scallop sampled.

8.3.1.2 Plaice

In 2010, female plaice were more abundant than males in both the Study and Reference Areas and sex ratios did not differ between Areas. All males and most females were mature, with again no differences in maturity between Areas. Size, age and condition for both males and female fish were similar between Areas in most cases. However, there was a marginally significant (p = 0.09) difference in hepatosomatic indices (HSI) for females, with lower indices in the Study Area. In spite of the indication of a difference in HSI between Areas, the adjusted means of

liver weight on gutted weight, a measure of condition similar to, and often more appropriate[31] than the HSI, were not significantly different between Areas.

8.3.2 BODY BURDEN

8.3.2.1 Scallop

>C_{10}-C_{21} Hydrocarbons

In baseline (1997), >C_{10}-C_{21} hydrocarbons were not detected in any Reference and Study Area scallop adductor muscle and viscera composite samples. In EEM years, >C_{10}-C_{21} hydrocarbons were not detected in any (of 35) Reference Area muscle samples but were detected in 16 of 35 Study Area muscle samples. >C_{10}-C_{21} hydrocarbons were detected in 6 of 35 Reference Area viscera samples and in all 35 Study Area viscera samples collected in EEM years. The chromatograms for Study Area scallop indicated the presence of the synthetic-based drill fluid PureDrill IA35-LV used at Terra Nova. Therefore, there was good evidence for hydrocarbon contamination of scallop tissue after drilling began.

Contamination of scallop muscle and viscera at Terra Nova has decreased over time. In 2000, median >C_{10}-C_{21} hydrocarbon levels in Study Area muscle and viscera samples were 32 and 110 mg/kg, respectively. In 2008, values were less than 15 mg/kg (i.e., below the detection limit) and 23 mg/kg for muscle and viscera, respectively. In 2010, all values for both muscle and viscera were below the laboratory detection limit. When contamination did occur in earlier years, levels of hydrocarbon were greater in viscera than in muscle sample, indicating that hydrocarbons taken up from food, sediment or water generally were eliminated rather than accumulated in muscle tissue.

Barium

Barium concentrations and frequencies of detection in Study Area viscera samples were generally greater than in Reference Area samples, with the largest differences occurring in EEM years. Barium levels in viscera have also progressively increased since 2001 and median barium concentrations in Study Area viscera samples were at their highest in 2010 (14 mg/kg wet versus 5 mg/kg wet during baseline (1997)). The foregoing may be evidence of barium contamination from drill muds in viscera. However, given that no drilling occurred using water-based muds and relatively little

[31] The HSI assumes that liver weight is linearly related to gutted weight, which is not always the case.

discharge of synthetic-based muds and completion fluid (which also contains barium) occurred since the last (2008) EEM program (see Section 4); and given that project-related barium levels in sediments have decreased in recent years, the link between project activities and barium concentration in viscera in 2010 is unclear. 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. Barium was detected in only six adductor muscle samples (four from the Study Area and two from the Reference Area) in EEM years.

The effects of barite (barium sulphate) and water-based muds on biota are primarily physical rather than chemical (e.g., Barlow and Kingston 2001; Armsworthy et al. 2005; Smit et al. 2008). At higher concentrations, barite interferes with ciliary activity in gills and other epithelial tissues or physically damages these tissues, which can reduce feeding rates and growth. These physical effects are not specific to barite and water-based muds but can occur whenever concentrations of fine particles (e.g., clay) from drill muds or natural sources are elevated.

Metals Other than Barium

Concentrations of other metals in adductor muscle and viscera have generally been low. Concentrations of most metals in adductor muscle differed significantly among years but not between Areas. However, arsenic concentrations were greater in the Reference Area than in the Study Area in every year, including baseline (1997); mercury concentrations were greater in the Study Area than in the Reference Area in every year except 2004.

Metals concentrations have been greater in Study Area viscera than in Reference Area viscera in most years including baseline (1997). Differences in viscera metals concentrations between the two Areas decreased over time, with Study Area metals concentrations similar to Reference Area concentrations in 2008 and 2010.

Tissue contamination by metals other than barium should be regarded as of little concern. There were some significant differences between Areas in tissue metal concentrations. However, these differences were generally small, differed between muscle and viscera, or were apparently natural and observed in baseline (1997) as well as in EEM years. At the low concentrations observed, many metals should be regarded as essential elements and not contaminants. Approximately one-third of all known enzymes require metals as catalysts and metals are components of cofactors, coenzymes and structural/functional molecules (e.g., iron in hemoglobin)

(Lehninger et al. 1993). Consequently, bivalves and other organisms may actively regulate metal uptake and incorporation into tissue to increase concentrations of essential elements such as iron, manganese or zinc (Gosling 1992; Newman and Unger 2003).

8.3.2.2 Plaice

>C_{10}-C_{21} Hydrocarbons

>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, 2011 pers. comm.) and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2011). In 2010, all samples from Terra Nova were analyzed further by mass spectroscopy and results indicated that there were no petrogenic hydrocarbons in any of the samples.

Barium and Other Metals

Barium has never been detected in plaice fillets or livers. Several other metals were detected frequently in plaice tissue, particularly livers (the major site of chemical accumulation, elimination and transformation). 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. As with scallop, metals in plaice tissue should be regarded as naturally occurring and often essential elements rather than contaminants. Effects at the low concentrations observed would not be expected.

8.3.3 TASTE TESTS

No significant difference in taste was noted between the Study and the Reference Areas for scallop in both the triangle and hedonic scaling test. For plaice, panellists were successful in discriminating between the two sampling Areas in the triangle test and preferred plaice from the Study Area in the hedonic scaling test. 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 of any fish.

8.3.4.2 Haematology

Haematology, including the analysis of red and white blood cells, has the potential to assess the overall health of fish as well as to indicate immunological effects that may be important in disease susceptibility. Payne et al. (2005) have noted changes in white blood cells (in a 50% difference range) in cunner chronically exposed to relatively high levels of produced water under laboratory conditions. Alteration of some immunological parameters has also been observed in Atlantic cod chronically exposed for several weeks to produced water collected from oil and gas facilities operating on the Grand Banks (Perez-Casanova et al. 2010).

There were no apparent qualitative differences in morphology or staining characteristics of red blood cells in samples of plaice from Terra Nova compared to the Reference Area. There was a slightly higher percentage of lymphocytes and slightly lower percentage of thrombocytes in fish from the Terra Nova Study Area. Although this trend was also observed in the 2008 survey, it is likely that these small differences can be attributed to natural variation (De Pedro et al. 2005 and references therein).

8.3.4.3 Mixed Function Oxygenase Activity

For male fish, a slight but significant difference was observed with enzyme activity 1.4-fold higher in fish from the Study Area compared to the Reference Area. A similar trend was also reported in males in 2002 (1.50-fold higher) and 2008 (1.66-fold higher) and in females in 2006 (1.35-fold higher). It is noted that the slight level of induction has not increased over time.

The small increase in MFO activity could be due to natural variability such as feeding differences between Areas. Although there are few studies investigating the extent to which nutritional environmental factors could affect MFO enzymes in fish, some

laboratory studies have shown that diet can modulate enzyme levels (Andersson et al. 1985; DiGiulio et al. 1993; Liao et al. 2011).

The slight MFO increase observed in males from the Study Area could also be due to exposure of fish to selected contaminants. Induction of MFO in fish has been established as a sensitive biological indicator of hydrocarbon pollution in aquatic environments (Payne et al. 1987; Whyte et al. 2000). Therefore, the small increase in MFO enzyme activity observed in male fish from the Study Area 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.

Some studies have indicated that produced water can induce MFO in fish (e.g. Payne et al., 2005; Casini et al., 2006; Abrahamson et al., 2008; Zhu et al., 2008; reviewed in Mathieu et al., 2011). That produced water could be linked to induction noted at the Terra Nova site cannot be ruled out. However, produced water would be expected to be highly diluted upon release. A number of field modelling studies carried out worldwide suggest dilution rates of 1,000x to 10,000x at distances of 0.5 to 1.0 km from the point of discharge (e.g., OGP 2002, 2005). Plume studies carried out for Terra Nova indicated similar results, with dilution ranging fro 400x to 800x at 0.25 km from the source (Lorax Environmental 2006).

Overall, there is a possibility that the slight enzyme induction being observed in male plaice is due to natural variability such as feeding, but a role for low level of contaminants cannot be ruled out.

There were no significant differences in MFO enzyme levels between the Reference and Study Areas for female fish.

8.3.4.4 Histopathology

Liver Histopathology

There were no cases of hepatic lesions that have been associated with chemical toxicity in field and laboratory studies (e.g., Myers and Fournie 2002; Feist et al. 2004) in either the Study Area or the Reference Area. These included nuclear pleomorphism, megalocytic hepatosis, fibrillar inclusions, eosinophilic, basophilic, and clear cell foci, carcinoma, cholangioma, cholangiofibrosis, proliferation of macrophage aggregates and hydropic vacuolation.

A few other hepatic conditions were noted. A “patchy distribution” of hepatocellular vacuolation, not associated with degenerative changes, was observed in similar proportions in fish from each Area and is likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelano 1990; Couillard et al. 1997). A mild peri-biliary inflammatory response was observed in one fish from the Reference Area. Also, liver tissues of some fish contained myxosporean parasites but no significant differences in the prevalence of fish affected were found between the two Areas.

Observations on parasitism, hepatocellular vacuolation and inflammatory response are of value in relation to providing general information on their presence in the survey area. However, it is important to note from an EEM perspective that liver lesions more commonly associated with chemical toxicity were absent.

Gill Histopathology

Microstructural changes such as telangiectasis, lamellar fusion and various types of hyperplasia (e.g. Mallat 1985) were absent or found at very low frequencies in both Areas and no significant differences were observed between the two Areas.

Overall, the results of the fish health survey carried out in 2010 indicated that the present health of plaice is similar at the Reference Area and the Terra Nova Study Area.

8.4 SUMMARY OF EFFECTS AND MONITORING HYPOTHESES

As discussed in Section 1, monitoring hypotheses (reiterated in Table 8-2) 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 8-2 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 2010 EEM program, the null hypothesis is rejected for the sediment quality component of the program, but the null hypotheses are not rejected for the commercial fish[32] and the water quality 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 2010, as in previous EEM years. In 2010, there was also evidence of project effects on sulphur and, to a lesser extent, on sediment fines content. Evidence of project effects on sulphur and fines have been noted in 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 2 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 3 km from drill centres. The zone of influence and absolute levels for $>C_{10}$-C_{21} hydrocarbons have decreased in 2008 and 2010, relative to levels observed from 2002 to 2006. 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. Distance gradients for affected taxa were too weak to provide robust estimates of the spatial extent of effects, but results from 2010, and from previous years, suggest that effects on the most affected taxa were greatest within 2 km of drill centres.

[32] The small increase in MFO activity in the Study Area, although possibly attributable to Terra Nova, was not coupled with effects on other health indicators and overall health of fish at Terra Nova was assessed to be similar to that at the Reference Area.

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.

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

To improve on the readability of results, analyses of relationships among physical and chemical variables, toxicity and benthic invertebrate data that precede analyses specifically geared toward effects assessment (e.g., assessment of relationships with distance) should be moved to an appendix (Volume 2) and summarized in the main body of the report (Volume 1). Correlation analyses are required for due diligence, to better understand the interrelationship among response variables, but are not central to effects assessment.

Because of the statistical extremes noted for many variables at station 30(FE) and, in 2010, at station 31(FE), these stations have been excluded from repeated-measures regression results in Volume 1, with results including those two stations provided in Appendix B-4. It is now proposed that the two stations be included in repeated-measures regression results in Volume 1. Results excluding the two stations will be reported in Volume 1 when they have a large influence on the significance of statistical tests. It may also be appropriate to consider a non-parametric repeated-measures rank-regression (i.e., a repeated-measures analysis using ranks of the data) to control some of the influence of those extreme values (e.g., Wang and Zhu, 2006).

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.

Suncor Energy has submitted a revised water quality water monitoring design that accepted by the C-NLOPB in August 2011. The revised water quality program is currently being incorporated into the overall EEM design.

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.

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