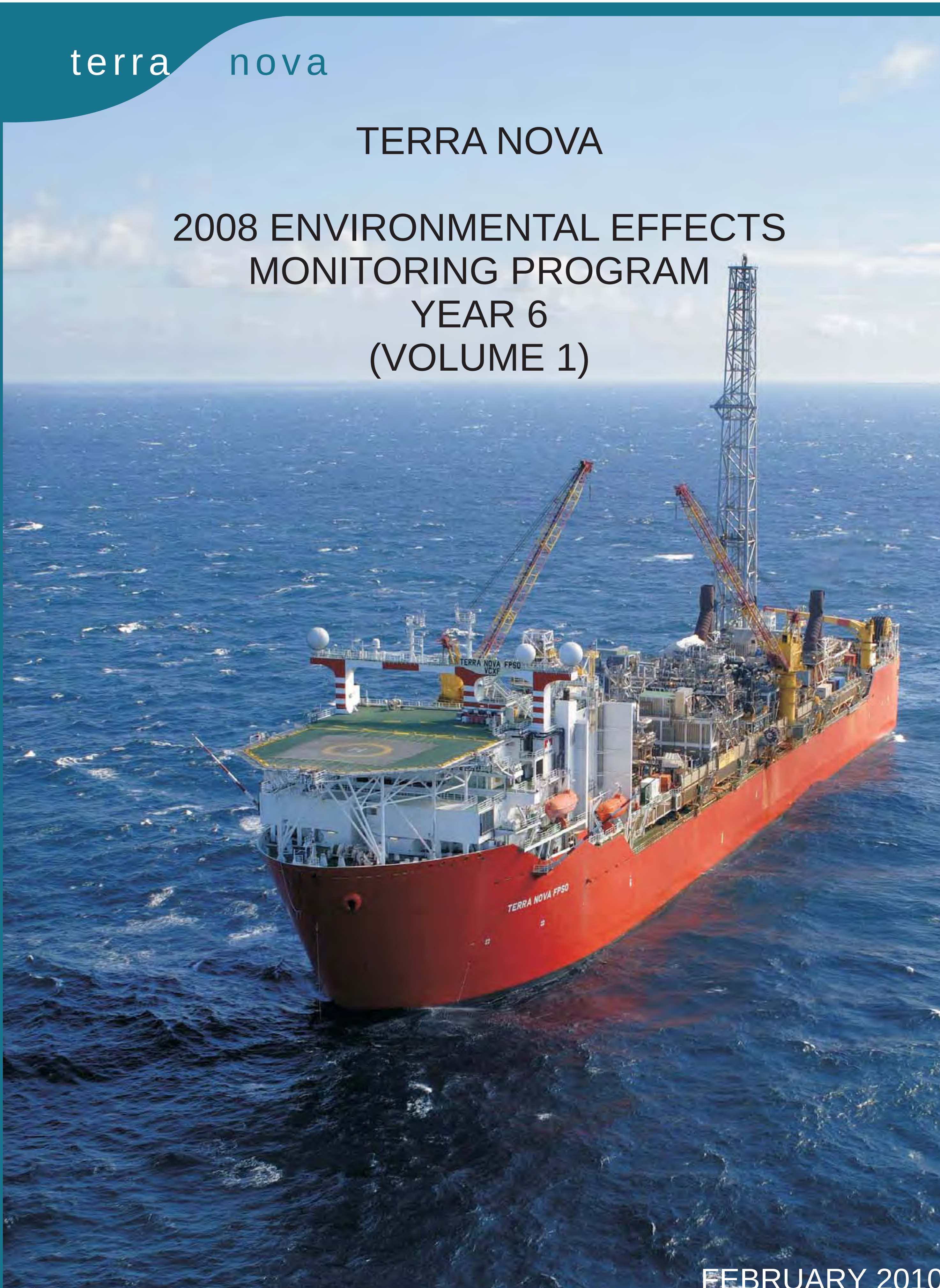
terra nova

TERRA NOVA

2008 ENVIRONMENTAL EFFECTS MONITORING PROGRAM YEAR 6 (VOLUME 1)



FEBRUARY 2010

EXECUTIVE SUMMARY

The Terra Nova Environmental Effects Monitoring (EEM) program was established to fulfil commitments made in the Terra Nova Environmental Impact Statement (EIS) (Petro-Canada 1996) and addendum document (Petro-Canada 1997). The design of the EEM Program drew on a number of information sources, including the Terra Nova Baseline Characterization Program (Petro-Canada 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[1].

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

In 2008, 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 and a marine amphipod species were performed, and benthic invertebrate infaunal species were identified and enumerated.

Water samples and conductivity, temperature, depth (CTD) data were collected at 16 stations in a Study Area, 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 data were also collected at all 53 sediment stations.

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

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

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 indicators of drilling activity and levels of both compounds were elevated near drill centres in 2008. Although contamination has increased in EEM years overall, contamination in 2008 was reduced compared to 2006, potentially as a result of reduced drilling. Maximum barium and $>C_{10}$-C_{21} hydrocarbon concentrations (7,200 and 340 mg/kg, respectively) occurred at station 30(FE), located 0.14 km from the Far East (FE) drill centre. In 2008, as in previous years, there was also some indication that sulphur, sulphide 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 predicts 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 1 to 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; elevated levels of sulphide occurred within 1 km of drill centres; and elevated levels of sulphur and fines occurred only in the immediate vicinity of drill centres.

Laboratory tests showed that sediments were toxic to laboratory amphipods at the most contaminated station (30(FE), located 0.14 km from the FE drill centre). Maximum contaminant levels and toxicity also occurred at 30(FE) in 2004 and 2006. Beyond this, there has been little evidence of project-related effects in laboratory toxicity tests.

There was evidence of project effects on benthic invertebrates near drill centres, with abundances of some taxa increasing, and abundances of other taxa decreasing, near drill centres and at higher $>C_{10}$-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, standing crop, richness and diversity) were only mildly affected by project activities. Overall, these results are consistent with EIS predictions, as well as with recent literature on benthic community effects that can be expected from offshore oil and gas development.

$>C_{10}$-C_{21} hydrocarbons and barium have never been detected in water column samples collected in the Terra Nova area since 1997. There were no project effects on suspended solids or the metals frequently detected in water samples (arsenic, copper and iron). In 2008, phytoplankton pigment concentrations were marginally higher near the centre of the development than at more remote stations.

Sediment contamination and effects on benthic invertebrates were not coupled with biological effects on commercial fish. Although contamination of scallop tissue was noted (median $>C_{10}$-C_{21} hydrocarbon levels of 23 mg/kg in scallop viscera), this did not translate into a taste difference (tainting) for scallop in the Terra Nova area. No contamination or tainting was noted for plaice and plaice health, as measured through various health indicators, was similar between the Terra Nova Study Area and the more distant Reference Area.

Conclusion

Effects at Terra Nova remain limited. Increases in sediment contamination have occurred over all post-drilling years. 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 and the recent literature on effects of offshore oil and gas development. There was no clear indication of project effects on water quality. Although contamination of scallop tissue was noted, this did not translate into effects on scallop taste. American plaice heath was similar between the Terra Nova Study Area and the Reference Area.

ACKNOWLEDGEMENTS

The Terra Nova EEM program (2008) was led by Jacques Whitford Stantec Limited (St. John's, NL) under contract to Suncor Energy and under the direction of Roger Crowley and Greg Janes (Suncor Energy).

Jacques Whitford Stantec Limited led data collection, with participants including Matthew Hynes, Barry Wicks, Chris Brown, John Pennell, Doug Rimmer and James Loughlin. Fugro Jacques Geosurvey's Inc. provided geopositional services for sediment and water collections. Benthic invertebrate sorting, identification and enumeration were led by Patricia Pocklington of 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 Jacques Whitford Stantec Limited. Sediment toxicity tests were supervised by Trudy Toms of Jacques Whitford Stantec Limited – Science 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 of Oceans Ltd. (St. John's, NL). Sediment quality, water quality and body burden data were analyzed by Dr. Michael Paine of Paine, Ledge and Associates (North Vancouver, BC). The overall technical advisor for the program was Dr. Elisabeth DeBlois (Elisabeth DeBlois Inc., St. John's, NL). The reporting team included Dr. Elisabeth DeBlois, Beverley Best and Carolyn Pelley. Project management was executed by Ellen Tracy (Jacques Whitford Stantec Limited). Ellen Tracy and Dr. Joe Kiceniuk reviewed the document before final printing.

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1.0 INTRODUCTION

1.1 PROJECT SETTING AND FIELD LAYOUT

The Terra Nova oil field is located on the Grand Banks, approximately 350 km east-southeast of St. John's and 35 km southeast of the Hibernia oil field (Figure 1-1). Suncor Energy acts as operator for the development on behalf of the owners (Suncor Energy, Mobil Oil Canada Properties, Husky Energy Inc., StatoilHydro ASA, Murphy Oil Company Ltd., Mosbacher Operating Limited and Chevron Canada Resources).

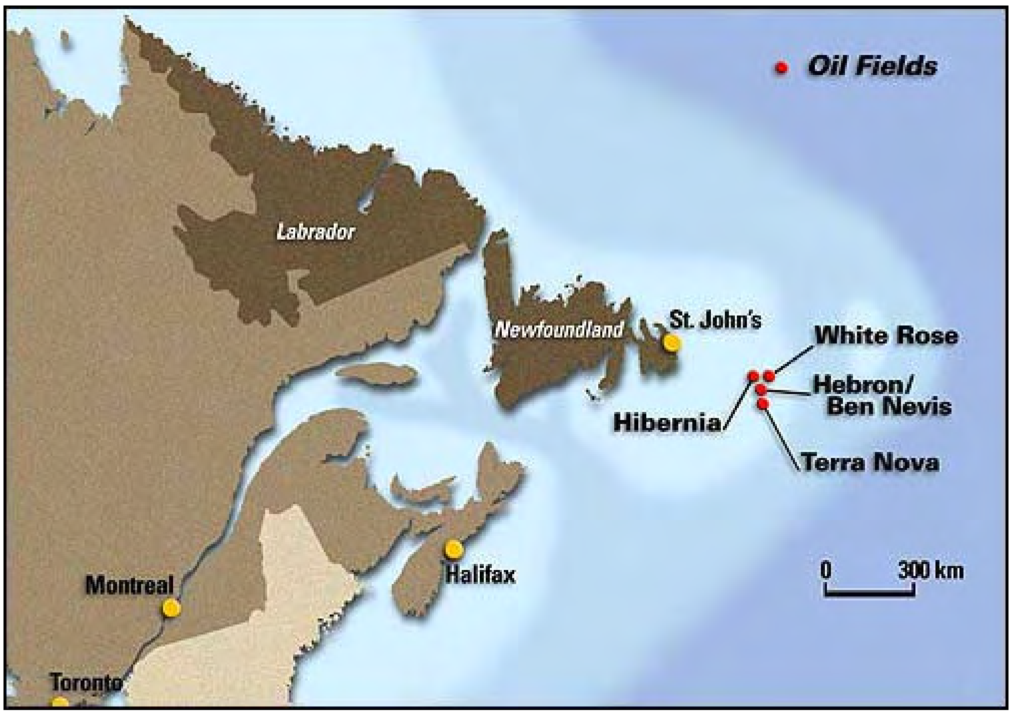

Figure 1-1 Terra Nova and Other Field Locations on the Grand Banks

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 are being 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

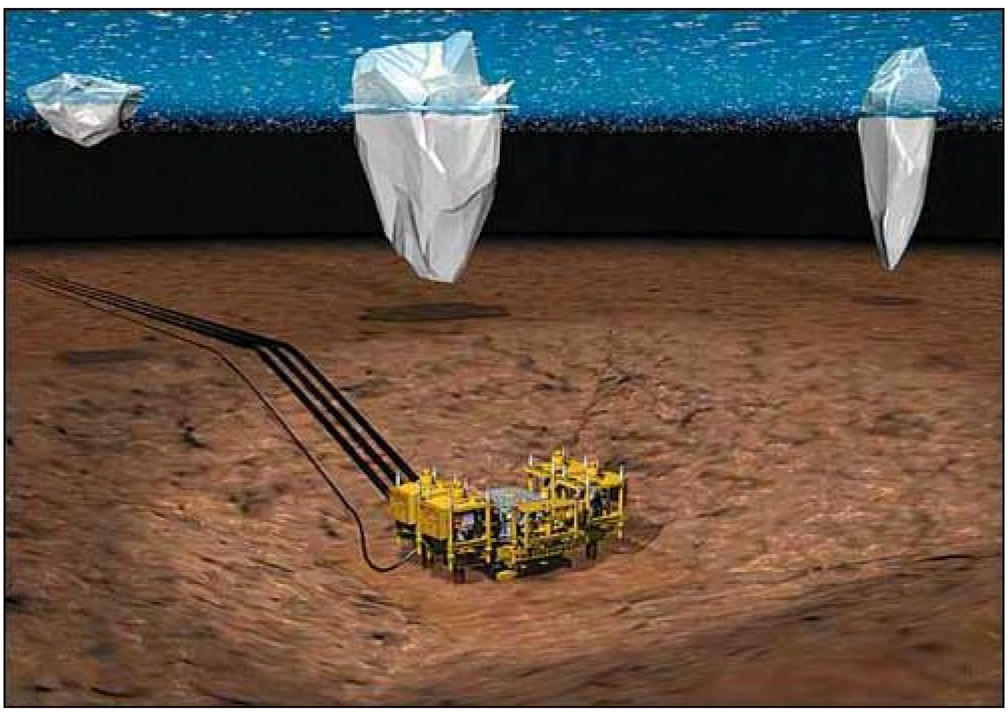

Figure 1-3 Typical Glory Hole Configuration

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[2] (C-NOPB). Pursuant to the Memorandum of Understanding concerning the Environmental Assessment of the Terra Nova Development, a Panel was established to review the EIS (Petro-Canada 1996) and addendum (Petro-Canada 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 C-NOPB supported the plan to develop the Terra Nova oil field, subject to conditions, in December 1997 (C-NOPB 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 submission was set out in Condition 23 of the C-NOPB Decision 97.02, which required that the proponent submit its EEM program 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 (Petro-Canada 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 (Jacques Whitford[3], St. John’s, NL), Sandra Whiteway (Jacques Whitford, St. John’s, NL), Ellen Tracy (Jacques Whitford, St. John’s, NL), Mary Murdoch (Jacques Whitford,

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

St. John's, NL), Dr. Michael Paine (Paine, Ledge and Associates, 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 (Petro-Canada 1998b) was submitted to the C-NOPB in October 1998. The EEM program has been implemented six times, in 2000, 2001, 2002, 2004, 2006 and 2008.

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 (Petro-Canada 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 (Petro-Canada 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 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.

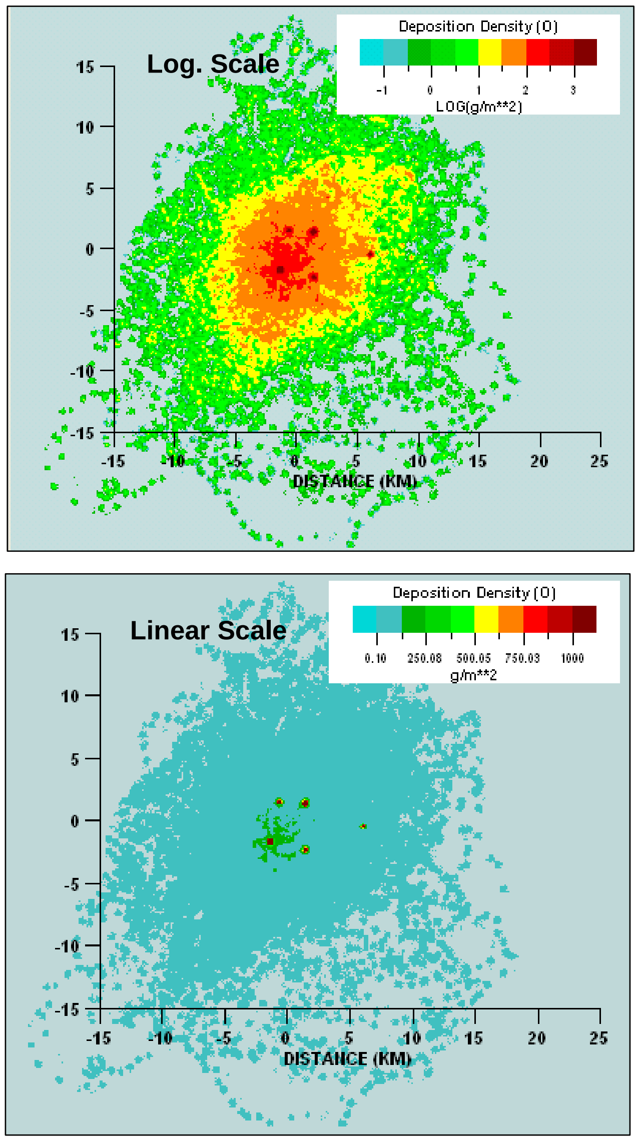

Figure 1-4 Zone of Influence for Drill Cuttings After Completion of Drilling (Seaconsult 1998)

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

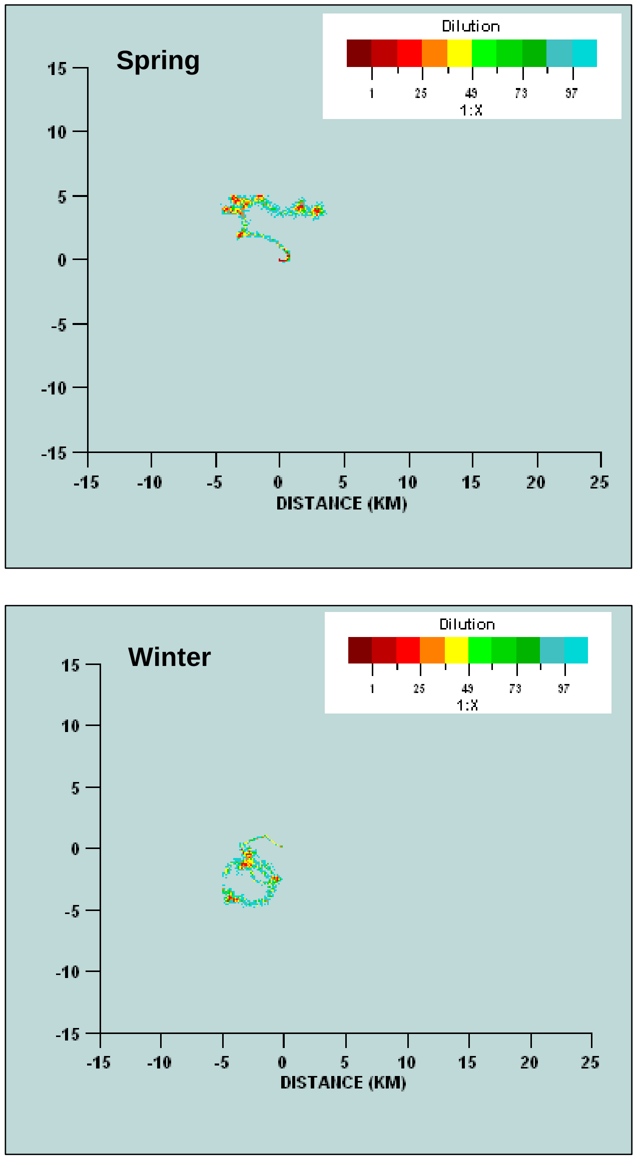

Figure 1-5 Snap-Shot of the Distribution of Produced Water (Seaconsult 1998)

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 Petro-Canada 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 (Petro-Canada 1996). For the purpose of the EEM program, testable hypotheses that draw on these effects predictions are developed in Section 1.7.

1.6 EEM PROGRAM COMPONENTS

Consistent with the effects assessment (Petro-Canada 1996), the Terra Nova EEM program is divided into three components dealing with effects on Sediment Quality, Water Quality and Commercial Fish species, including American plaice (plaice) and Iceland scallop (scallop). Assessment of Sediment Quality includes measurement of alternations 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 (SQT) (Chapman 1992, Chapman et al. 1987). 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, 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 (Petro-Canada 1998b), as well as the Baseline program report (Petro-Canada 1998a).

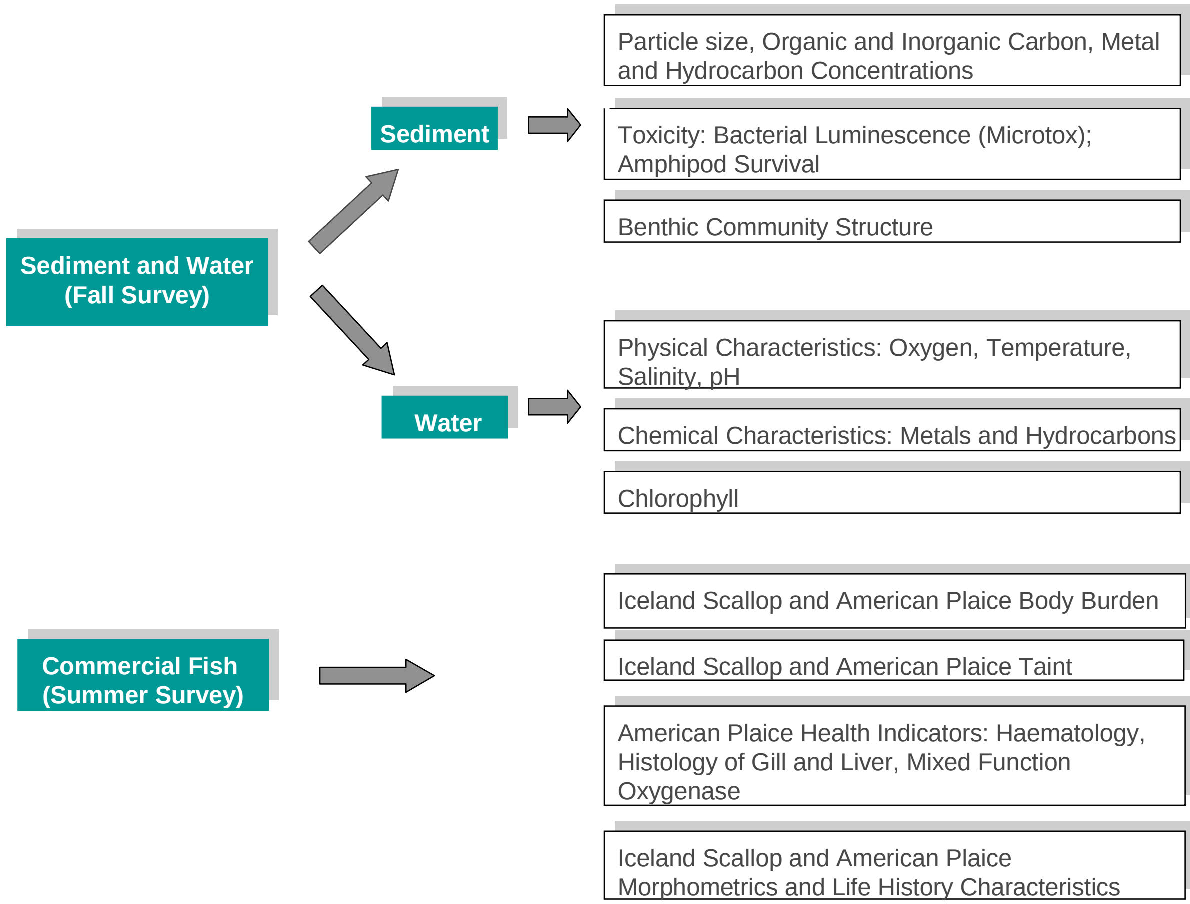

Figure 1-6 EEM Components

1.7 MONITORING HYPOTHESES

Monitoring, or null (H_o), hypotheses (Table 1-1) were developed in Petro-Canada (1998b) as part of EEM program design. Null hypotheses differ from EIS effects predictions. They are an analysis and reporting construct established to assess effects predictions. 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_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[5] induction.

Note: - No hypotheses were developed for fish body burden, life history and morphometric characteristics, as these are considered to be supporting variables, providing information to aid in the interpretation of results from other monitoring variables, such as taint or health indicators

1.8 SAMPLING DESIGN

In EEM programs, 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 Petro-Canada 1998b for details).

The general spatial distribution of sampling sites was established during the design phase of the Terra Nova EEM program (Petro-Canada 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 Petro-Canada (2000a, 2000b).

The FEZ was not yet established and therefore posed no restrictions for the Baseline program in 1997 and for collection of plaice and scallop in Spring 2000. However, sediment and water could not be collected inside the FEZ in the Fall of 2000. Plaice, scallop, 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

[5] MFO: Mixed Function Oxygenase.

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 plaice and scallop for the Baseline program and the EEM programs are shown in Figures 1-9 to 1-18. Station name changes that have occurred since the Baseline program are identified in Table 1-2.

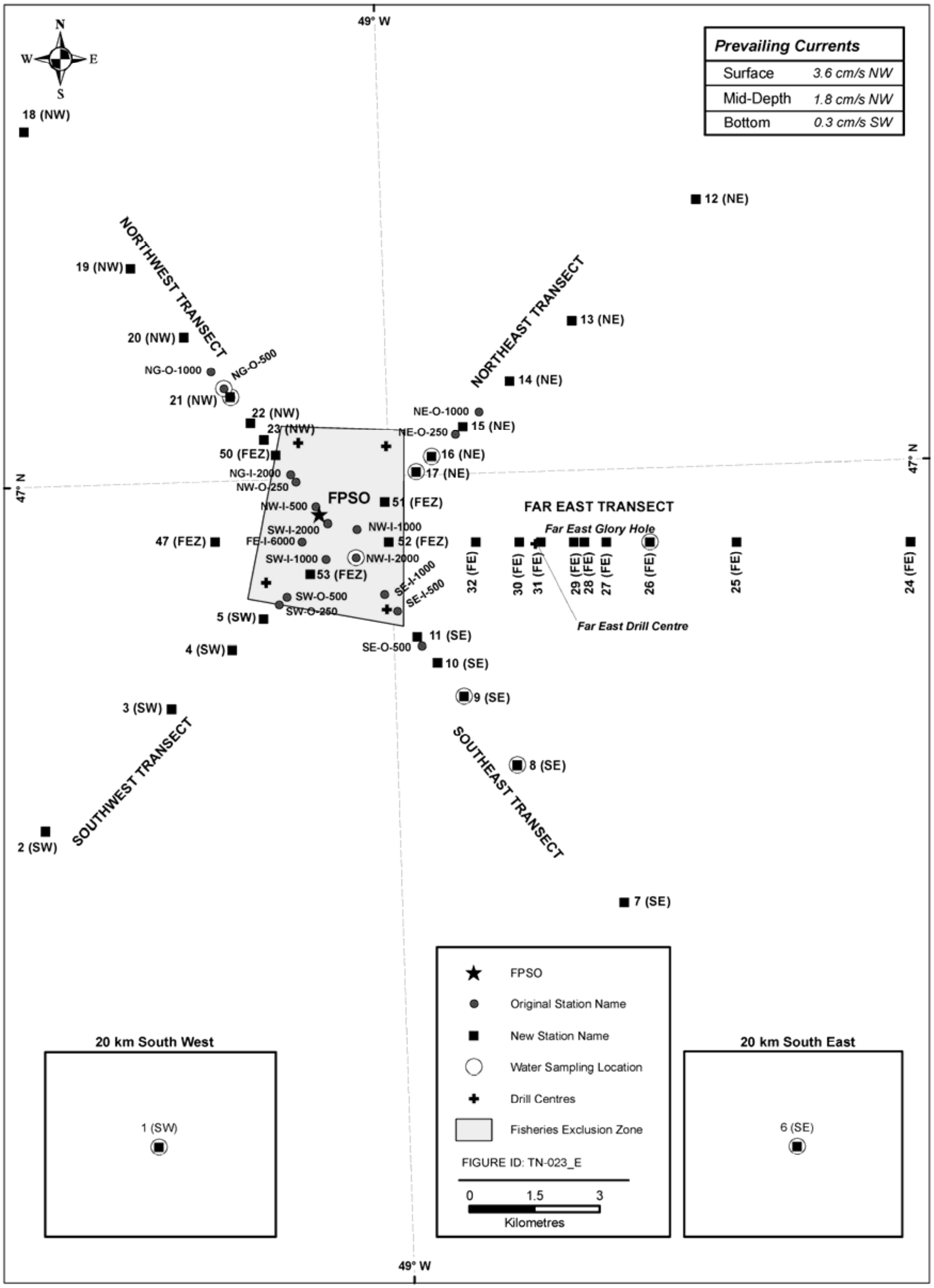

Figure 1-7 Station Locations for the Baseline Program (1997) Sediment and Water Collections

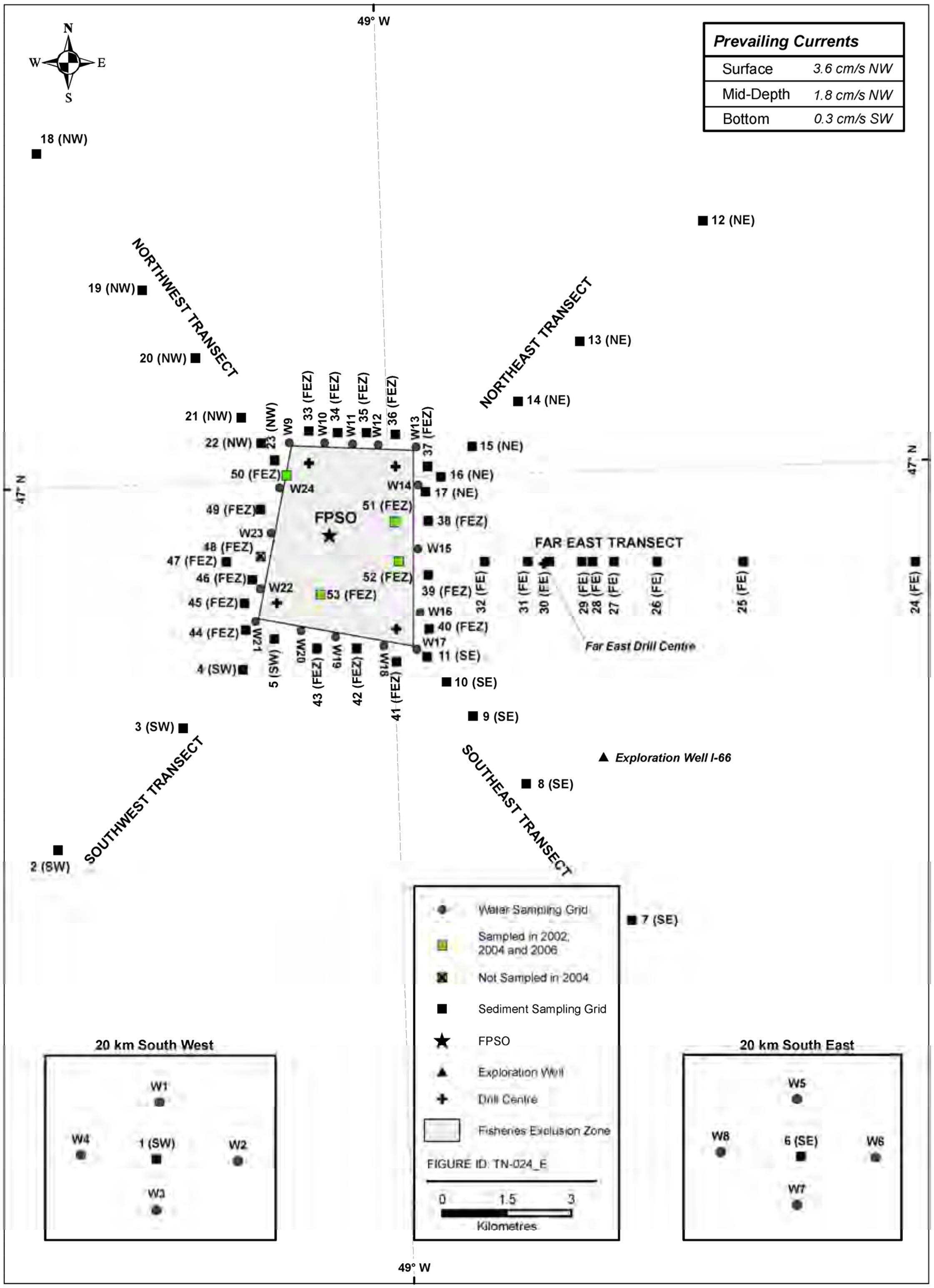

Figure 1-8 Station Locations for the EEM Program Sediment and Water Collections

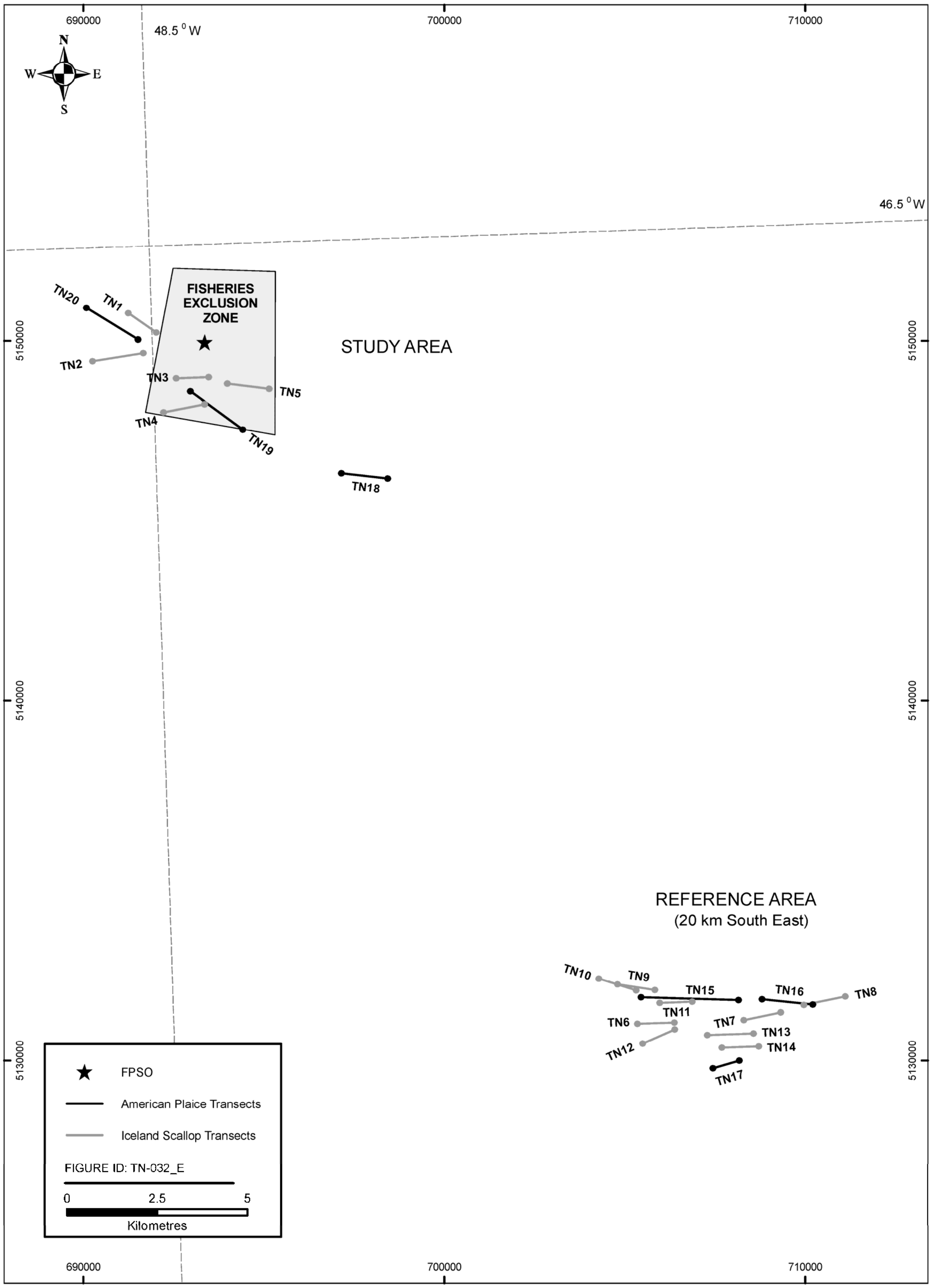

Figure 1-9 Transect Locations for Plaice and Scallop (1997)

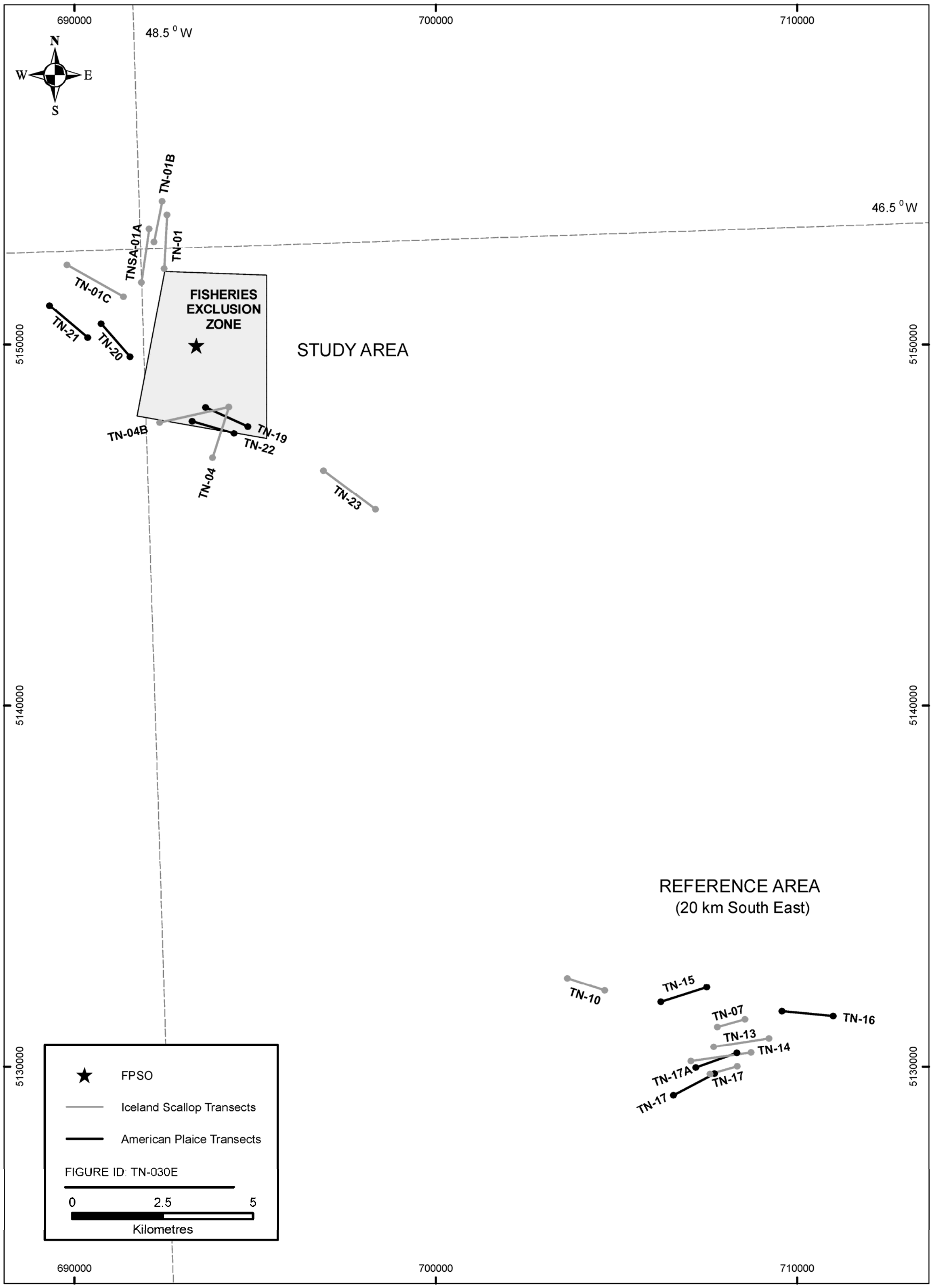

Figure 1-10 Transect Locations for Plaice and Scallop (2000)

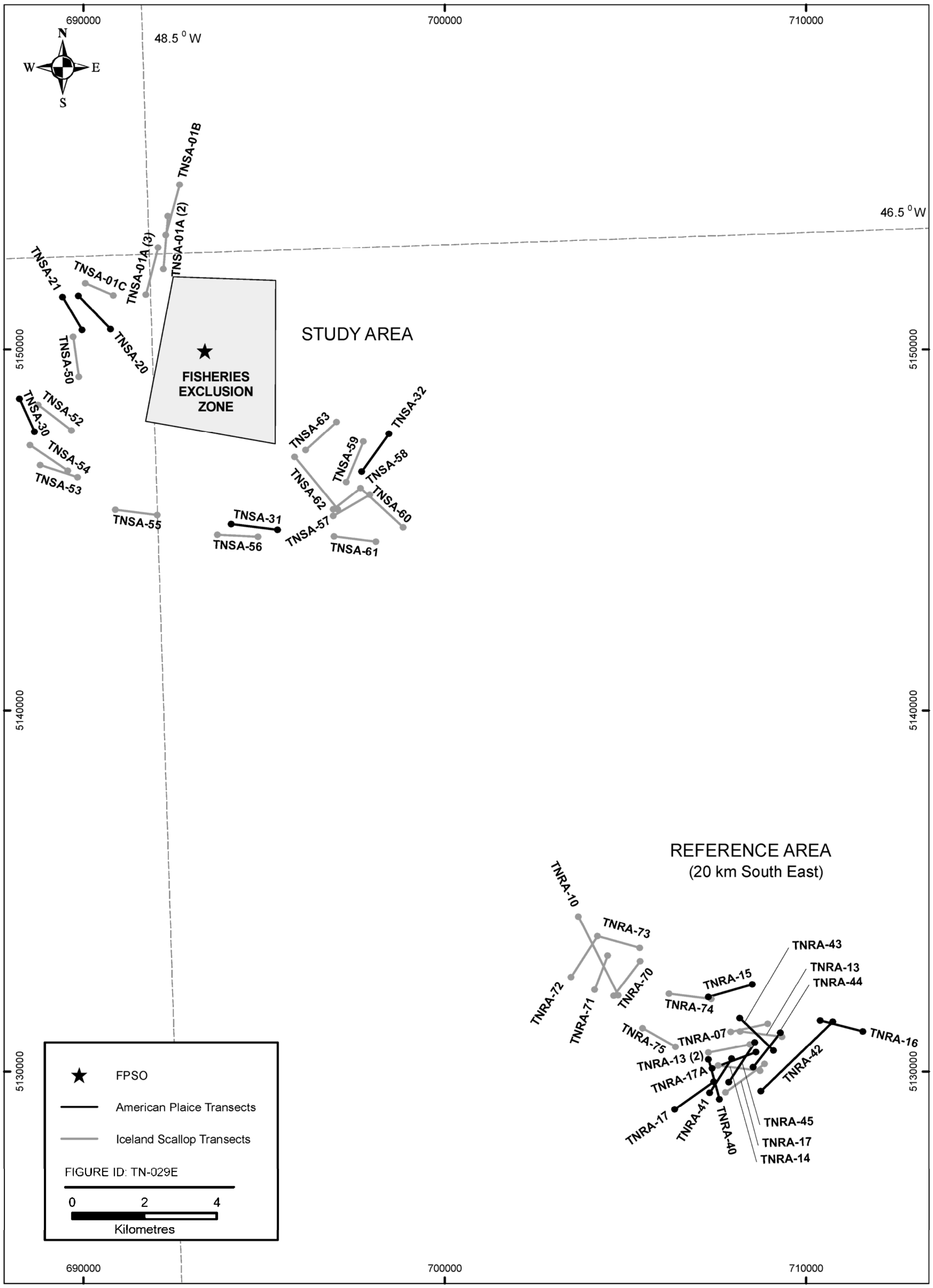

Figure 1-11 Transect Locations for Plaice and Scallop (2001)

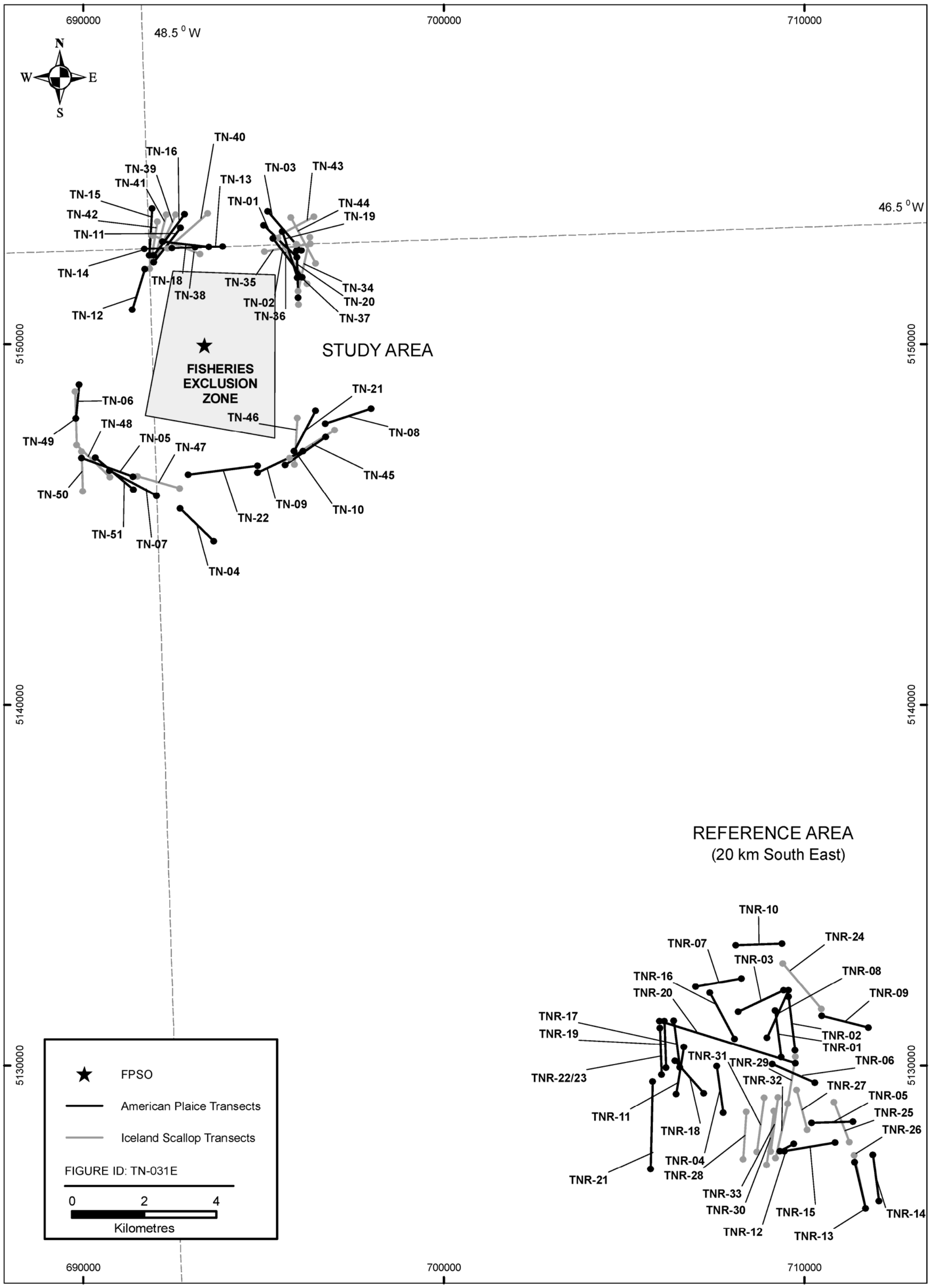

Figure 1-12 Transect Locations for Plaice and Scallop (2002)

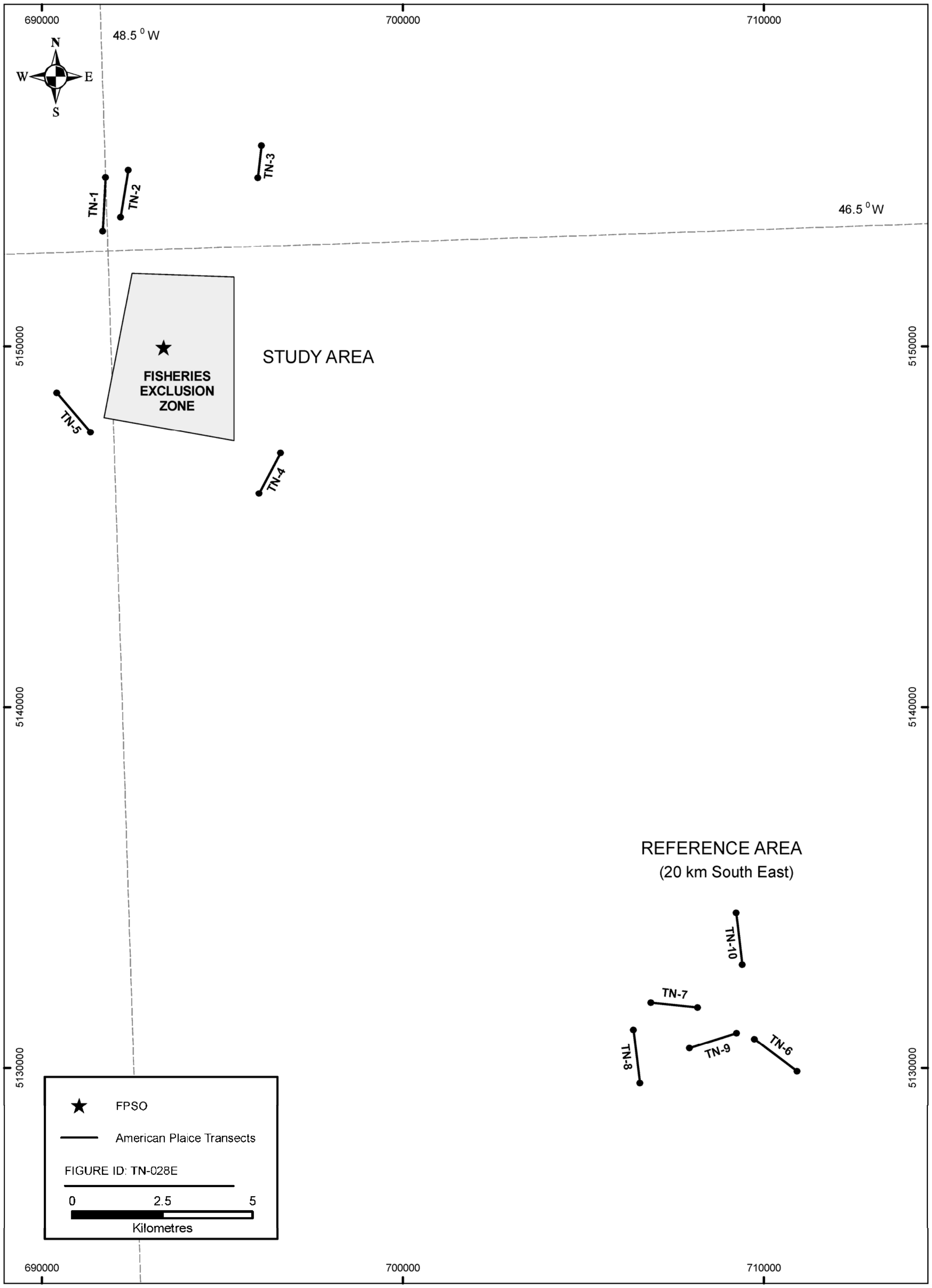

Figure 1-13 Transect Locations for Plaice (2004)

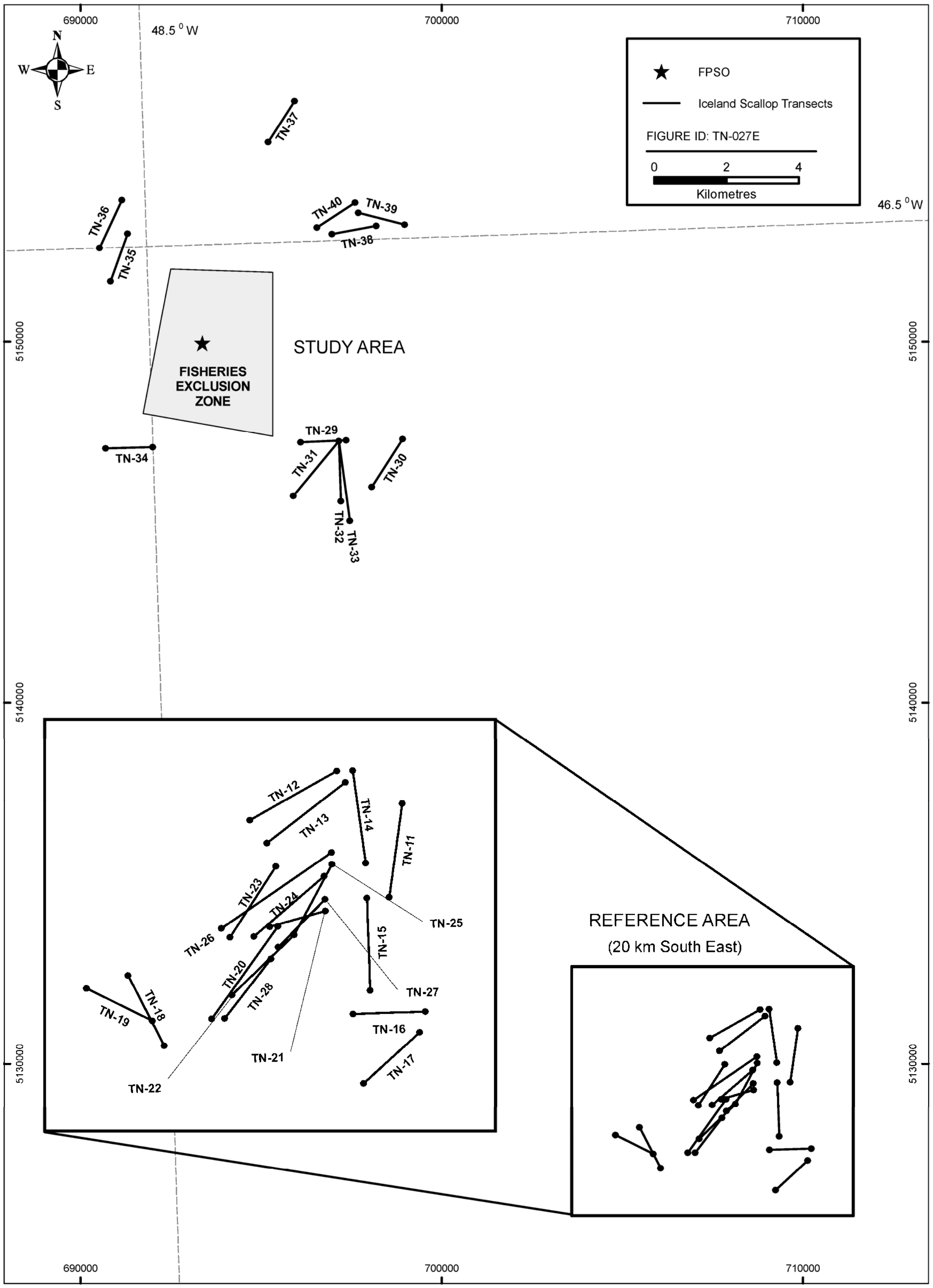

Figure 1-14 Transect Locations for Scallop (2004)

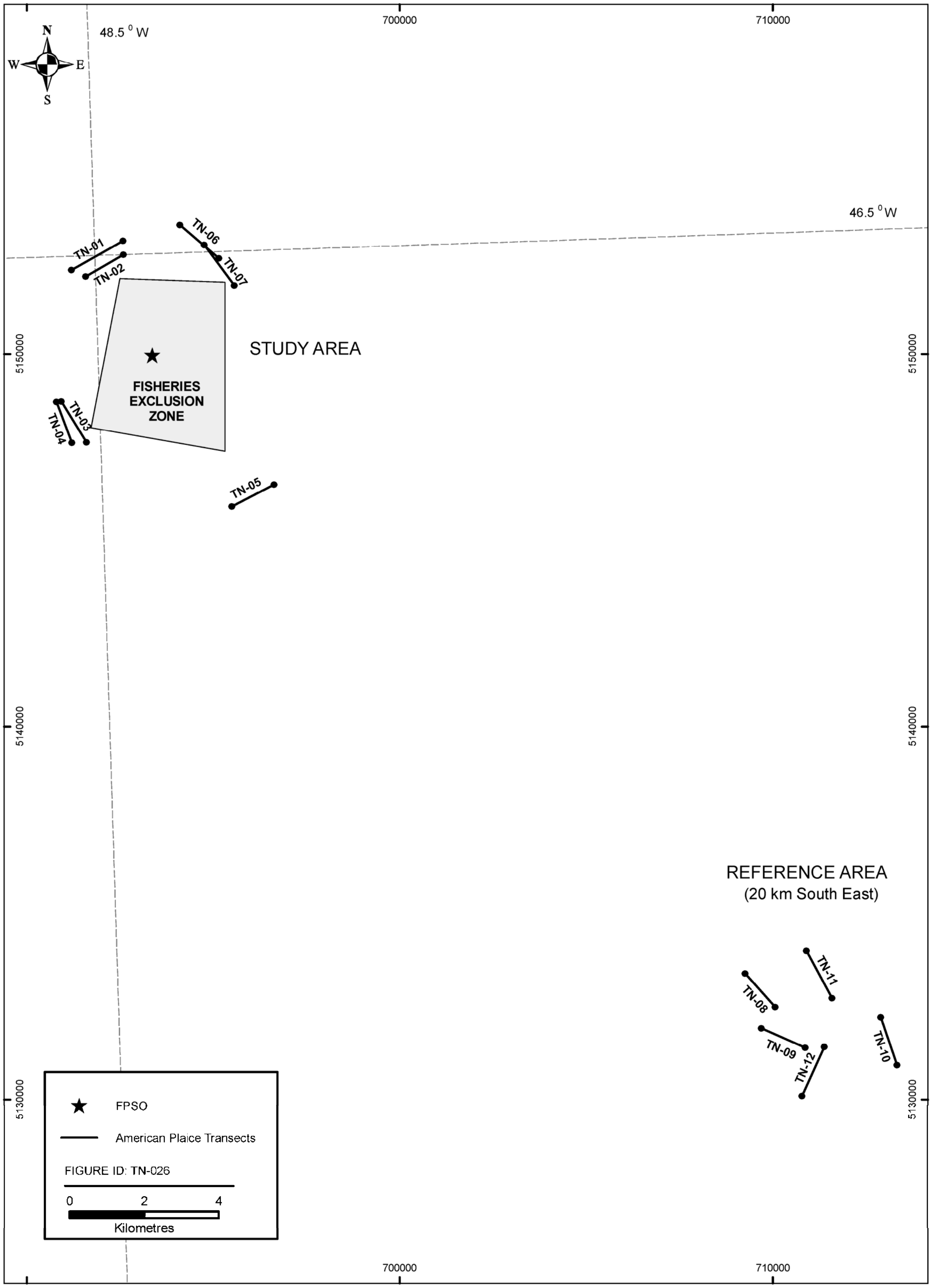

Figure 1-15 Transect Locations for Plaice (2006)

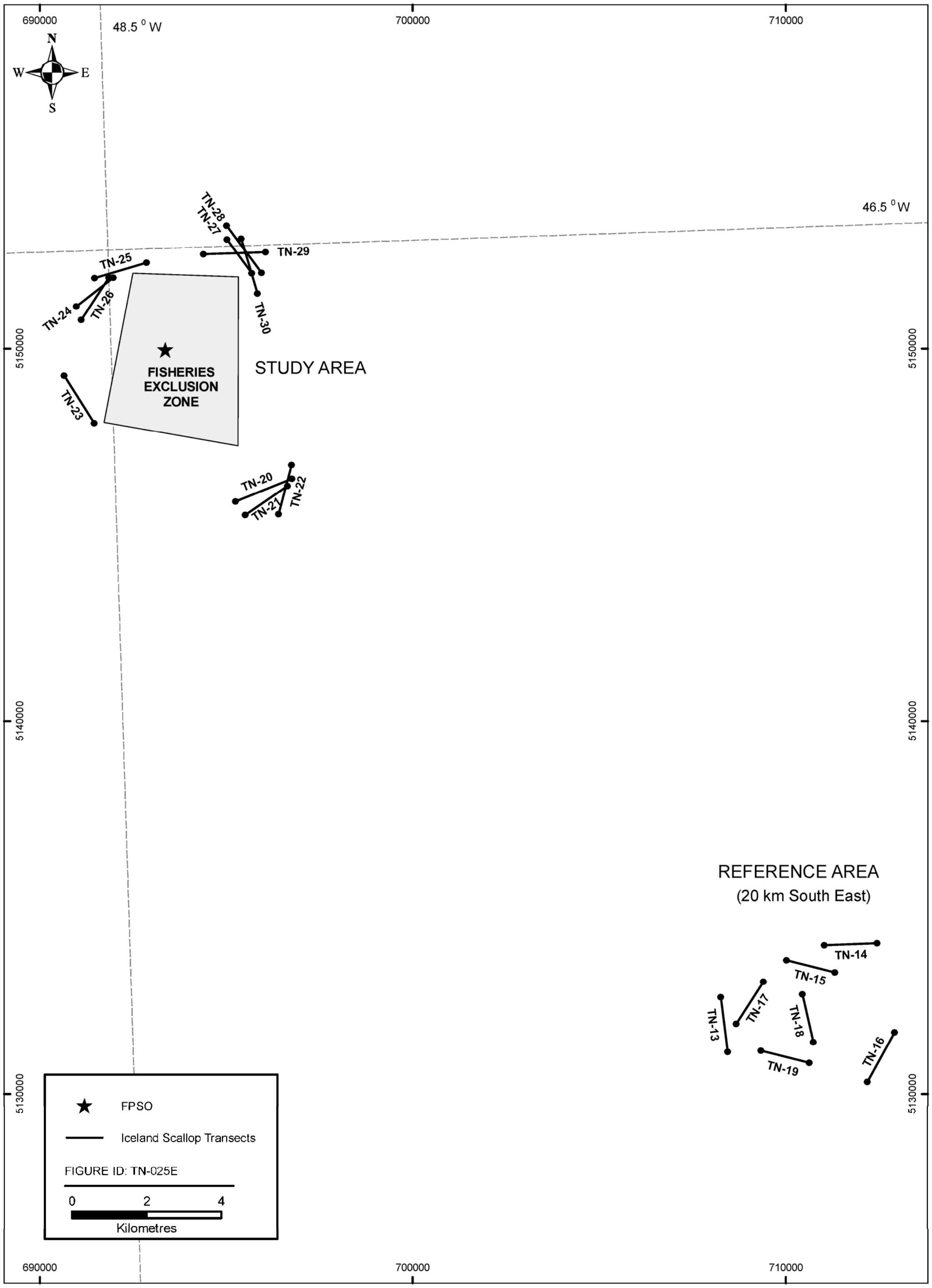

Figure 1-16 Transect Locations for Scallop (2006)

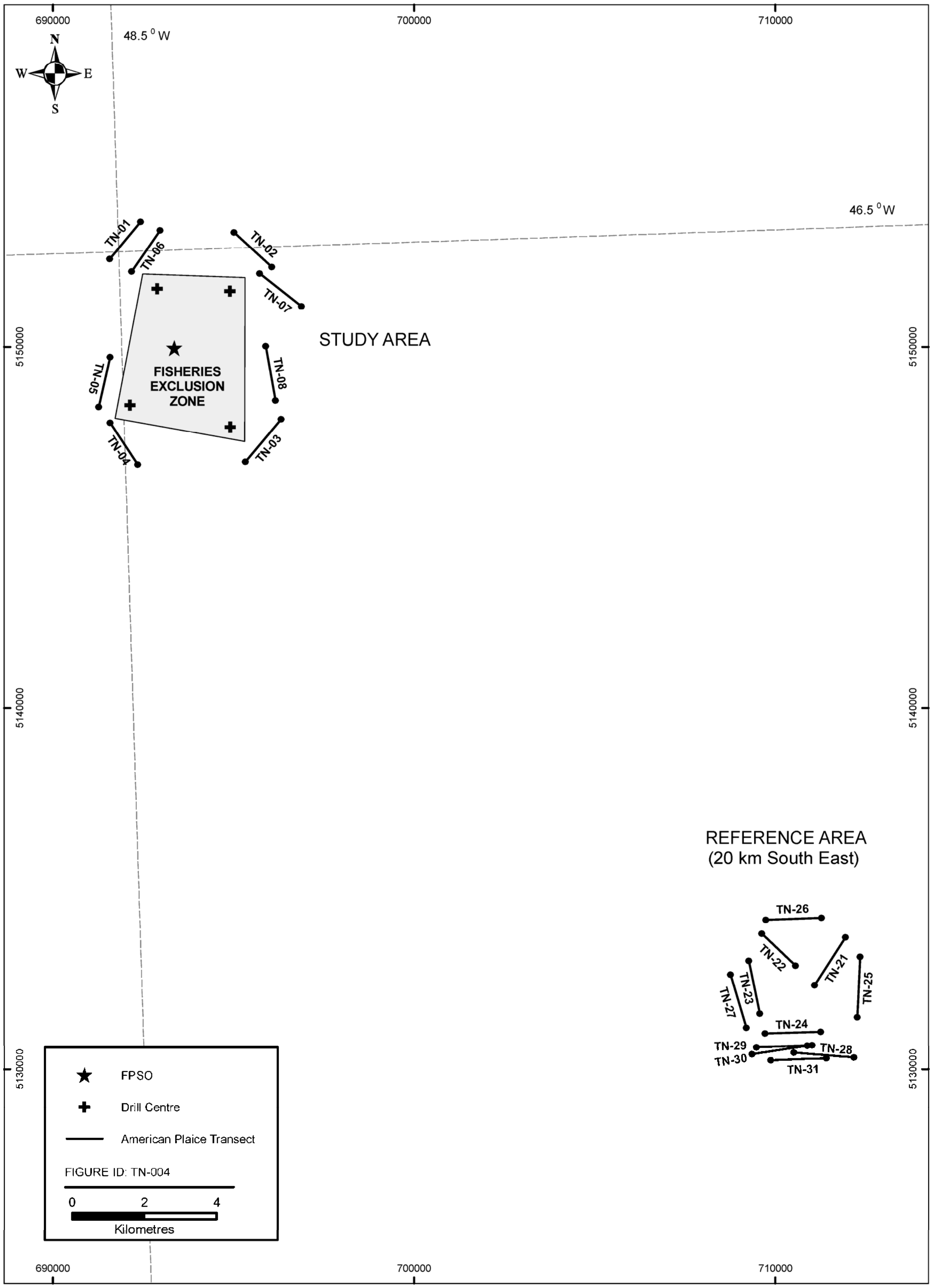

Figure 1-17 Transect Locations for Plaice (2008)

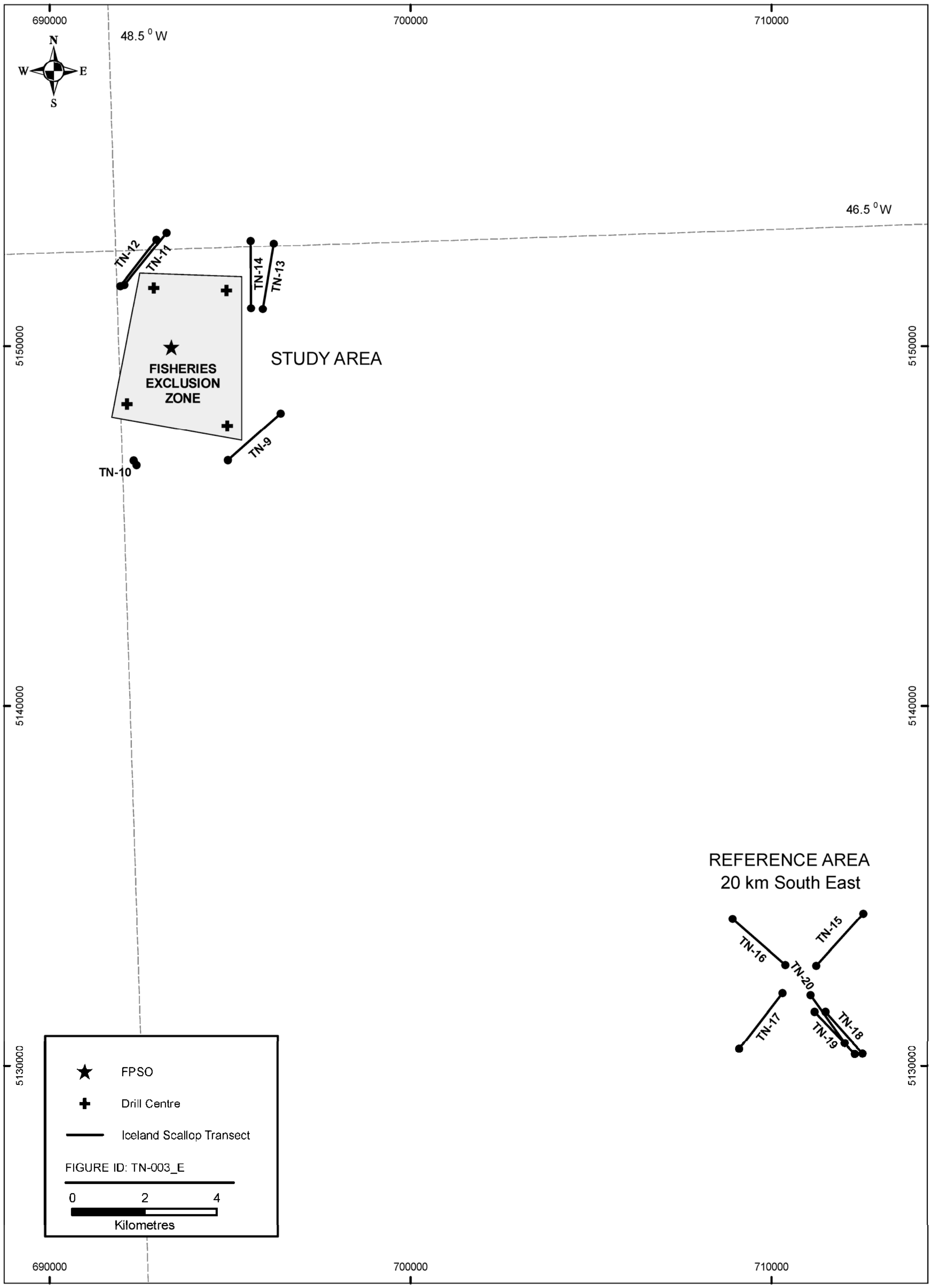

Figure 1-18 Transect Locations for Scallop (2008)

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)	NG-O-8000	46° 33.41’N	48° 33.95’W
	19 (NW)	NG-O-4000	46° 31.66’N	48° 32.11’W
	20 (NW)	NG-O-2000	46° 30.79’N	48° 31.19’W
	21 (NW)	NG-O-250	46° 30.03’N	48° 30.38’W
	22 (NW)	NG-I-500	46° 29.70’N	48° 30.04’W
	23 (NW)	NG-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

Sample type	Station Name 2002	Station Name in Previous Programs	Latitude	Longitude
Sediment	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
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 2008 (Volume 1)*, provides summary results, analysis and interpretation for the Terra Nova 2008 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 results are often highly technical, a summary of findings section is included at the end of each results section. The discussion section of the report provides interpretation of results and an overall assessment of potential project effects with respect to monitoring hypotheses. The discussion also includes recommendations for future EEM programs based on findings in 2008.

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 2008 (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
CL	Confidence Limit
C-NLOPB	Canada Newfoundland and Labrador Offshore Petroleum Board
C-NOPB	Canada Newfoundland Offshore Petroleum Board
CTD	Conductivity Temperature Depth
DFO	Department of Fisheries and Oceans
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EQL	Estimated Quantification Limit
EROD	7-ethoxyresorufin O-deethylase
FE	Far East
FEZ	Fisheries Exclusion Zone
FPSO	Floating Production Offloading and Storage
GSI	Gonado-somatic Index
HC	Hydrocarbons
HSI	Hepato-somatic Index
HPLC	High Performance Liquid Chromatography
IC50	(50% inhibitory concentration); molar concentration of an agonist which produces 50% of the maximum possible inhibitory response to that agonist
LOWESS	Locally Weighted Scatter-Plot Smoothing
MDL	Method Detection Limit
MFO	Mixed Function Oxygenase
MODU	Mobile Offshore Drilling Unit
NE	North East

Acronym	Meaning
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
RDL	the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions
RM	Repeated Measures
SBM	Synthetic-Based Mud
SE	South East
SQT	Sediment Quality Triad
SW	South West
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
UCM	Unresolved Complex Mixture
WBM	Water-Based Mud

4.0 PROJECT-RELATED ACTIVITIES AND DISCHARGES

A number of site development activities occurred between 1997, when baseline field collection took place, and September 17, 2008, when the final collections for the sixth sampling year of the EEM program were initiated. These activities were related to site development and operation, as described in the following sections[6].

4.1 CONSTRUCTION ACTIVITIES

Glory hole 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 glory holes were excavated at the Terra Nova site using the *Queen of the Netherlands*. Dredge spoils from the glory holes 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 glory holes 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 September 2008, when EEM sampling was performed. The discharge statistics do not reflect the production and drilling activities conducted beyond this period.

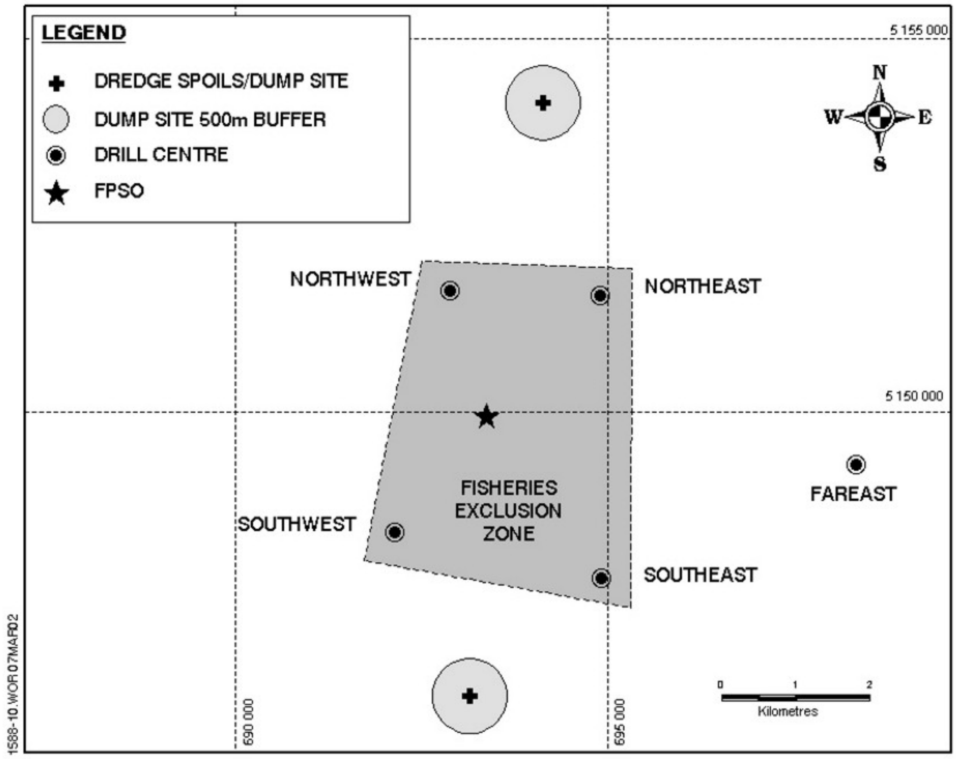

Figure 4-1 Drill Centre Locations and Dump Sites for Dredge Spoils

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 (glory hole locations): 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.

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.

In-field construction activities since 2006 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. Additionally, during August 2006, an 1,860 m section of gas injection flowline servicing Host D in the southwest drill centre was installed parallel to the existing flowline that had failed. Rock dumping operations were not performed for this new section of flowline.

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. As of the end of drilling in 2007, 34 distinct wellbores and sidetracks have been drilled within the field. Since first oil in 2002, 28 wells in the NW, NE, SW and SE drill centres have been used for production activities. Of these 28 wells, 15 were oil producers, four were gas injectors and nine were water injectors. One of the four gas injectors has also been abandoned.

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

1. Water-based Muds (WBMs);
2. Synthetic-based Muds (SBMs); and
3. Water-based Completion Fluid.

WBMs are used during the first two hole sections (conductor and surface) of each well. SBMs 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

WBMs are 90% water, the remaining 10% is comprised of barite, gel, caustic soda and lime. Cuttings generated using WBMs are returned to the seafloor and then transferred out of the glory hole using the cuttings transfer system. Three wells were drilled with WBMs from August 2006 to February 2007. No drilling with WBMs occurred between this date and September 2008, when EEM sampling was performed. One well was drilled with WBMs out of the SW drill centre, one well was drilled out of the NW drill centre and one exploration well (I-66 (PF8)) was drilled in the Far East (see Figure 1-8, Section 1, for the location of this exploration well; see Table 4-1 for details on discharges).

Table 4-1 Discharges of Water-based Drilling Fluid from August 2006 to February 2007

Year	Month	Well	Drill Centre	Discharges To Sea	
				Fluid Volume (m^3)	**Dry Solids (kg)**
2006	August	G-90 8 (F1)	NW	895	208,540
2006	October	G-90 8 (F1)	NW	3,157	2,656
2006	November	I-66 (PF8)	Exploration Well	1,075	288,856
2006	December	I-66 (PF8)	Exploration Well	2,639	659
2006 Total NE drill centre				**0**	**0**
2006 Total NW drill centre				**4,052**	**211,196**
2006 Total SE drill centre				**0**	**0**
2006 Total SW drill centre				**0**	**0**
2006 Total FE drill centre				**0**	**0**
2006 Total Far East exploration well drill site				**3,714**	**289,515**
2007	February	I-66 (PF8)	Exploration Well	2,614	1,249
2007	February	L-98 6Z (D4))	SW	2,449	18,552
2007 Total NE drill centre				**0**	**0**
2007 Total NW drill centre				**0**	**0**
2007 Total SE drill centre				**0**	**0**
2007 Total SW drill centre				**2,449**	**18,552**
2007 Total FE drill centre				**0**	**0**
2007 Total Far East exploration well drill site				**2,614**	**1,249**
August 2006 to 2007 Total				**12,829**	**520,512**

From 2006 to September 2008, Suncor Energy reported cumulative WBM discharges of 12,829 m^3. Of these, 2,449 m^3 were released at the SW drill centre, 4,052 m^3 were released at the NW drill centre and 6,328 m^3 were released at the drill site for the exploration well I-66 (PF8). From the beginning of drilling to September 2008, Suncor Energy reported cumulative WBM discharges of 54,622 m^3. Of these, 18,471 m^3 were released at the SW drill centre, 10,511 m^3 were released at the NE drill centre, 4,593 m^3 were released at the SE drill centre, 10,854 m^3 were released at the NW drill centre, 3,865 m^3 were released at the Far East (FE) drill centre and 6,328 m^3 were released at the drill site for the exploration well I-66 (PF8).

4.2.2 SYNTHETIC-BASED MUD DISCHARGES

SBMs were used to facilitate the drilling of 3 wells from August 2006 to July 2007. The composition of SBMs is approximately 70% base oil (Petro-Canada 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).

Between August 2006 and July 2007, one well was drilled with SBMs out of the SW drill centre, one well was drilled out of the NW drill centre and exploration well I-66 (PF8) was drilled in the east (see Table 4-2 for details). No drilling with SBMs occurred between July 2007 and September 2008, when EEM sampling was performed.

Table 4-2 PureDrill IA35-LV Base Oil Fluid on Cuttings Discharged from 2006 to July 2007

Year	Month	Well	Drill Centre	Discharge to Sea		
				Oil Volume (m^3)	Oil Weight (tonne)	Cuttings Weight (tonne)
2006	August	G-90 8 (F1)	NE	68	56	968
2006	September	G-90 8 (F1)	NE	198	163	1,897
2006	October	G-90 8 (F1)	NE	67	55	628
2006	November	I-66 (PF8)	Exploration Well	4	3	31
2006	December	I-66 (PF8)	Exploration Well	113	93	1,161
2006 Total NE drill centre				**332**	**274**	**3,493**
2006 Total NW drill centre				**0**	**0**	**0**
2006 Total SE drill centre				**0**	**0**	**0**
2006 Total SW drill centre				**0**	**0**	**0**
2006 Total FE drill centre				**0**	**0**	**0**
2006 Total Far East exploration well drill site				**116**	**96**	**1,192**
2007	January	I-66 (PF8)	Exploration Well	82	67	797
2007	February	I-66 (PF8)	Exploration Well	24	20	240
2007	February	L-98 6Z (D4)	SW	4	3	44
2007	March	L-98 6Z (D4))	SW	27	22	336
2007	April	L-98 6Z (D4)	SW	131	108	1,359
2007	May	L-98 6Z (D4)	SW	3	2	25
2007	July	L-98 6Z (D4)	SW	1	1	3
2007 Total NE drill centre				**0**	**0**	**0**
2007 Total NW drill centre				**0**	**0**	**0**
2007 Total SE drill centre				**0**	**0**	**0**
2007 Total SW drill centre				**165**	**136**	**1,767**
2007 Total FE drill centre				**0**	**0**	**0**
2007 Total Far East exploration well drill site				**106**	**88**	**1,038**
August 2006 to 2007 Total				**719**	**594**	**7,489**

Drill cuttings from the SBM hole sections are discharged overboard at 18 m below the waterline and allowed to freefall to the seafloor. Cuttings displaced to glory holes were transferred outside glory holes using a cuttings transfer system. The mass of base oil discharged on drill cuttings can be derived from reporting of SBM-on-cuttings, in keeping with the Offshore Waste Treatment Guidelines (NEB et al. 2002).

From August 2006 to September 2008, Suncor Energy reported cumulative SBM-on-cuttings discharges of 594 tonnes: 136 tonnes were discharged at the SW drill centre, 274 tonnes were discharged at the NE drill centre and 184 tonnes were released at the drill site for the exploration well I-66 (PF8). Since the beginning of drilling to September 2008, Suncor Energy reported cumulative SBM-on-cuttings discharges of 5,426 tonnes: 1,749 tonnes were discharged at the SW drill centre, 521 tonnes were discharged at the NW drill centre, 1,988 tonnes were discharged at the NE drill centre, 469 tonnes were released at the FE drill centre, 515 tonnes were released at the SE drill centre and 184 tonnes were released 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; KD-40; SAFE COR 220X; Hogwash; SAFE SURF E; Clean-up; biocide (X-Cide 102W); sodium hypochlorite; XCD polymer; caustic soda; calcium chloride; nutplug (i.e., walnut shells); and sodium sulphite. Seawater has been used recently as the base fluid during completions, replacing sodium chloride, calcium chloride and calcium bromide brines. In the instances where Clean-up is used as a component of water-based completion fluid, all of the return is captured and none is discharged to the marine environment.

Two wells were completed with water-based completion fluids from August 2006 to May 2007. No wells were completed with water-based completion fluid between May 2007 and September 2008, when EEM sampling was performed. One well was completed in the SW drill centre and one well was completed in the NE drill centre (see Table 4-3 for details).

Table 4-3 Discharges of Water-based Completion Fluid from August 2006 to May 2007

Year	Month	Well	Drill Centre	Discharges To Sea	
				Fluid Volume (m^3)	Dry Solids (kg)
2006	November	G-90 8 (F1)	NE	12,023	14,209
2006 Total NE drill centre				12,023	14,209
2006 Total NW drill centre				**0**	**0**
2006 Total SE drill centre				**0**	**0**
2006 Total SW drill centre				**0**	**0**
2007	May	L-98 6Z(D4)	SW	6,593	8,823
2007 Total NE drill centre				**0**	**0**
2007 Total NW drill centre				**0**	**0**
2007 Total SE drill centre				**0**	**0**
2007 Total SW drill centre				6,593	8,823
August 2006 to 2007 Total				**18,616**	**23,032**

Between August 2006 and September 2008, Suncor Energy reported cumulative water-based completion fluid discharges of 18,616 m^3. Of these, 6,593 m^3 were released at the SW drill centre and 12,023 m^3 were released at the NE drill centre. From the beginning of drilling to September 2008, Suncor Energy reported cumulative water-based completion fluid discharges of 42,053 $m^{3:}$ 11,844 m^3 were released at the SW drill centre, 22,848 m^3 were released at the NE drill centre, 2,636 m^3 were released at the SE drill centre and 4,725 m^3 were released at the NW drill centre.

4.3 PRODUCED WATER

The FPSO arrived at the Terra Nova oil field on August 4, 2001. Start-up of oil production occurred on January 20, 2002, with the opening of the HPE5 well from the SW drill centre at 1720 hours. Production was shut-down 11 times between August 2006 and September 2008. Shut-down periods are listed in Table 4-4.

Table 4-4 Production Shut-Down Periods from August 2006 to September 2008

Year	Shut-Down Interval
2006	June 17 to November 12
	December 12
2007	May 30 to June 5
	September 7
	October 12
	October 28 to 29
	December 2 to 4
2008	January 25
	May 1
	June 14 to 26
	September 19 to 20

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 contaminants resulting from exposure to the reservoir and the various drilling and production operations. The monthly average oil-in-water concentrations and volumes for produced water from August 2006 to September 2008 are provided in Table 4-5.

Table 4-5 Produced Water Discharges from August 2006 to September 2008

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
August 2006	0	0
September 2006	0	0
October 2006	0	0
November 2006	17.29	27,720
December 2006	21.82	141,753
January 2007	29.36	116,193
February 2007	28.47	153,006
March 2007	24.17	236,321
April 2007	25.81	192,541
May 2007	30.79	151,103
June 2007	24.74	201,043
July 2007	23.53	242,577
August 2007	25.99	290,841
September 2007	22.35	260,887
October 2007	31.85	179,808
November 2007	26.74	232,604
December 2007	19.48	162,795

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
January 2008	20.42	300,070
February 2008	18.89	242,733
March 2008	19.15	350,744
April 2008	21.34	349,018
May 2008	19.52	372,273
June 2008	29.18	158,779
July 2008	18.48	372,373
August 2008	24.41	368,275
September 2008	24.57	190,616
Overall Average	**19.61**	**190,371**

Note: - Average oil concentration is the average calculated over non-zero value (i.e., 0 values when no produced water is being released are excluded).

4.4 OTHER WASTE STREAMS

A number of other waste streams are regulated under the Offshore Waste Treatment Guidelines (NEB et al. 2002). 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 regulatory limits were:

1. *Bilge Water* – regulatory limit of 15 mg/L oil; and
2. *Deck/Drilling Area Drainage* – regulatory 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* from August 2006 to August 2007 was 451 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 regulatory limits are:

1. *Chlorinated Seawater* – regulatory limit of 2.0 mg/L; Suncor Energy targets a residual concentration of 0.5 to 0.7 mg/L;
2. *Bilge Water* – regulatory limit of 15 mg/L oil; and
3. *Deck Drainage* – regulatory 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 regulatory compliance. From August 2006 to

September 2008, Suncor Energy did not exceed its target chlorinated seawater discharge.

Bilge water and deck drainage for the FPSO are pumped to the slops tanks for settling and pass through an oil-in-water separator and analyzer before being discharged. The total volume of water discharged between August 2006 and September 2008 was 20,622 m^3.

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 2008 EEM program was conducted from September 5 to 17, 2008, using the offshore supply vessel *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 Petro-Canada (1998a, 2001, 2002, 2003, 2005, 2007). Sediment collection stations for the 2008 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

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 (SQT components; see Section 1).

Sediment samples collected for physical and chemical analysis, as well as for archive, were a composite from the top 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.

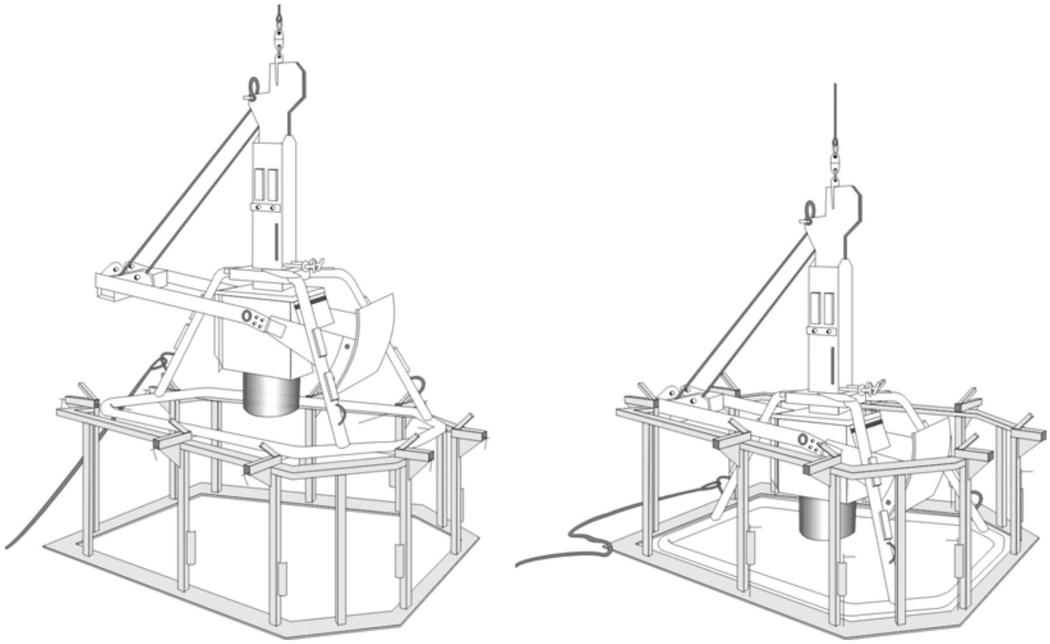

Figure 5-1 Sediment Corer Diagram

Figure 5-2 Sediment Corer

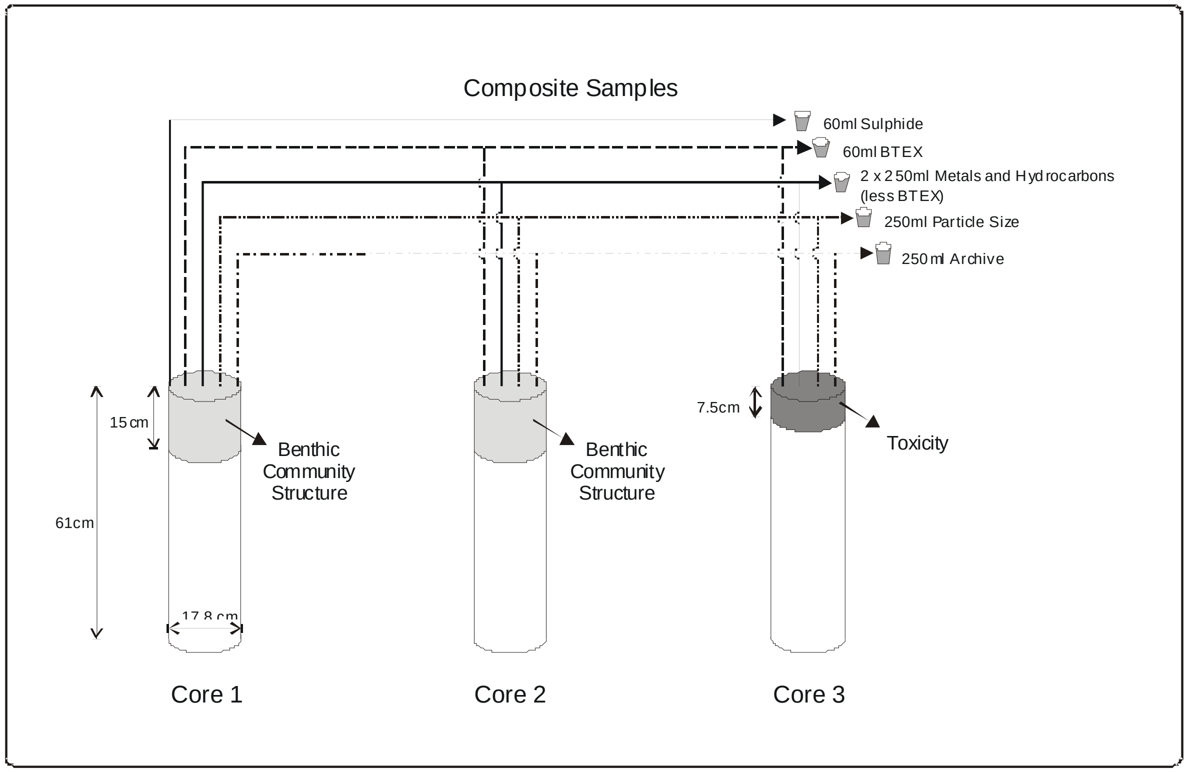

Figure 5-3 Allocation of Samples from Cores

Sediment chemistry field blanks composed of clean sediment obtained from Maxxam Analytics were collected for stations 9(SE), 12(SE) and 44(FEZ). Blank vials were opened as soon the core sampler from these three stations was brought on board the vessel and remained opened until chemistry samples from that station were processed. Blank vials were then sealed and stored with other chemistry samples. Field duplicates were collected for chemical analysis at stations 7(SE), 17(NE), 19(NW), 26(FE) and 44(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, HCs and metals (Tables 5-2 and 5-3). Particle size analysis was conducted by Jacques Whitford Stantec (JWSL) Limited in St. John's, Newfoundland and Labrador. HCs 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 2008)

Variable	Method	RDL						Units
		1997	2000 &2001	2002	2004	2006	2008	
HCs								
Benzene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	mg/kg
Xylenes	Calculated	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	mg/kg
>C_{10}-C_{21}	GC/FID	15	0.25	0.25	0.25	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	15	0.25	0.25	0.25	0.3	0.3	mg/kg
PAHs								
1-Chloronaphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Benz[*a*]anthracene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg

Variable	Method	RDL						Units
		1997	2000 &2001	2002	2004	2006	2008	
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg
Carbon								
Total Carbon	LECO	NA	0.1	0.1	0.2	0.2	0.2	g/kg
Total Organic Carbon	LECO	NA	0.1	0.1	0.2	0.2	0.2	g/kg
Total Inorganic Carbon	By Diff	NA	0.1	0.1	0.2	0.2	0.2	g/kg
Metals (Total)								
Aluminum	ICP-MS	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	5	5	2	2	2	mg/kg
Cadmium	GFAAS	0.3	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	20	20	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	5	2	2	2	2	mg/kg
Manganese	ICP-MS	2	2	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	2	2	5	5	5	mg/kg
Other								
Ammonia (as N)	COBAS	NA	NA	0.25	0.25	0.3	0.3	mg/kg
Sulphide	SM4500	NA	NA	20	2	0.2	0.2	mg/kg
Sulphur	LECO	NA	NA	0.03	0.02	0.002	0.01	%(w)
Moisture	Grav.	0.1	0.1	0.1	1	1	1	%

Notes:
- The RDL (Reportable Detection Limit) is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. RDLs 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 acronym EQL (Estimated Quantification Limit) was used in previous years instead of RDL. 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.
- 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} HCs from other years, values of $>C_{10}$-C_{13} and $>C_{13}$-C_{21} HCs for 2002 were added. Where values of $>C_{10}$-C_{13} HCs were less than RDL (0.25 mg/kg) and values of $>C_{13}$-C_{21} HCs were greater than RDL (0.25 mg/kg), values of $>C_{10}$-C_{13} HCs were set to zero.
- NA = Not Analyzed.

Within the HCs, 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}). HCs 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 HCs over the C_6-C_{32} range (see Appendix B-2). When complex HC 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.

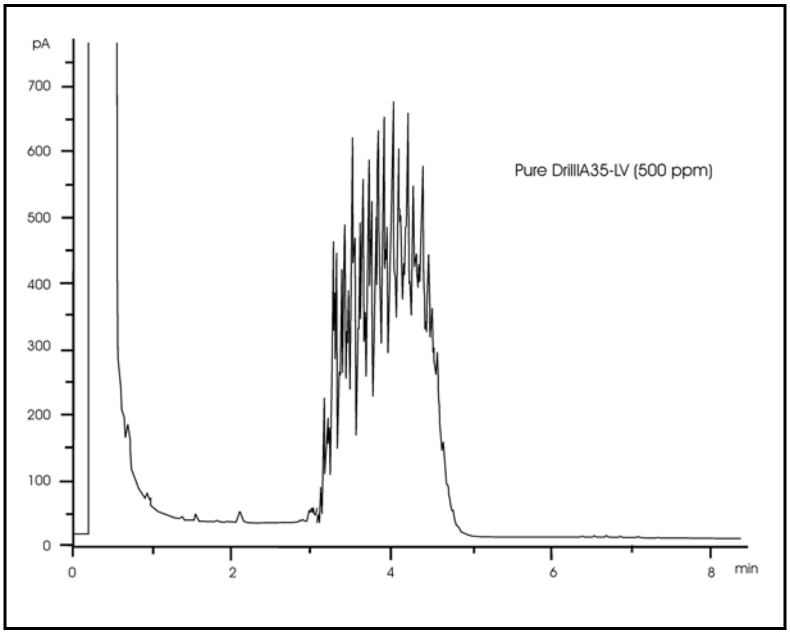

Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.2.2 TOXICITY

JWSL's Laboratory Division 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 10 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 by an ammonia ion selective probe and 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 and 2008 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 were processed within six weeks of sample collection, meeting the storage time requirement recommended by Environment Canada guidance (Environment Canada 1998, 2002).

5.2.2.1 Results Interpretation

The statistical endpoint for the amphipod toxicity test is the determination of whether the biological endpoint (percent survival) differs statistically from the control or reference sample, 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 (K. Doe, pers. comm.). 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.

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

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

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

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 2008 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,

[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).

with a suitable balance of flow in and out of the bucket, could be separated as well. Elutriation was continued until the water leaving the pail was free of organisms and when no additional heavier organisms could be seen after close examination of the sediment. Usually, larger organisms such as scallop and propeller clams were separated manually as they were found. Barnacles and sponges were scraped off rocks. With coarser sediments such as gravels, which were occasionally encountered, a 1.2-cm mesh in combination with the 0.5-mm screen was used to aid in separating the organisms.

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

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

Benthic invertebrate samples collected in 2001 and 2002 were processed (sieved and identified) by Pat Stewart of Envirosphere Ltd. Identification of invertebrates was performed by Pat Stewart of Envirosphere Ltd in 2000. Arenicola Marine Limited identified invertebrates in 1997 and sieved and identified samples in 2004, 2006 and 2008. 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 Petro-Canada 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 (primarily drilling and deposition of drill cuttings)?

This is the attenuation with distance from the drill centres hypothesis, a regression approach. The *Y* variables analyzed were sediment quality values in individual years and changes in those values over time. The *X* 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 SQT 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, are used as *X*.

5.3.1.1 Analysis of 2008 Data

For the 2008 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} HCs (major constituents of SBMs) and barium (a major constituent of WBMs and SBMs). 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 was a qualitative and/or non-parametric comparison of distance gradients and overall *Y* variable values among years. These comparisons were based on all stations sampled in each year. The second component consisted of parametric comparisons of distance gradients among EEM years based on the Repeated Measures (RM) regression model described in Appendix B-4 and the subset of 48 stations (RM stations) sampled in each EEM 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 2008, 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 in the first EEM year (2000).

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 RM regression model described in Appendix B-4 requires that the same stations be re-sampled over time. Past RM analyses (e.g., Petro-Canada 2007) have focused on the 33 stations sampled in all years, including 1997, when possible. However, those analyses excluded 15 other stations sampled in every EEM year,

[9] For EEM years, a drill centre is considered active if drilling has occurred at any time at that drill centre, even though drilling may not have occurred since the last EEM sampling period (2006).

and could not be conducted on variables that were not measured in 1997, or on variables that were not directly comparable between 1997 and EEM years (e.g., benthic invertebrate community variables; see Section 5.3.4). Therefore, in this report, RM analyses were restricted to comparisons among EEM years based on the 48 stations sampled every EEM year. 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. The results of past comparisons to baseline (Petro-Canada 2001, 2002, 2003, 2005, 2007) also would not change with the addition of a sixth EEM year (2008) unless results were unusual for that year, which would be detectable in comparisons of the six EEM years.

Analyses for some variables were conducted with and without stations 30(FE) and 31(FE), located at 0.14 and 0.37 km from the FE drill centre, respectively. These two stations were closer to a drill centre than other stations and represented extreme 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.

Multiple regression slopes for *Y* variables versus FEZ *d* and FE *d* were calculated for each EEM year based on the stations included in RM 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).

5.3.1.3 Other Issues

Analyses were conducted using SYSTAT Version 11 statistical software and Microsoft Excel 2002. All log-transformations were $\log_{10}$ rather than natural logs (ln or $\log_e$). Values less than RDL were set at ½ RDL for parametric analyses, or non-parametric analyses (which treat values less than RDL as tied for the lowest rank) were used.

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 two-fold) differences over space or time.

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} HCs and barium);
2. particle size (% fines, sand and gravel) and total organic carbon (TOC);
3. metals other than barium; and
4. other variables (sulphur, sulphide, ammonia, redox).

As noted in Section 5.3.1, >C_{10}-C_{21} HCs are major constituents of SBMs and barium is a major constituent of WBMs and SBMs. Barium occurs naturally in marine sediments at concentrations well above RDL, so low-level elevation of barium from deposition of drill cuttings can be difficult to detect.

Most variables in the other three subgroups could potentially be altered by project activities. However, background levels were often high or natural processes can measurably affect values, both of which make project-related alterations difficult to detect.

Deposition of fine drill cuttings and HCs from SBMs could elevate fines and TOC content in sediments. Organic carbon, regardless of source, is typically associated with finer particles, as are metals and synthetic HCs. Fine organic particles are a food source for deposit- and filter-feeding invertebrates. Elevated fines levels can negatively affect toxicity test organisms (amphipods and bacteria) used in this study.

In general, 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 concentration that might be expected in the absence of drilling.

Sulphur (in barium sulphate) is a major constituent of WBMs and SBMs, and could be considered a secondary drilling mud indicator. However, background sulphur levels are greater than background barium levels and these levels are affected by many natural factors. Sulphides are naturally present in marine sediments and may be produced from sulphate or from biodegradation of natural and synthetic organic compounds under reducing conditions. High ammonia concentrations could occur as a result of breakdown of HCs originating from project activities, but would also occur wherever natural decomposition occurs. Decomposition would also reduce redox levels. High sulphide and ammonia levels and low redox levels can have negative effects on toxicity test organisms and invertebrate communities.

5.3.2.2 Statistical Analysis

Statistical analysis of sediment physical and chemical variables generally followed the basic analyses outlined in Section 5.3.1, with some modifications and extensions.

Analysis of 2008 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[10]) was used to develop multivariate summary measures of metals concentrations and mixtures (Metals PCs), and then to derive a summary measure of sediment type (Sediment PC1) based on physical and chemical characteristics excluding $>C_{10}$-C_{21} HCs and barium.

In 2008 and past years, aluminum, iron, lead, manganese, strontium and vanadium were detected in every sample. Chromium was detected in all samples prior to 2006, in all samples in 2008 and in 51 of 53 samples in 2006. PCA was also used to assess relationships among concentrations of these seven metals and to derive two summary measures (Metals PC1 and PC2) used for further analyses (e.g., to derive Sediment PC1). The metals PCA was based on log-transformed concentrations, with ½ RDL used for the two chromium concentrations less than RDL (2 mg/kg). All 363 samples collected from 1997 to 2008 were included, so that the Metals PC could be used for a broad range of analyses of various subsets of the data.

For 2008, 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

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[10] 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 sediment 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 2008, but at concentrations at or barely above RDL (i.e., variance was minimal). Zinc was detected in all samples prior to 2004, when a lower RDL of 2 mg/kg was used, but was only detected in 30 of 52 samples in 2004, 12 of 53 samples in 2006 and 44 of 53 samples in 2008, when a higher RDL (5 mg/kg) was used.

Bivariate correlations among the physical and chemical characteristics (excluding >C_{10}-C_{21} HCs and barium) were almost all positive, so PCA was used to assess overall relationships among those variables and derive a summary measure of "sediment type" (Sediment PC1). Rank correlations were then calculated between Sediment PC1 and the variables used to derive that PC versus >C_{10}-C_{21} HCs and barium.

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} HCs, barium, Sediment PC1 and sulphide. Distances and >C_{10}-C_{21} HC, barium and sulphide concentrations were log-transformed.

Comparison Among Years

>C_{10}-C_{21} HCs, barium, fines, gravel, TOC, Metals PC1 and PC2, ammonia, sulphur 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 RM regression analyses of EEM years). RM regression analyses were conducted with and without stations 30(FE) and 31(FE) included. Multiple regression distance slopes for 1997 were also calculated based on the RM stations sampled in that year for qualitative comparison to regression slopes for EEM years. Parametric threshold hockey-stick distance models for >C_{10}-C_{21} HCs and barium were also compared among years using all stations sampled in each year. Distances, barium, >C_{10}-C_{21} HCs, fines, gravel, TOC, ammonia and redox were log-transformed for RM and hockey-stick regression analyses.

>C_{10}-C_{21} HCs were not detected in 1997 when a higher RDL (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 HCs. Prior to 2006, RDLs for >C_{10}-C_{21} HCs were reported as 0.25 mg/kg. In 2006 and 2008, RDLs 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} HC concentrations less than RDL in EEM years were set at 0.15 mg/kg (½ the

recent RDL). 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.

Ammonia was not measured in 1997 and 2000, so analyses were restricted to 2001 and subsequent years. One ammonia concentration less than 0.31 mg N/kg from 2001 was set at ½ RDL. Sulphur has been measured since 2001, but RDLs have varied over time (Table 5-3). Therefore, parametric RM 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 RDL 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 RDL of 0.03% (from 2001 and 2002) were set at ½ of that RDL (0.015%), even if they were greater than lower RDL achieved from 2004 to 2008 (0.002% to 0.2%). Redox was only measured at a subset of 29 stations in 1997, so all analyses were restricted to EEM years.

5.3.3 TOXICITY

Microtox IC50s and amphipod survival were analyzed using the basic methods provided in Section 5.3.1. For analyses of 2008 data, rank correlations were calculated between the response variables and between these variables and sediment physical and chemical variables. Distance regressions were calculated based on rank-transformed IC50s, amphipod survival and distance values.

Amphipod survival was not compared among years because survival has been uniformly high, most samples were non-toxic and distance gradients were weak or non-existent.

Two benchmarks were used for qualitative comparisons of Microtox IC50s among years because classification of samples as toxic based on recent 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 2008[11]. 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 was the average of the four other IC50s between 98,500 and 197,000 mg wet/L, or 139,325 mg wet/L.

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 2008 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 Petro-Canada 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 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.

[11] 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).

Meiofauna, including nematodes, nemerteans, oligochaetes, archiannelid polychaetes (mostly Family Protodrilidae), ostracods and copepods, were excluded from calculation of all variables except standing crop. These small organisms are poorly recovered with the 0.5 cm sieve used but were not removed before all recovered invertebrates in samples were weighed to estimate standing crop. The contribution to overall standing crop 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. standing crop or 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 298 Elutriate samples from the six 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 median and mean 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. In past reports, Simpson’s diversity (*D*) and evenness *(E),* which are also measures of richness relative to abundance, were analyzed. Appendix B-4 provides the rationale for using adjusted richness instead. Appendix B-4 also provides *S*-*N* regression relationships for Elutriate samples, as well as a comparison of adjusted richness values to values of Simpson’s *D* and *E*.

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 2008 (*n* = 298 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 added 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. Appendix B-4 provides selected results for other sub-dominant taxa.

5.3.4.2 Statistical Analysis

Analysis of 2008 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 (RM) 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. Distance correlations were calculated for selected variables for 1997 baseline samples processed using the Wash recovery method for qualitative comparison to distance correlations in EEM years.

RM regression analyses were restricted to the 47 stations sampled in every year from 2001 to 2008, with all samples processed using the Elutriate recovery method. The RM regression analyses excluded station 30(FE), 0.17 km from the FE drill centre, which was sampled every EEM year but was often an outlier that did not fit distance regressions for the other 47 stations. Past analyses have included the Elutriate samples from 2000, but that restricted analyses to 37 stations. Petro-Canada (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 for 2001 to 2008.

For the RM analyses, distances and total abundance were log-transformed. The original adjusted richness values, or residuals from the log-log S-N regression, were analyzed, which is effectively a log transformation of the back-transformed values reported in most tables and figures.

5.3.5 INTEGRATED ASSESSMENT

For 2008, correlations among toxicity test responses, benthic invertebrate community variables and sediment physical and chemical characteristics were examined as part of the analyses described above. The integrated assessment extended that approach to examine multi-year relationships between:

1. Microtox toxicity test responses versus $>C_{10}$-C_{21} HCs and other selected sediment physical and chemical characteristics;
2. benthic invertebrate community variables versus $>C_{10}$-C_{21} HCs and other selected sediment physical and chemical characteristics; and

3. Microtox toxicity test responses versus benthic invertebrate community variables.

Statistical analyses were restricted to EEM years and, for invertebrate community variables, to samples processed using the Elutriate recovery method.

General methods used were:

1. calculation, testing and summary of bivariate Spearman rank correlations (r_s) among toxicity test, invertebrate community and selected sediment physical and chemical variables within each EEM year (i.e., as for 2008); and
2. statistical comparison of those correlations among years and calculation and testing of correlations over all EEM years as outlined in Appendix B-4.

In bivariate plots provided in figures, Locally Weighted Scatter-Plot Smoothing (LOWESS) trend lines were used to describe relationships between variables. Hirsch et al. (1994) provide details on LOWESS trend lines.

$>C_{10}$-C_{21} HCs rather than barium was the drilling mud constituent used to assess potential project-related effects on biological responses (i.e., laboratory toxicity test and field invertebrate community variables). $>C_{10}$-C_{21} HC concentrations varied over a wide range and any concentrations greater than the recent RDL of 0.3 mg/kg can reasonably be considered evidence of contamination from drill cuttings discharges. In contrast, except for relatively few elevated concentrations near drill centres, variance of barium concentrations was mostly natural over a more limited range.

Other sediment physical and chemical characteristics included in integrated assessments were variables strongly correlated with toxicity test and invertebrate community responses in most or all EEM years. Effects of these other variables, which were largely unaffected by project activity, were presumably natural.

Microtox IC50s were the only toxicity test responses analyzed, since amphipod survival in toxicity tests has generally been high, with little evidence that variance in survival was related to either project activities or most sediment quality variables. Rank correlations between IC50s and “toxicity” (i.e., with samples with IC50s greater than 50,000 mg wet/L scored as 0 (Non-toxic) and samples with IC50s less than 50,000 mg wet/L scored as 1 (Toxic)) versus $>C_{10}$-C_{21} HCs and other sediment physical and chemical characteristics were calculated and tested. Parametric logistic regressions were used to examine relationships between frequencies/probabilities of toxicity versus various physical and chemical *X* variables. Appendix B-4 provides detailed methods and results for logistic regression, analogous to standard linear regression but with *Y* values (i.e., probabilities or frequencies of toxicity) constrained to lie within the 0% to 100% range.

5.4 RESULTS

5.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Summary statistics for sediment physical and chemical characteristics from 1997 to 2008 are provided in Appendix B-2. Only those metals and organic compounds with at least one value above RDL are reported. Table 5-3 reports all measured metals and organic compounds in each year. Raw data for 2008 are also provided in Appendix B-2.

$>C_{10}$-C_{21} HC concentrations have increased since 2000. Baseline (1997) data cannot be compared to subsequent years because RDLs in 1997 (15 mg/kg) were much higher than RDLs in other years (0.25 or 0.3 mg/kg). Median $>C_{10}$-C_{21} HC concentrations across all stations increased from 0.67 mg/kg in 2000 to 4.30 mg/kg in 2006, and were 1.40 mg/kg in 2008 (Appendix B-2). The maximum $>C_{10}$-C_{21} HC concentration (6,550 mg/kg) over all years occurred in 2004 at station 30(FE), located 0.14 km from the FE drill centre. The maximum concentrations in 2002 (925 mg/kg), 2006 (980 mg/kg) and 2008 (340 mg/kg) also occurred at station 30(FE). In 2008, as in previous years, concentrations decreased rapidly with distance from drill centres, especially the FE drill centre (Figure 5-6). All chromatograms for stations with HC concentrations above RDL (47 of 53 stations in 2008) showed a UCM in the range of PureDrill IA35-LV (Appendix B-2).

In 2008 and previous years, concentrations of $>C_{21}$-C_{32} HCs above RDL were recorded at many stations where $>C_{10}$-C_{21} HC concentrations were high, but this was because of a laboratory artefact called tailing (where high $>C_{10}$-C_{21} HC levels result in measurable levels in the $>C_{21}$-C_{32} range, even if levels of the latter HCs are not elevated) (J. Kiceniuk, pers. comm., Maxxam Analytics, pers. comm.). Based on interpretation of chromatograms, $>C_{21}$-C_{32} HCs were present only in trace amounts (Appendix B-2; J. Kiceniuk, pers. comm.).

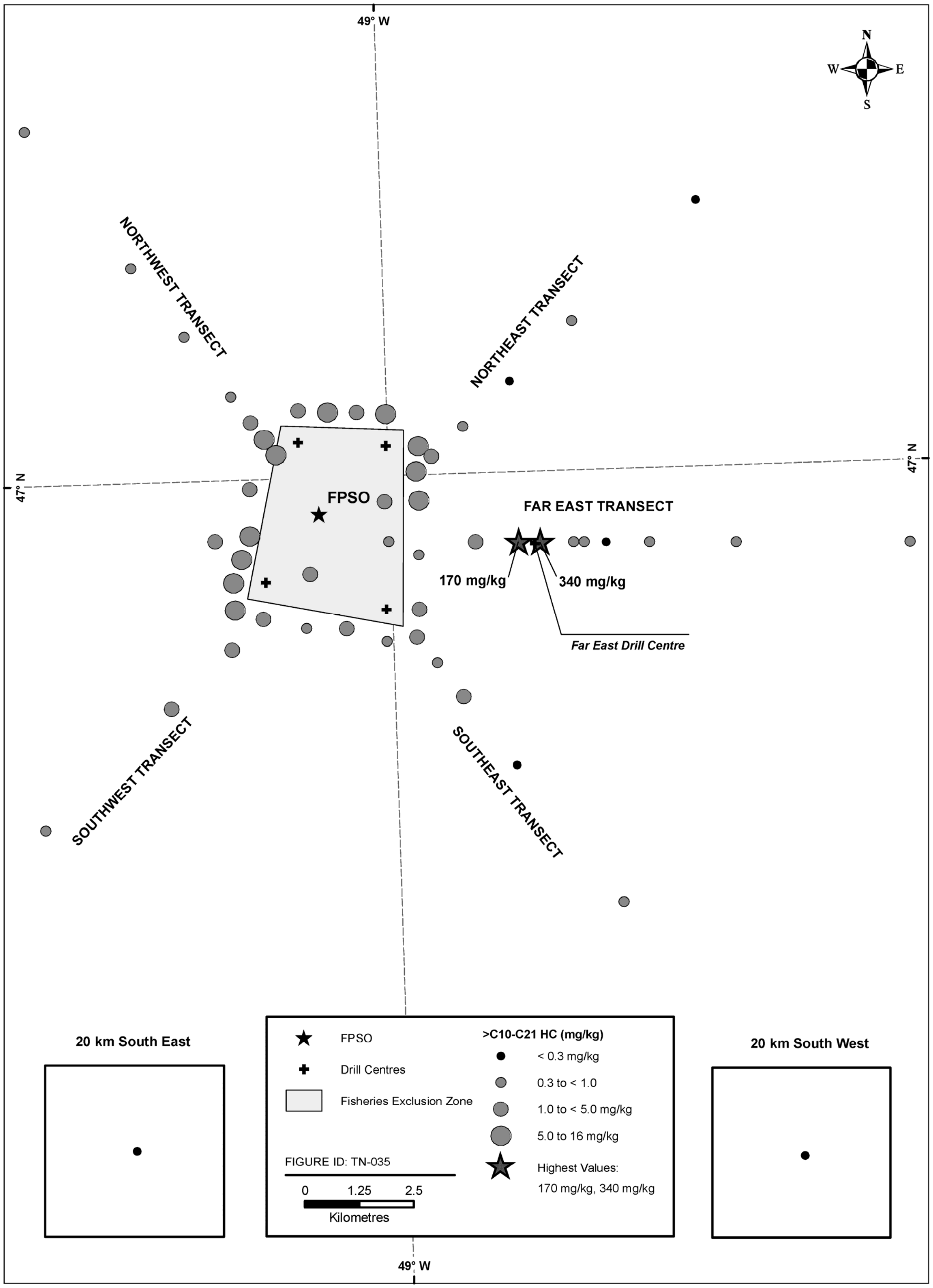

Figure 5-6 Spatial Distribution of >C_{10}-C_{21} HCs (2008)

Median barium concentrations increased after drilling began from 120 mg/kg in 1997 to 130 to 170 mg/kg from 2000 to 2008. (Appendix B-2). Maximum levels from 2002 to 2008 (all greater than 2,000 mg/kg) occurred at station 30(FE), located 0.14 km from the FE drill centre. In 2008, many barium concentrations within 2 km of the FEZ drill centres were also elevated (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 (1997) 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 2008, and for barium as well as for $>C_{10}$-C_{21} HCs, 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).

Low level PAHs were detected at two stations located less than 1 km from a drill centre in 2008. Dibenz(a,h)anthracene (0.12 mg/kg) and Indeno(1,2,3-cd) pyrene (0.07 mg/kg) were detected at station 29(FE). Fluoranthene (0.14 mg/kg), fluorene (0.07 mg/kg), naphthalene (0.42 mg/kg), phenanthrene (0.22 mg/kg) and pyrene (0.09 mg/kg) were detected at station 44(FEZ) (Appendix B-2).

A more detailed analysis of physical and chemical characteristics follows.

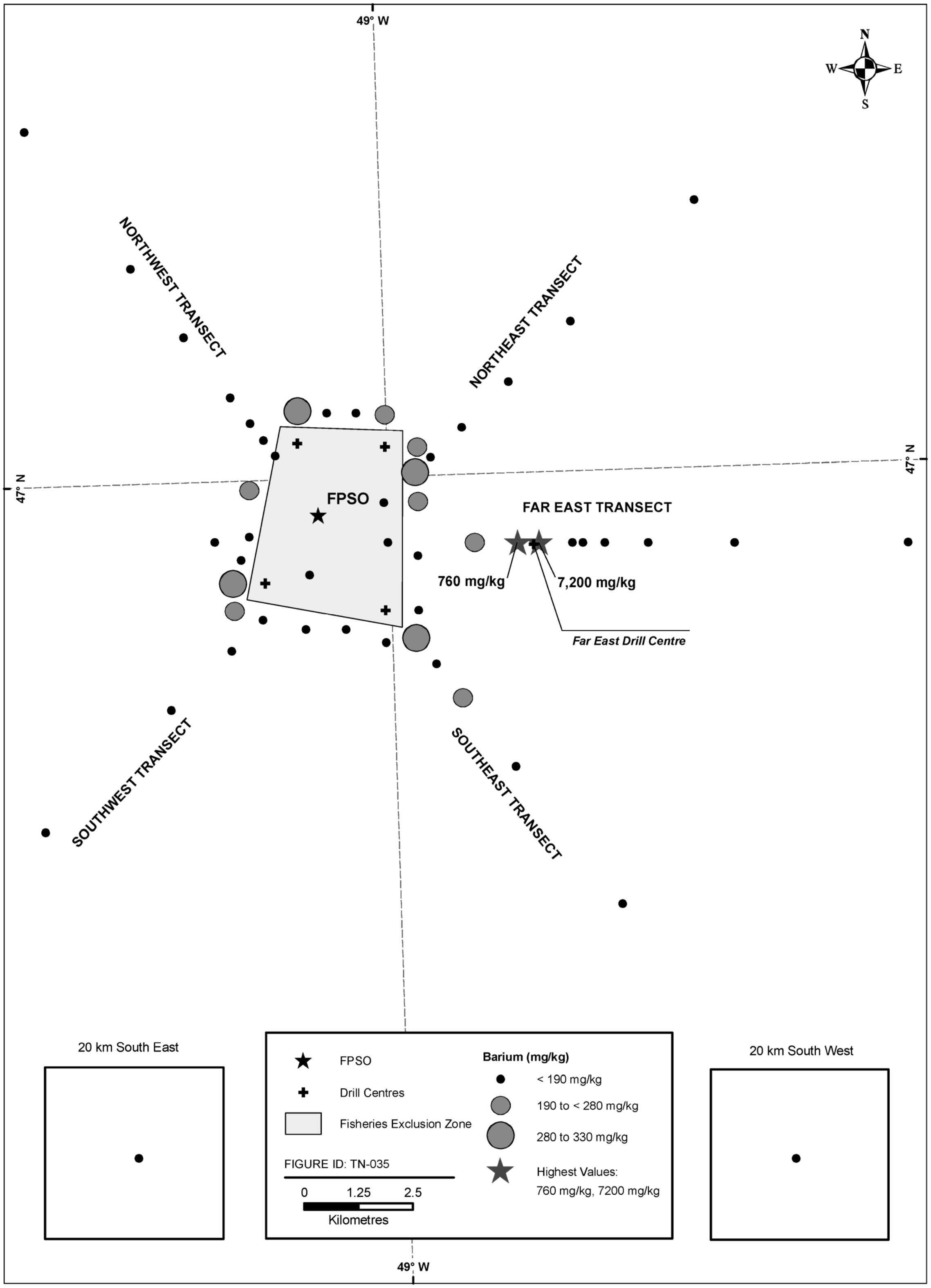

Figure 5-7 Spatial Distribution of Barium (2008)

5.4.1.1 Analysis of 2008 Data

HCs and Barium

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

Table 5-4 Spearman Rank Correlations (r_s) Between >C_{10}-C_{21} HCs, >C_{21}-C_{32} HCs and Barium (2008)

	>C_{10}-C_{21} HCs	**>C_{21}-C_{32} HCs**
>C_{21}-C_{32} HCs	**0.768*** **	
Barium	**0.826*** **	**0.693*** **

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

Other Sediment Physical and Chemical Characteristics

Sediments in the study area were predominantly sand, with mean and median % sand approximately 90% for the 53 samples collected in 2008 (Appendix B-2; Figure 5-8). Fines content was low (0.5% to 7%; median = 1%). Silt and clay contents were less than 1% in most samples (Appendix B-2; Figure 5-8). Therefore, there were no areas dominated by finer particles, such as one might find in harbours and other near-shore sites. Gravel content varied widely, from 0% to approximately 30% (Appendix B-2; Figure 5-8)[12].

[12] 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.

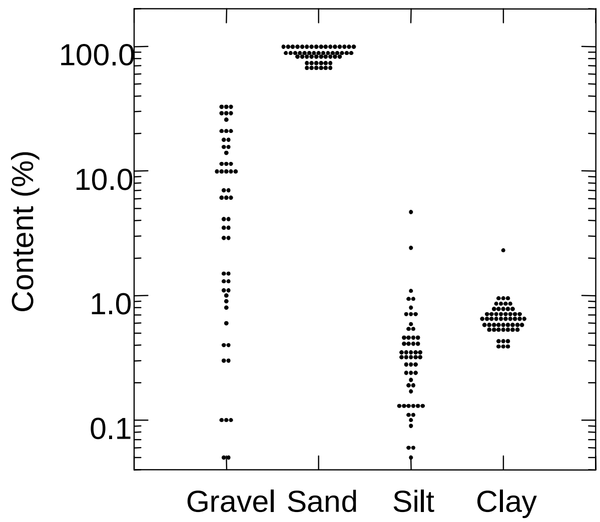

Figure 5-8 Distribution of Values for Four Particle Size Categories (2008)

Sand and gravel content were strongly negatively correlated because gravel was the major "non-sand" component of the sediments (Table 5-5). Gravel content (% gravel) was approximately 100 minus % sand, so correlations between % gravel and other variables were the inverse of correlations between those variables and % sand. Because of these correlations, sand content was not included in further analyses. In 2008, fines content and gravel content were uncorrelated. In past years, fines content and gravel content have generally been positively correlated (Petro-Canada 2007), suggesting that finer particles were deposited in interstitial spaces of sediments with a higher gravel content. In 2008, sediment TOC content was low, ranging from 0.3 to 1.3 g/kg (0.03% to 0.13%) (Appendix B-2). TOC content was significantly positively correlated with fines and gravel content and significantly negatively correlated with sand content (Table 5-5).

Table 5-5 Spearman Rank Correlations (r_s) Among Sediment Particle Size Categories and Total Organic Carbon Content (2008)

	% fines	% sand	% gravel
% sand	–0.146		
% gravel	0.078	**–0.991*** **	
TOC	**0.505*** **	**–0.527*** **	**0.485*** **

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

Concentrations of aluminum, chromium, iron, lead, manganese, strontium and vanadium from the 363 samples collected from 1997 to 2008 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 61% 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 iron concentrations and negatively correlated with manganese and lead concentrations. Metals PC2 scores reflect differences independent of the general positive correlation among concentrations of all metals. Higher PC2 scores indicate higher strontium levels (and to a lesser extent, aluminum and lead) relative to manganese and iron.

Table 5-6 Correlations Between Metal Concentrations in Sediments and Principal Components Derived from those Concentrations (1997 to 2008)

Metal	Correlation (*r*) with:	
	Metals PC1	Metals PC2
Aluminum	**0.800**	0.386
Chromium	**0.747**	–0.159
Iron	**0.849**	–0.461
Lead	**0.798**	0.398
Manganese	**0.697**	**–0.655**
Strontium	**0.629**	**0.556**
Vanadium	**0.911**	–0.011
% variance	60.9	18.3

Notes: - $|r| \geq 0.5$ in **bold.**
- Concentrations were log-transformed prior to deriving PC.
- n = 363 stations; 54 in 1997, 49 in 2000 and 2001, 53 in 2002, 52 in 2004 and 53 in 2006 and 2008.

Concentrations of uranium and zinc, the only other metals frequently detected in 2008 samples, were positively correlated with Metals PC1 (Table 5-7), despite the limited variance and presence of many values near or below RDL. Therefore, the general tendency for metal concentrations to co-vary extended beyond the seven metals used to derive Metals PC1.

Table 5-7 Spearman Rank Correlations (r_s) Between Metals Principal Components and Concentrations of Uranium and Zinc (2008)

Metal	No. Values <RDL (of 53)	Correlation (r_s) with:	
		Metals PC1	Metals PC2
Uranium	0	**0.574*** **	0.126
Zinc	9	**0.711*** **	–0.036

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

In 2008, all bivariate rank correlations among fines and gravel content, TOC, Metals PC1 and PC2, sulphur, sulphide and ammonia were positive, with 21 of the 28 correlations significant at $p \leq 0.05$ (Appendix B-4). Redox was not significantly correlated with any other variable. The first PC (Sediment PC1) derived from rank-transformed values of these variables accounted for 38% of the total variance among samples and was positively correlated (all $r > 0.5$) with all variables except redox (Table 5-8). Therefore, higher Sediment PC1 scores indicated less sandy sediments with higher fines, gravel, TOC, metal, sulphur, sulphide and ammonia levels (i.e., more heterogeneous and probably more chemically and biologically active sediments).

Table 5-8 Correlations Between Sediment Physical and Chemical Characteristics and Principal Components Derived from those Variables (2008)

Variable	Correlation (r) with:		
	Sediment PC1	Sediment PC2	Sediment PC3
% fines	**0.594**	0.045	**0.524**
% gravel	**0.640**	0.183	–0.466
TOC	**0.861**	0.030	0.044
Metals PC1	**0.599**	–0.430	–0.386
Metals PC2	**0.669**	0.467	0.242
Sulphur	**0.582**	–0.301	0.205
Sulphide	**0.674**	–0.101	0.243
Ammonia	**0.534**	0.228	**–0.502**
Redox	–0.132	**0.781**	–0.023
% variance	37.8	13.4	11.7

Notes: - $|r| \geq 0.5$ in **bold.**
- Variable values were rank-transformed prior to deriving PCs.

Sediment PC2 accounted for 13% of total variance and sediment PC3 accounted for 12% of total variance (Table 5-8). Sediment PC2 was strongly positively correlated with redox, the only variable uncorrelated with Sediment PC1. Sediment PC3 was positively correlated with fines content and negatively correlated with gravel content and ammonia concentrations. Sediment PC2 and PC3 were not analyzed further, because they would add little to analyses of individual variables correlated with those two PCs.

Table 5-9 provides correlations between $>C_{10}$-C_{21} HCs and barium and other sediment physical and chemical characteristics for the 53 stations sampled in 2008. Sediment PC1 was positively and highly significantly ($p < 0.001$) correlated with both $>C_{10}$-C_{21} HCs and barium. Except for redox, individual variables were also positively correlated with $>C_{10}$-C_{21} HCs and barium, although correlations were usually weaker and less significant than correlations with Sediment PC1.

Table 5-9 Spearman Rank Correlations (r_s) Between C_{10}-C_{21} HCs and Barium and Other Sediment Physical and Chemical Characteristics (2008)

Variable	>C_{10}-C_{21} HCs	Barium
Sediment PC1	**0.564*** **	**0.713*** **
% fines	0.244	0.341*
% gravel	0.288*	**0.504*** **
TOC	**0.590*** **	**0.617*** **
Metals PC1	0.355*	**0.627*** **
Metals PC2	0.341*	**0.462*** **
Sulphur	0.201	0.270
Sulphide	**0.504*** **	**0.574*** **
Ammonia	0.201	0.373**
Redox	0.013	–0.055

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

The positive and often significant correlations between other sediment variables and >C_{10}-C_{21} HCs and barium in Table 5-9 should be considered partly natural, reflecting the general and natural tendency, also observed in baseline, for most sediment variables values to be higher near the centre of the Terra Nova development (see Section 5.4.1.2).

Distance Relationships

Based on rank-rank regressions, >C_{10}-C_{21} HC and barium concentrations decreased significantly with distance from drill centres, primarily the FEZ drill centres (Table 5-10). Rank transformation reduced the influence of stations 30(FE) and 31(FE), which represent extreme *Y* (>C_{10}-C_{21} HCs and barium) and *X* (distance) values. These two stations had a greater influence on parametric regressions (see below). For >C_{10}-C_{21} HCs and barium (and several other variables), r_s for regressions on distance from the nearest drill centre (Min *d*) were greater than *R* for multiple regressions on distances from the FEZ and FE drill centres. Therefore, a single distance measure (Min *d*) was usually the best predictor of >C_{10}-C_{21} HCs and barium.

Table 5-10 Results of Rank-Rank Regressions of Selected Sediment Physical and Chemical Variables (Y) on Distance (X) Variables (2008)

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	Partial *r*: *Y*-FE *d*/ FEZ *d* constant	
>C_{10}-C_{21} HCs	**0.736*** **	**–0.721*** **	–0.095	**–0.786*** **
Barium	**0.601*** **	**–0.555*** **	–0.202	**–0.683*** **
Sediment PC1	0.327	–0.321*	0.000	–0.361**
Fines	0.208	–0.204	–0.002	–0.258
Gravel	0.136	–0.096	–0.076	–0.138
TOC	0.422**	–0.406**	0.218	–0.309*
Metals PC1	0.207	–0.094	–0.164	–0.254
Metals PC2	0.319	–0.163	–0.246	–0.273*
Sulphur	0.332	–0.251	0.274*	–0.107
Sulphide	0.460**	–0.238	–0.370**	–0.450**
Ammonia	0.150	–0.119	0.115	–0.003
Redox	0.198	–0.105	0.187	0.002

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

For all 53 stations, adding a threshold in a hockey-stick model of >C_{10}-C_{21} HC concentrations versus distance to the nearest drill centre significantly ($p < 0.001$) reduced error variance relative to a bivariate regression (Table 5-11; the fitted line in the upper left plot in Figure 5-9 is the hockey-stick model). The estimated threshold distance (zone of influence) was 2.5 km, with a 95% Confidence Interval (CI) of 1.8 to 3.5 km. Adding a threshold also significantly ($p < 0.001$) reduced error variance for barium distance relationships. The estimated threshold distance for barium was 1.0 km, with a 95% CI of 0.9 to 1.2 km.

Table 5-11 Results of Parametric Distance Regressions for >C_{10}-C_{21} HCs, Barium and Sulphide (2008)

Result/Estimate	>C_{10}-C_{21} HCs		Barium		Sulphide
	All stations	30(FE), 31(FE) excluded	All stations	30(FE), 31(FE) excluded	All stations
r for bivariate regression	**0.782*** **	**0.733*** **	**0.631*** **	**0.582*** **	**0.560*** **
R for hockey-stick model	**0.833*** **	**0.753*** **	**0.868*** **	**0.614*** **	**0.631*** **
p for adding threshold (X_T)	**<0.001**	0.075	**<0.001**	0.089	0.010
antilog *a* (blade/background *Y* value; mg/kg)	0.36	0.34	128	105	0.49

Result/Estimate	$>C_{10}$-C_{21} HCs		Barium		Sulphide
	All stations	30(FE), 31(FE) excluded	All stations	30(FE), 31(FE) excluded	All stations
95% CI	0.23 to 0.59	0.20 to 0.58	114 to 144	88 to 125	0.36 to 0.67
b (slope of shaft)	–2.4	–1.8	–1.8	–0.3	–2.1
95% CI	–3.0 to – 1.7	–2.6 to –1.1	–2.2 to –1.5	–0.5 to –0.1	–3.0 to –1.2
antilog X_T (threshold distance; km)	2.5	3.2	1.0	4.3	1.1
95 % CI	1.8 to 3.5	1.9 to 5.5	0.9 to 1.2	1.7 to 11.1	0.8 to 1.4

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.

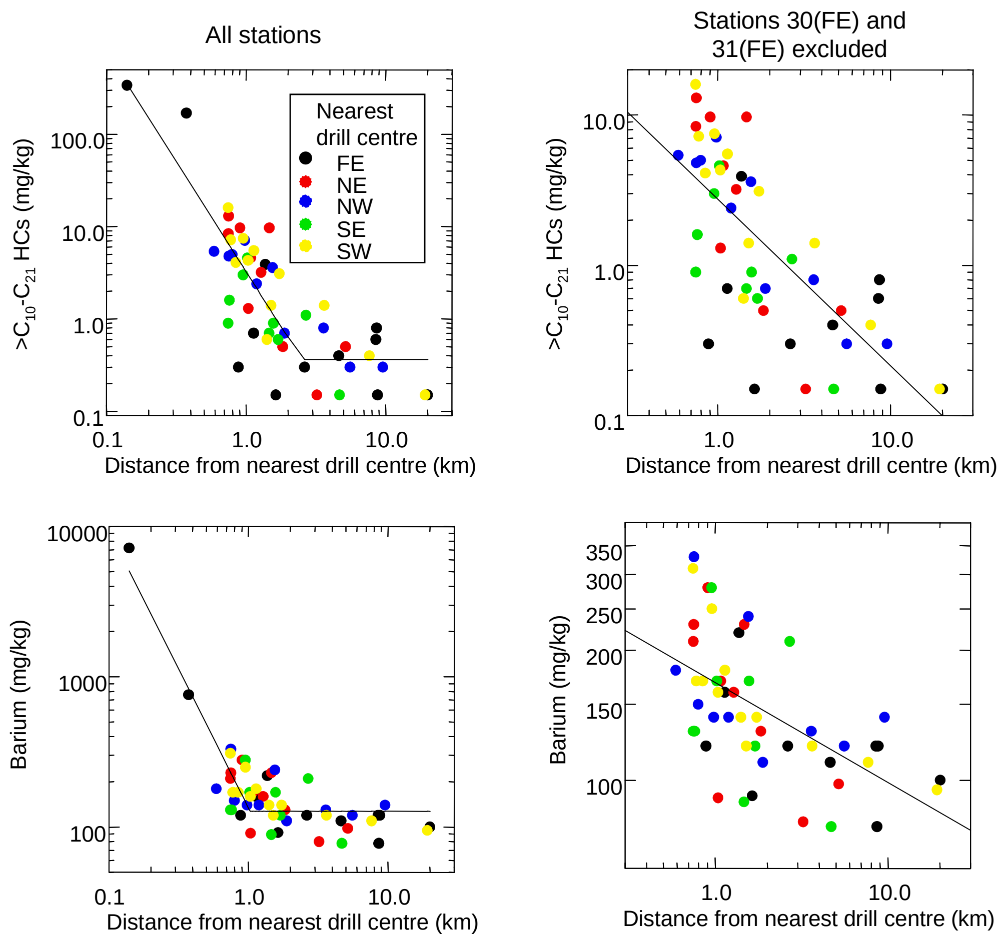

Figure 5-9 Distance Gradients for $>C_{10}$-C_{21} HCs and Barium (2008)

For >C_{10}-C_{21} HCs and barium, adding a threshold distance significantly and substantially 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 for these two variables provided only marginally significant ($0.05 < p < 0.10$) reductions in error variances (Table 5-11). The fitted lines provided in Figure 5-9 (right plots) are the bivariate regressions.

For >C_{10}-C_{21} HCs, excluding stations 30(FE) and 31(FE) increased the estimated threshold distance from 2.5 to 3.2 km, and its lower 95% Confidence Limit (CL) from 1.8 to 1.9 km (Table 5-11). These are minor differences, given the width and overlap of 95% CI for threshold distances in Table 5-11. Therefore, approximately 3 km would be a reasonable estimate of the zone of influence for >C_{10}-C_{21} HCs in 2008, which coincides with the distance beyond which all but one of 14 concentrations were below 1 mg/kg[13] (Figure 5-9).

With all stations included, the estimated zone of influence of 1.0 km for barium is a reasonable estimate of the distance at which concentrations in 2008 approached or were within the baseline (1997) range. The estimated background level for 2008 was 128 mg/kg (Table 5-11), similar to the 1997 median of 130 mg/kg. In 2008, only 4 of the 15 concentrations exceeding the baseline 90th percentile of 190 mg/kg occurred at distances greater than 1 km from the nearest drill centre.

With most barium concentrations at stations other than 30(FE) and 31(FE) near or within the baseline range, estimating a zone of influence with those two stations excluded was not useful. The estimated threshold distance was 4.3 km, but the 95% CI of 1.7 to 11.1 km were wide and included most of the distance range sampled (Table 5-11). These 95% CI also excluded the 95% CI (0.9 to 1.2 km) estimated with stations 30(FE) and 31(FE) included, and the estimated background or blade level of 105 mg/kg was less than the baseline 20th percentile of 110 mg/kg (i.e., more than 80% of baseline concentrations exceeded 105 mg/kg).

[13] If background >C_{10}-C_{21} HC concentrations are assumed to be less than RDL, then the hockey-stick models underestimate the extent of the zone of influence. Background concentrations estimated for >C_{10}-C_{21} HCs by the hockey-stick models were approximately 0.3 mg/kg. The RDL is 0.3 mg/kg. Therefore, thresholds were distances at which concentrations approached or reached RDL, and estimated background concentrations are effectively an average of concentrations less than RDL plus detectable concentrations at or near RDL. For example, >C_{10}-C_{21} HCs were detected at six of seven (86%) stations 5 to 10 km from drill centres, which the hockey-stick models suggest are largely outside the zone of influence.

For barium, the reasonable conclusion is that the minimum extent of the zone of influence, or occurrence of above-background concentrations, was somewhere between 1 to 2 km, a conclusion that can be reached via many other approaches (e.g., as discussed above). Beyond 2 km, most concentrations were within the baseline or background range and it was difficult to separate project-related distance gradients from natural gradients.

In 2008, concentrations of $>C_{10}$-C_{21} HCs were generally greater near (i.e., within 2 km of) the NE and SW drill centres (red and yellow circles in Figure 5-9) than near the SE drill centre (green circles). However, similar differences were not observed for barium, as concentrations near all four FEZ drill centres spanned a wide range.

Most concentrations of $>C_{10}$-C_{21} HCs and barium at stations 0.5 to 2 km from the FE drill centres (black circles in Figure 5-9) were lower than concentrations at comparable distances from other drill centres. FE distance gradients for $>C_{10}$-C_{21} HCs and barium were largely dependent on the differences between the elevated values observed at stations 30(FE) and 31(FE) and values at other stations more than 0.5 km from the FE drill centre. For this reason, the effects of distance from the FE drill centre were weak and rarely significant when stations 30(FE) and 31(FE) were excluded, or when the influence of those stations was reduced in rank-rank regressions and correlations (e.g., as in Table 5-10).

Values for Sediment PC1 decreased significantly with distance from the nearest drill centre and also with distance from the FEZ (but not FE) drill centres (Table 5-10). Distance gradients for Sediment PC1 can be considered weaker versions of gradients for barium, combining project-related and natural gradients. For all stations, a threshold distance for Sediment PC1 could not be estimated[14]. Thresholds can rarely be estimated with any precision, if at all, when correlations are weak.

Figure 5-10 provides the parametric bivariate distance regression of Sediment PC1 on distance to the nearest drill centre, which, like the rank-rank regression (Table 5-10), was significant at $p < 0.01$. Sediment PC1 scores varied widely about the regression line at distances of 1 to 2 km and were generally higher near the SE drill centre (green circles) than near the NE drill centre (red circles).

[14] The parametric hockey-stick models conducted in SYSTAT NONLIN “defaulted” to a linear bivariate regression (i.e., any threshold was outside the range of distances sampled and p = 1.0 for adding the threshold).

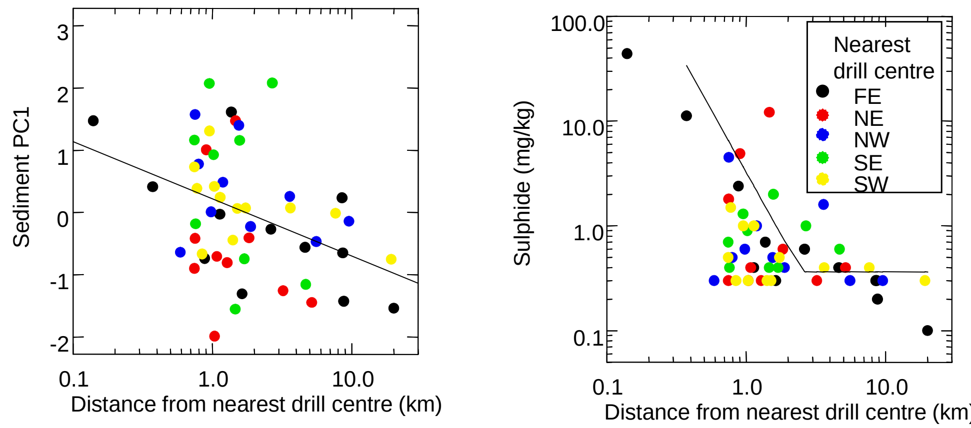

Figure 5-10 Distance Gradients for Sediment PC1 and Sulphide (2008)

Except for redox, which was uncorrelated with Sediment PC1, 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 5-10). However, these correlations were weak and rarely significant at $p \leq 0.05$. Partial correlations with distance from the FE drill centre were also weak and, of the two significant correlations, one was positive (sulphur) and one was negative (sulphide). Any negative effects of the FE drill centre were generally limited to station 30(FE) and occasionally station 31(FE).

Based on rank-rank regressions, decreases with distance were stronger for sulphide than for other variables used to derive Sediment PC1 (Table 5-10). Sulphide concentrations decreased with distances from the FEZ drill centres, the FE drill centres and the nearest drill centres, with correlations for the latter two distance measures significant at $p < 0.01$. Concentrations were higher at stations 30(FE), 31(FE) and several other stations within 2 km of drill centres than at most remote stations (Figure 5-10). For all 53 stations, adding a threshold distance significantly reduced error variance relative to a bivariate regression (Table 5-11). The estimated zone of influence was 1.1 km, with 95% CI of 0.8 to 1.4 km, similar to the estimated zone of influence for barium. With stations 30(FE) and 31(FE) excluded, a threshold could not be estimated for sulphide in 2008, although both the parametric (r = –0.418) and non-parametric correlations (r_s = –0.385) with distance from the nearest drill centre were significant at $p < 0.01$.

In 2008, fines and gravel content were not significantly correlated with any distance measure (Table 5-10). Fines content was high (3.2%) at station 30(FE), 0.17 km from the FE drill centre, but highest (7%) at station 44(FEZ), 0.95 km from the SW drill centre (Figure 5-11). Fines is a good example of a variable for which elevated levels and possible effects may have occurred at one or a few stations near drill centres, but not over any large scale (also see Section 5.4.1.2).

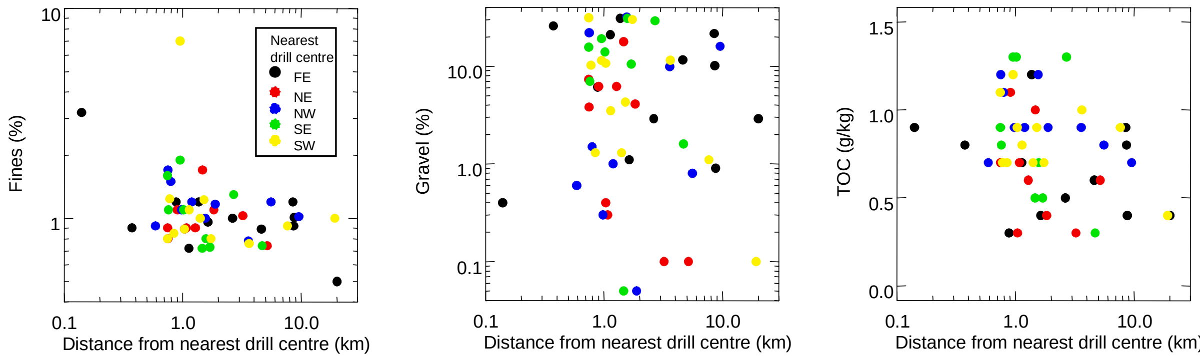

Figure 5-11 Distance Gradients for Fines, Gravel and TOC Content (2008)

In 2008, gravel content varied widely at all distances (Figure 5-11) and distance correlations were weakly negative and not significant. TOC was significantly negatively correlated with distances from the FEZ drill centres and the nearest drill centre, but was positively (although not significantly) correlated with distance from the FE drill centre. Similar differences in TOC distance gradients (i.e., decreases with distance from FEZ drill centres; increases with distance from the FE drill centre) have occurred in every sample year, including 1997 (Section 5.4.1.2).

Metals PC1 and PC2 scores were elevated at station 30(FE). Metals PC1 scores were also elevated at station 31(FE) (Figure 5-12). Partial correlations with distance from the FE drill centre for both metals PCs were negative and stronger than partial correlations with distance from the FEZ drill centres (Table 5-10). Correlations with distance to the nearest active drill centre for the two Metals PCs were weakly negative and close to the critical value of r_s = –0.272 for p = 0.05 and n = 53 stations.

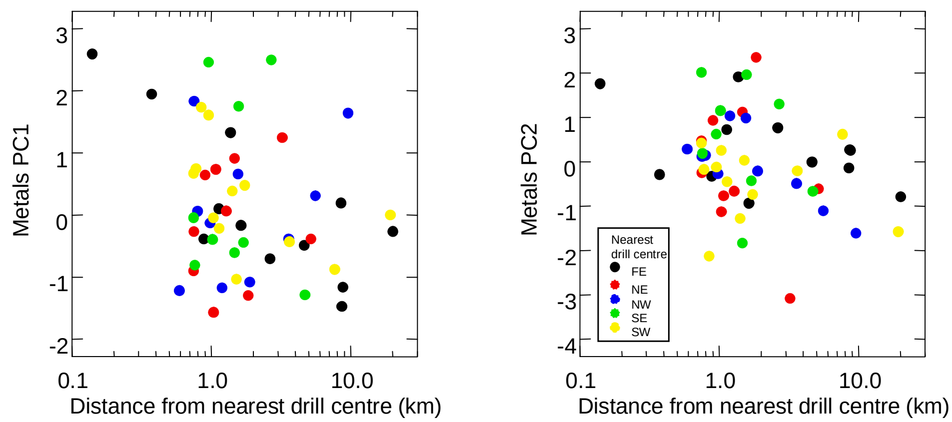

Figure 5-12 Distance Gradients for Metals PCs (2008)

In 2008, sulphur concentrations decreased, but not significantly, with distance from the FEZ drill centres, and increased significantly with distance from the FE drill centre (Table 5-10). This relationship was weak (Figure 5-13). Concentrations were highest at station 30(FE). Although not apparent from Figure 5-13, the positive correlation with distance from the FE drill centre was a function of low concentrations at several stations approximately 1 km from the FE drill centre (black circles in Figure 5-13) and higher concentrations at several remote stations.

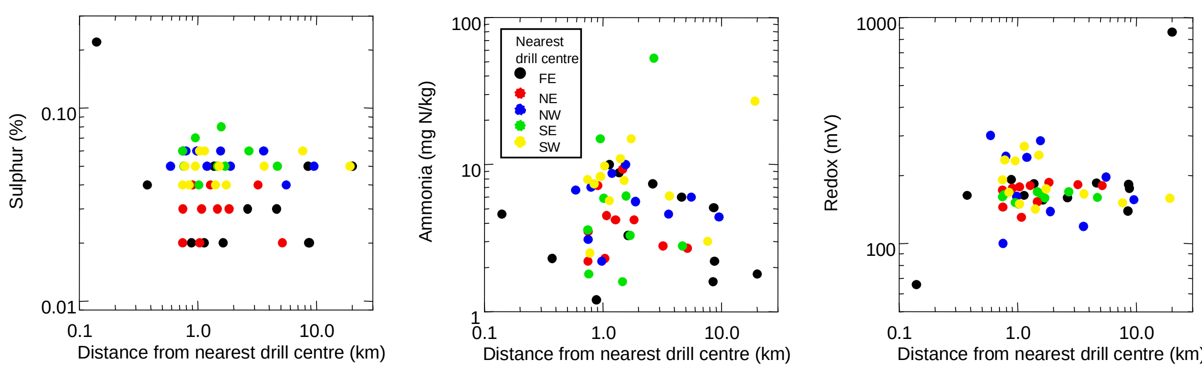

Figure 5-13 Distance Gradients for Sulphur, Ammonia and Redox (2008)

Ammonia concentrations were uncorrelated with distance measures (Table 5-10). The two highest concentrations occurred 2.7 and 19.2 km from the nearest drill centre (Figure 5-13) and concentrations were not elevated at stations 30(FE) and 31(FE). Redox was also uncorrelated with distance (Table 5-10), although the lowest value occurred at station 30(FE) (Figure 5-13).

5.4.1.2 Comparison Among Years

$>C_{10}$-C_{21} HCs and Barium

Figure 5-14 provides rank correlations (r_s) between $>C_{10}$-C_{21} HC and barium concentrations versus distance to the nearest active drill centre. The vertical dashed line before the year 2000 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 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} HCs and barium so that distance correlations can be directly compared between them.

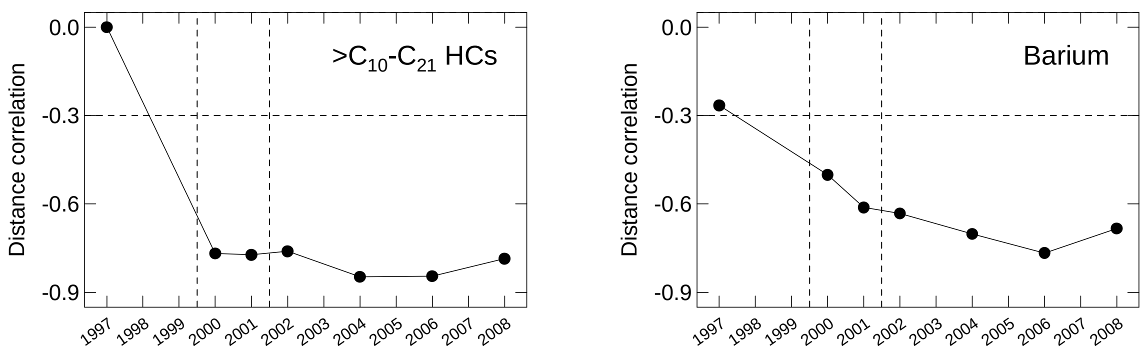

Figure 5-14 Annual Distance Correlations (r_s) for $>C_{10}$-C_{21} HCs and Barium (All Stations)

The baseline (1997) distance correlation for $>C_{10}$-C_{21} HCs is shown as 0 in Figure 5-14, based on the assumption that all concentrations in 1997 were near or below the current RDL of 0.3 mg/kg (as they were at most stations more than 10 km from active drill centres in EEM years). In EEM years, distance correlations were approximately –0.8 and were slightly stronger in 2004 and 2006 than in other years.

In 1997, the barium distance correlation was approximately –0.3 (i.e., there was a significant natural distance gradient) (Figure 5-14). Barium distance correlations progressively increased in strength over time, from approximately –0.5 in 2000 to approximately –0.8 in 2006, then decreased slightly in strength in 2008 (to r_s = –0.683).

Figure 5-15 provides annual distributions of individual >C_{10}-C_{21} HC concentrations, median, 20th and 80th percentiles for EEM years. The horizontal dashed line is the RDL of 0.3 mg/kg, with individual values less than RDL plotted as 0.15 mg/kg. Medians and 80th percentiles for >C_{10}-C_{21} HCs increased approximately 5-fold from 2000 to 2002, and decreased approximately 2-fold between 2006 and 2008. Except for 2000, 20th percentiles were at or above the RDL of 0.3 mg/kg (i.e., less than 20% of concentrations were less than RDL). The highest concentration in every year from 2002 to 2008 occurred at station 30(FE) (0.17 km from the FE drill centre). Concentrations at 30(FE) were more than 10 times concentrations at other stations within any given year except in 2008, when concentrations were also high at station 31(FE) (0.37 km from the FE drill centre).

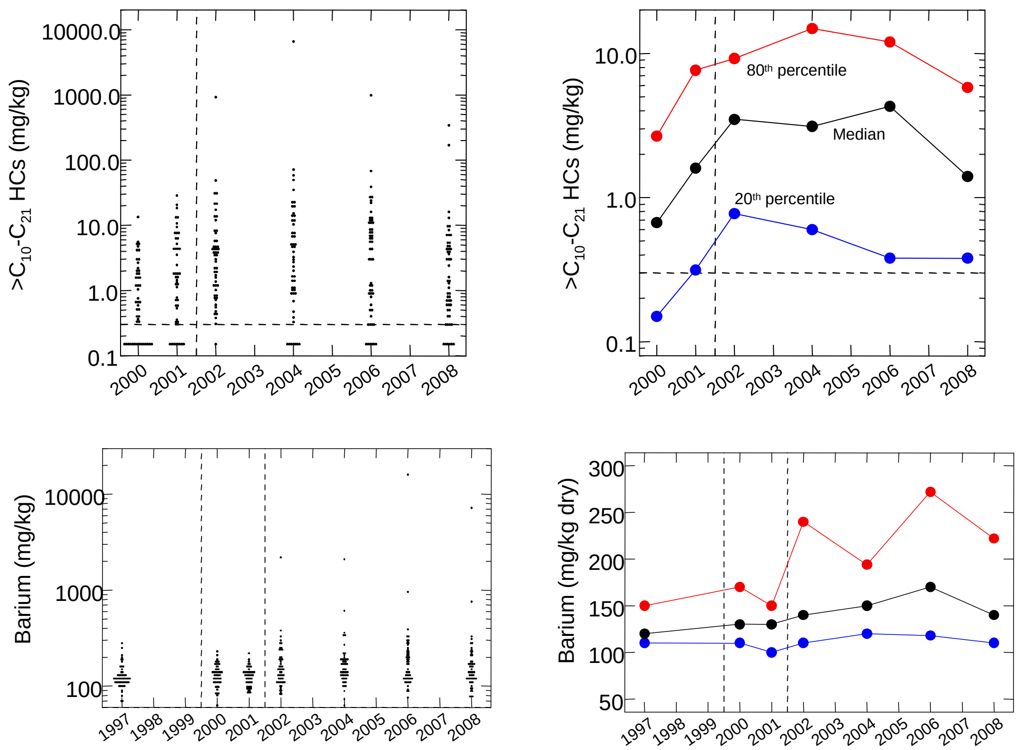

Figure 5-15 Annual Distributions, Medians, and 20th and 80th Percentiles for >C_{10}-C_{21} HCs and Barium (All Stations)

Median barium concentrations increased from 120 mg/kg in 1997 to 170 mg/kg in 2006, then decreased to 140 mg/kg in 2008 (Figure 5-15). Barium concentrations at station 30(FE) were much greater than concentrations at other stations from 2002 to 2008 (highest values in the distributions of individual values in Figure 5-15; the second highest values from 2004 to 2008 were from station 31(FE)). 80th percentiles were greater from 2002 to 2008 than in 1997, 2000 and 2001.

Table 5-12 provides results of RM analyses of log-log distance regressions for >C_{10}-C_{21} HCs and barium, with and without stations 30(FE) and 31(FE), for the 48 stations sampled in every EEM year. Appendix B-4 provides details on the RM models. For interpretation of RM regression results in Table 5-12 and elsewhere:

1. **The Among Stations terms** test relationships between multi-year means and the two distance (X) measures (FEZ and FE d).
2. **The 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 differences in Y values over time were similar at all or most stations, unless distance 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 among years.
5. **The Within Stations contrasts** test for specific types of differences: Before versus After drilling began at the FE drill centre (2000-2001 versus 2002 to 2008) and Before versus After drilling began at the FEZ NW and SE drill centres (2000 versus 2001).
6. **The Trend (2002 to 2008) contrasts** test for a progressive increase or decrease in Y values (Year terms) or distance gradients (Year $\times$ d terms) over time after drilling began at the FE drill centre and continued at the FEZ drill centres.

Results in Table 5-12 and elsewhere are presented as F values. $F > 1$ indicates added variance attributable to the term tested.

With or without stations 30(FE) and 31(FE) in RM regression analyses, the Overall Within Stations Year term was highly significant for >C_{10}-C_{21} HCs and barium ($p < 0.001$; Table 5-12), indicating that distance regression intercepts changed over time, primarily because of increased concentrations near drill centres prior to 2008.

Intercepts for >C_{10}-C_{21} HCs increased from 2000 to 2002 and then decreased in 2008, as did medians and 80th percentiles (Figure 5-15). The changes in intercepts over time were more significant with stations 30(FE) and 31(FE) included; the extreme values at those stations from 2002 to 2008 had a much greater influence on parametric regression intercepts (which are related to means) than on medians.

Table 5-12 Results (F Values) of RM Regressions Comparing >C_{10}-C_{21} HC and Barium Concentrations (2000 to 2008)

Term	>C_{10}-C_{21} HCs		Barium	
	All stations	30(FE), 31(FE) excluded	All stations	30(FE), 31(FE) excluded
Among Stations				
FEZ *d*	**79.7*** **	**242.9*** **	6.8*	**42.8*** **
FE *d*	7.1*	8.0**	**21.9*** **	0.5
Error 1 (Carry-over)	**6.6*** **	**3.8*** **	**10.2*** **	**8.6*** **
Within Stations				
Overall				
Year	**38.3*** **	**9.8*** **	**36.7*** **	**5.8*** **
Year × FEZ *d*	2.8*	**5.1*** **	0.3	**4.8*** **
Year × FE *d*	**24.8*** **	1.7	**26.8*** **	0.2
Before versus After FE Drilling (2000-2001 vs 2002 to 2008)				
Year	**71.9*** **	**22.1*** **	**53.7*** **	**20.4*** **
Year × FEZ *d*	0.0	3.3	0.0	**15.5*** **
Year × FE *d*	**49.6*** **	4.1*	**38.5*** **	0.4
Before versus After NW, SE Drilling (2000 vs 2001)				
Year	6.4*	3.6	3.2	1.0
Year × FEZ *d*	7.3**	6.6*	0.2	0.3
Year × FE *d*	2.4	1.1	1.6	0.3
Trend (2002 to 2008)				
Year	2.2	3.1	**18.2*** **	0.4
Year × FEZ *d*	0.4	0.2	1.2	0.0
Year × FE *d*	1.2	0.1	**23.8*** **	0.3

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations sampled every EEM year (n = 46 with the two FE stations excluded).
- Distance variables (X) and Y variables were log-transformed.
- See Appendix B-4 for description and interpretation of terms in the RM regression models.

For barium, with stations 30(FE) and 31(FE) excluded, changes in intercepts were similar to changes in medians (i.e., increasing from 2000 to 2006, then decreasing in 2008; Figure 5-15). With the two FE stations included, change in intercepts were similar to changes in 80^{th} percentiles (i.e., with the greatest changes occurring after drilling began at the FE drill centre).

Carry-over effects, or persistent spatial differences over time, were highly significant ($p < 0.001$) for >C_{10}-C_{21} HCs and barium (Table 5-12). Carry-over effects for >C_{10}-C_{21} HCs should be considered persistent small-scale or localized project-related effects unrelated to distance, assuming that background concentrations were near or below the current RDL 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} HCs because barium carry-over effects incorporated both natural and project-related persistent small-scale spatial variance. Project-related carry-over effects would dominate near drill centres, with natural carry-over effects dominating at more remote stations.

With the two FE stations excluded, the overall FEZ distance gradient for $>C_{10}$-C_{21} HCs in EEM years was highly significant (Table 5-12). In every EEM year, $>C_{10}$-C_{21} HC concentrations decreased with distance from the nearest FEZ drill centre (i.e., multiple regression FEZ distance slopes were negative; Figure 5-16). The decreases in $>C_{10}$-C_{21} HC concentrations with distance from the FEZ drill centres accounted for most of the significant overall decreases in concentrations with distance from the nearest active drill centre (Figure 5-14). Prior to 2002, only FEZ drill centres were active. From 2002 to 2008, effects of drilling at the FE drill centre (i.e., elevated $>C_{10}$-C_{21} HC concentrations) were largely restricted to stations 30(FE) and 31(FE) and had minimal influence on non-parametric distance correlations (see below).

There were significant changes in FEZ distance gradients over time (Table 5-12), with gradients increasing in strength from 2000 to 2001, decreasing in strength from 2001 to 2002 and somewhat weaker in 2008 than in 2004 and 2006 (Figure 5-16). These were small changes relative to the strong distance gradients in all years.

Including stations 30(FE) and 31(FE) did not substantially alter FEZ distance slopes (Figure 5-16). The primary effect of including those two stations was to increase the error variances of the distance slopes. However, with the two stations included, there was a highly significant change in FE distance gradients for $>C_{10}$-C_{21} HCs after drilling began at that drill centre (Table 5-12). Specifically, distance slopes changed from weakly positive (increases in concentration with distance) in 2000 and 2001 to negative (decreases in concentration with distance) from 2002 to 2008 (Figure 5-16). With stations 30(FE) and 31(FE) excluded, regression slopes were positive, with concentrations increasing with distance in all years (Figure 5-16). After drilling began at the FE drill centre, slopes significantly decreased (i.e., became less positive).

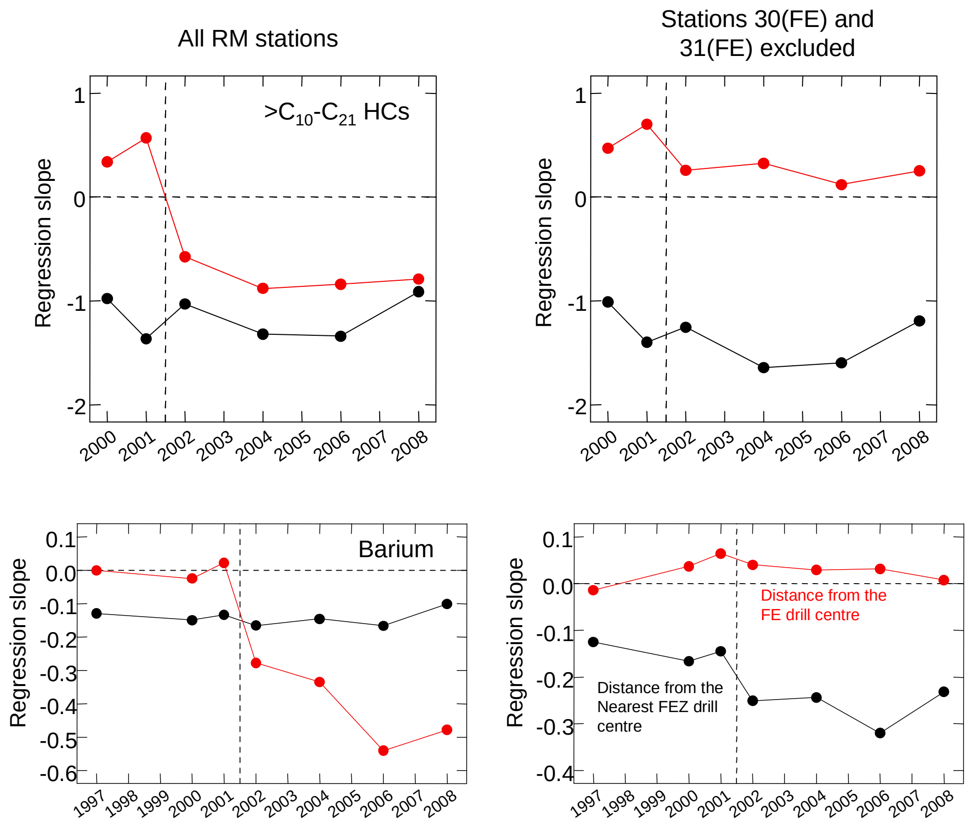

Figure 5-16 Multiple Regression Distance Slopes for >C_{10}-C_{21} HCs and Barium

Figure 5-17 plots annual >C_{10}-C_{21} HC concentrations for the five stations within 1.5 km of the FE drill centre. Prior to 2002, >C_{10}-C_{21} HC concentrations were near or below the RDL of 0.3 mg/kg at all five stations. In 2002 and later years, concentrations at stations 30(FE) and 31(FE) were much greater than in 2000 and 2001. Concentrations also increased in 2002 at the other three stations. The increases were relatively minor at stations 28(FE) and 29(FE) to the East, and the increases at station 32(FE) to the West may have been partly attributable to continued drilling at the FEZ drill centres. As a result, within every year from 2002 to 2008, >C_{10}-C_{21} HC concentrations decreased by more than 100-fold from station 30(FE) to stations 28(FE) and 29(FE) (i.e., within 1.5 km from the FE drill centre).

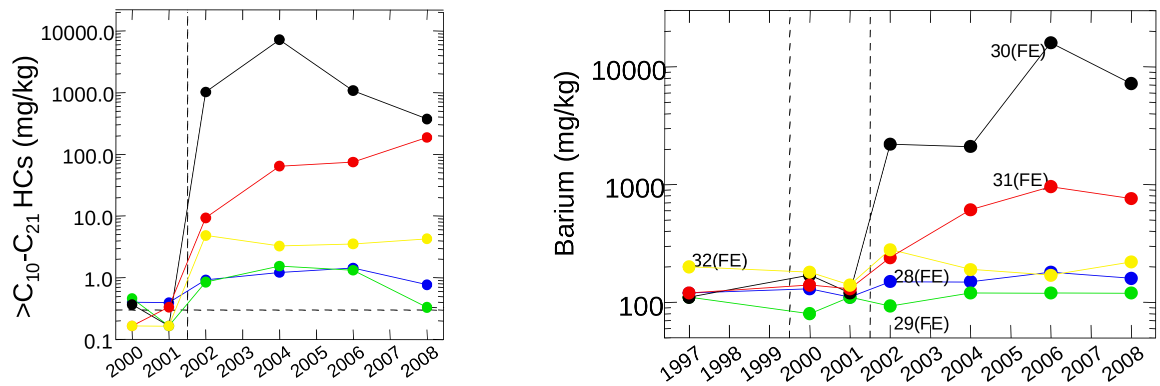

Figure 5-17 >C_{10}-C_{21} HC and Barium Concentrations at the Five Stations Nearest the FE Drill Centre

Results of tests of distance effects on barium were generally weaker versions of results for >C_{10}-C_{21} HCs (Table 5-12). The overall FEZ distance gradient for barium in EEM years was highly significant (Table 5-12), with barium concentrations decreasing with distance from the FEZ drill centres in every EEM year (Figure 5-16). With station 30(FE) and 31(FE) excluded, there was also a significant difference in FEZ distance gradients Before versus After drilling began at the FE drill centre. From 2002 to 2008, multiple regression slopes for the FEZ drill centres were steeper (more negative) than in 2000 and 2001. As was the case for >C_{10}-C_{21} HCs, FEZ distance gradients accounted for most of the overall significant non-parametric distance correlations in Figure 5-14. FEZ distance slopes, as well as distance correlations, were also negative in 1997, although not as strong as in EEM years (Figure 5-16; the 1997 slopes were based on the 33 RM stations also sampled in 1997).

With stations 30(FE) and 31(FE) excluded, there were no significant changes in FE distance gradients for barium over time (Table 5-12). Barium concentrations at the three stations 0.5 to 1.5 km from the FE drill centre have remained relatively constant over time (Figure 5-17). Therefore, it is reasonable to conclude that the increased frequency of concentrations of 200 to 400 mg/kg from 2002 to 2008, excluding stations 30(FE) and 31(FE), was largely a function of increased concentrations near FEZ drill centres.

With stations 30(FE) and 31(FE) included, differences in FE distance gradients for barium between 2000 and 2001 versus 2002 to 2008 were highly significant (Table 5-12). The FE distance gradient (decrease with distance) progressively increased in strength from 2002 to 2008 as barium concentrations increased at stations 30(FE) and 31(FE) (Figure 5-17).

As discussed in the analysis of 2008 distance relationships, threshold (hockey-stick) models may be more appropriate for >C_{10}-C_{21} HCs and barium than the linear log-log regressions used in the RM and other analyses. Table 5-13 provides results for hockey-stick models for >C_{10}-C_{21} HCs and barium for all years, with all stations included.

Table 5-13 Distance Relationships and Thresholds for >C_{10}-C_{21} HCs and Barium (1997 to 2008)

Variable	Year	*r* bivariate	*R* hockey-stick	*p* threshold	Threshold distance (km)	95% CI (km)
>C_{10}-C_{21} HCs	2000	**–0.762*****	**0.773*****	0.175	8.5	4.3 to 16.7
	2001	**–0.798*****	**0.801*****	0.414	12.5	4.1 to 37.7
	2002	**–0.786*****	**0.793*****	0.215	4.9	2.7 to 9.0
	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
Barium	1997	–0.247	0.247	1.000	Not estimable	
	2000	**–0.481*****	**0.481*****	1.000	Not estimable	
	2001	**–0.567*****	**0.593*****	0.153	5.2	2.0 to 13.9
	2002	**–0.622*****	**0.739*****	**<0.001**	1.9	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

Notes:
- **p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 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 2008. 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; 53 stations in 2006 and 2008.

From 2000 to 2002, adding a threshold in hockey-stick models did not significantly reduce error variances for >C_{10}-C_{21} HCs (Table 5-13). From 2004 to 2008, adding a threshold significantly reduced error variances. Estimated threshold distances decreased over time from approximately 10 km in 2000 and 2001, to approximately 5 km in 2002, 2004 and 2006, and then to 2.5 km in 2008. However, caution should be applied when comparing estimates from 2000 to 2002, when hockey-stick models were relatively poor fits, with estimates from 2004 to 2008, when hockey-stick models were better fits. Estimated thresholds, and the width of their CI, will usually be reduced when hockey-stick models are better fits.

Estimated thresholds for $>C_{10}$-C_{21} HCs can be compared among recent years and indicate that zones of influence for $>C_{10}$-C_{21} HCs decreased from 2004 and 2006 to 2008. There was very little overlap in 95% CI for threshold distances between 2008 and the two earlier years, and median and 80th percentile concentrations were lower in 2008 than in 2004 and 2006 (Figure 5-15). Estimated background $>C_{10}$-C_{21} HC concentrations in hockey-stick models for the past three EEM years have been near the RDL of 0.3 mg/kg.

Threshold distances for barium could not be estimated from 1997 and 2000, when distance correlations were relatively weak (Table 5-13). In 2001, adding a threshold did not significantly reduce error variance. The estimated threshold distance of 5.2 km was much greater than in subsequent years and had wide CI. From 2002 to 2008, adding a threshold significantly reduced error variances ($p < 0.001$ for all four sample years), primarily because the high concentrations at station 30(FE) and 31(FE) were extreme outliers for bivariate log-log regressions. Estimated threshold distances were 1.9 km in 2002 and ranged from 1.0 to 1.2 km from 2004 to 2008.

Sediment Particle Size and Organic Carbon Content

Weak negative distance correlations (decreases with distance) were noted for fines content in 1997 (baseline) (Figure 5-18). Distance correlations were stronger in EEM years, especially in 2000 and 2006. 20th percentile, median and 80th percentile fines content decreased from 1997 to 2000 and then progressively increased from 2000 to 2004 (Figure 5-19). Values in 2006 and 2008 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 RM regression results below).

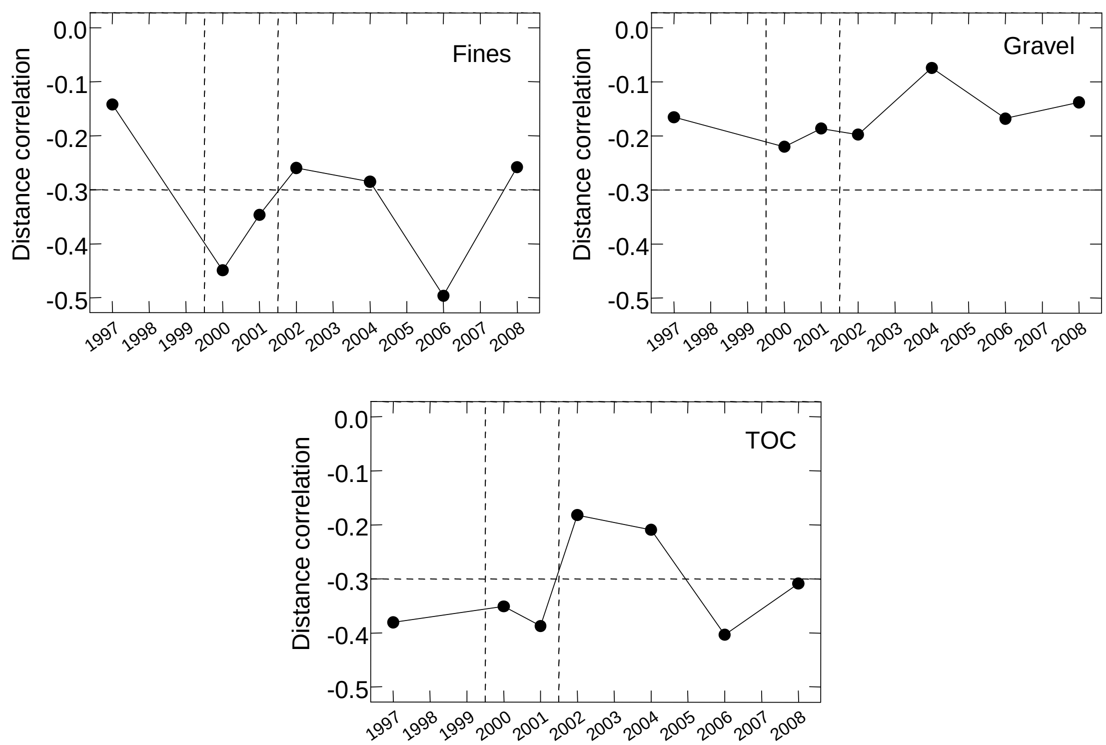

Figure 5-18 Annual Distance Correlations (r_s) for Sediment Fines, Gravel and TOC Content (All Stations)

Distance correlations for gravel have never been significant but have always been negative (decreases with distance), even in 1997 (Figure 5-18). 20th percentiles, medians and 80th percentiles for gravel content increased from 1997 to 2008, 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 5-19).

TOC content has always decreased with distance from drill centres (Figure 5-18). The baseline (1997) correlation of approximately –0.4 was among the strongest observed and correlations in 2002 and 2004 were weaker than in other years. TOC content in all years has generally been low, with most values between 0.5 and 1 g/kg (Figure 5-19). Medians and 80th percentiles increased somewhat since 2000, when TOC content was lower than in 1997. The net result was that 1997 and 2008 medians (0.8 g/kg) and 80th percentiles (1.00 versus 1.02 g/kg) were almost identical.

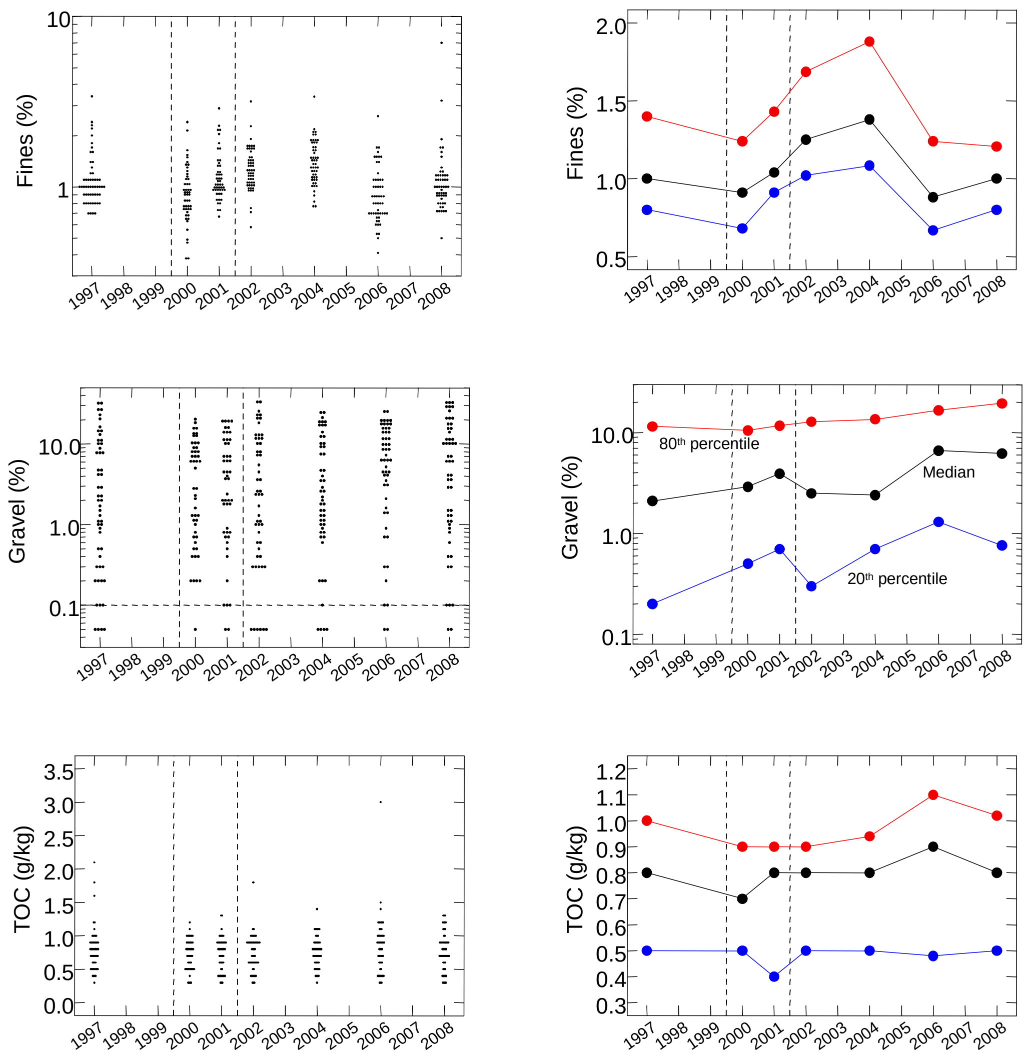

Figure 5-19 Annual Distributions, Medians, and 20th and 80th Percentiles for Fines, Gravel and TOC Content (All Stations)

Table 5-14 provides results of RM regression analyses comparing EEM years for sediment particle size, TOC, Metals PC1 and PC2, ammonia and redox. Results exclude stations 30(FE) and 31(FE), the two stations within 0.5 km of the FE drill centre. RM regression results with those two stations included, and time profiles for stations near the FE drill centre, are provided in Appendix B-4 and summarized below. In general, any effects of drilling at the FE drill centre were largely confined to one or both of the two stations nearest the drill centre. As was the case for $>C_{10}$-C_{21} HCs and barium, excluding those two stations from RM analyses usually increased the power and resolution of tests of effects of distance from the FEZ drill centre. Carry-over effects, or persistent spatial differences over time, were significant at $p \leq$

0.001 for all variables except redox, and strongest for gravel and TOC content (Table 5-14).

Table 5-14 Results (F Values) of RM Regressions Comparing Sediment Particle Size, Total Organic Carbon Content and Metal Concentrations (2000 to 2008)

Term	Fines	Gravel	TOC	Metals PC1	Metals PC2	Ammonia	Redox
Among Stations							
FEZ *d*	**13.5*** **	0.7	**16.2*** **	10.0**	0.5	5.3*	**34.2*** **
FE *d*	0.0	1.5	5.4*	0.2	1.3	1.3	0.2
Error 1 (Carry-over)	**5.4*** **	**12.4*** **	**17.9*** **	**6.2*** **	**8.2*** **	**3.0*** **	0.8
Within Stations							
Overall							
Year	**5.7*** **	1.1	2.0	0.1	1.3	1.0	**14.5*** **
Year × FEZ *d*	0.7	0.1	2.7*	2.4*	3.2**	0.9	3.4**
Year × FE *d*	1.0	0.7	0.6	0.8	2.3*	0.5	**4.9*** **
Before versus After FE Drilling (2000-2001 vs 2002 to 2008)							
Year	0.3	0.4	0.0	0.0	0.3	4.2*	**25.2*** **
Year × FEZ *d*	0.0	0.3	0.9	4.2*	3.3	0.2	**16.2*** **
Year × FE *d*	0.6	1.6	0.9	0.0	0.0	0.2	0.4
Before versus After NW, SE Drilling (2000 vs 2001)							
Year	**21.3*** **	0.0	0.0	0.0	0.7	Not tested	**13.1*** **
Year × FEZ *d*	1.8	0.2	0.4	1.3	10.5**		6.3*
Year × FE *d*	6.9*	0.1	0.0	0.9	4.0		1.2
Trend (2002 to 2008)							
Year	4.8*	0.7	7.6**	0.3	3.4	0.4	4.5*
Year × FEZ *d*	0.9	0.2	7.6**	1.4	0.3	0.0	2.5
Year × FE *d*	0.2	0.1	1.9	3.0	5.6*	0.8	4.7*

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 PC, were log-transformed.
- See Appendix B-4 for description and interpretation of terms in the RM regression models, and for results with stations 30(FE) and 31(FE) included.

Temporal (year-to-year) variance at most stations was the major factor affecting fines content, as indicated by the significant Year terms in Table 5-14 and changes in summary statistics in Figure 5-19.

The overall FEZ distance gradient for fines content was significant (Table 5-14), with fines content decreasing with increasing distance from the FEZ drill centres in every year including baseline (1997) (Figure 5-20). The FEZ distance gradient did not change significantly over time (Table 5-14), although parametric distance slopes for the FEZ drill centres were steepest in 2000 and 2006 (Figure 5-20), when nonparametric distance correlations were also strongest (Figure 5-18).

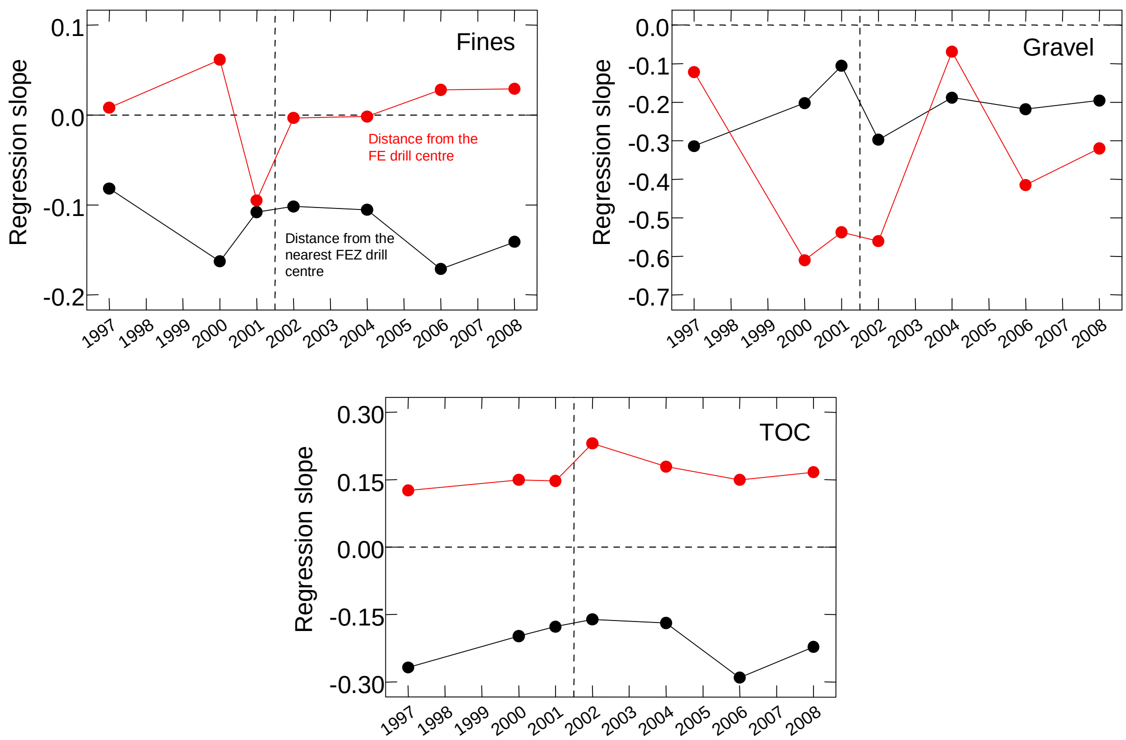

Figure 5-20 Multiple Regression Distance Slopes for Fines, Gravel and TOC Content (Stations 30(FE) and 31(FE) Excluded)

Fines content increased at station 30(FE) from less than 2% in 2001 and 2002 to approximately 3% in later years. Values at 30(FE) were highest in 2004 and 2006, and the second highest in 2008. With or without stations 30(FE) and 31(FE) included, FE distance gradients did not differ significantly between 2000 and 2001 versus 2002 to 2008 (Table 5-14). Instead, with the two stations excluded, the largest and only significant change occurred between 2000 and 2001, before drilling began at the FE drill centre (Table 5-14). The FE distance slope reversed from positive to negative from 2000 to 2001, and returned to values near 0 in subsequent years (Figure 5-20).

Carry-over effects (persistent spatial differences over time) were the only significant term for gravel content in RM regression analyses, with or without stations 30(FE) and 31(FE) included (Table 5-14; Appendix B-4). Although weak, 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 5-20).

Overall differences in RM regression intercepts for TOC were not significant (Table 5-14). Intercepts increased significantly from 2002 to 2008 (Table 5-14), although that trend was not as evident for medians (Figure 5-19).

The overall FEZ distance gradient for TOC was highly significant ($p < 0.001$; Table 5-14), because TOC decreased with distance from the FEZ drill centres in EEM years. The FEZ distance slope for 1997 (baseline) was also negative and as strong as in EEM years (Figure 5-20).

With stations 30(FE) and 31(FE) excluded, and the effects of distance from the FEZ drill centre removed in multiple regressions, TOC levels increased with increasing distance from the FE drill centre in EEM years and in 1997 (baseline) (Figure 5-20). The overall FE distance gradient was significant, and there were no significant changes in that gradient among years (Table 5-14).

Including stations 30(FE) and 31(FE) affected FE distance gradients for TOC (Appendix B-4). TOC values at those two stations were not outliers in the RM regression analyses and TOC levels there were always lower than at most other stations after drilling began at the FE drill centre. However, TOC content at the two stations increased from low levels of approximately 0.5 g/kg in 1997, 2000 and 2001 (i.e., near 20th percentiles) to approximately 1 g/kg in 2006 and 2008 (i.e., near 80th percentiles). As a result, the distance gradient (increase with distance) before drilling began was stronger, and the distance gradient after drilling began was weaker, than with the two stations excluded (Appendix B-4).

Metals

Overall metal concentrations and Metals PC1 scores decreased with distance from the FEZ drill centres in every year, with distance correlations stronger in EEM years than in 1997 (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 were weaker than correlations for Metals PC1 from 2000 to 2002, and similar in strength in recent years.

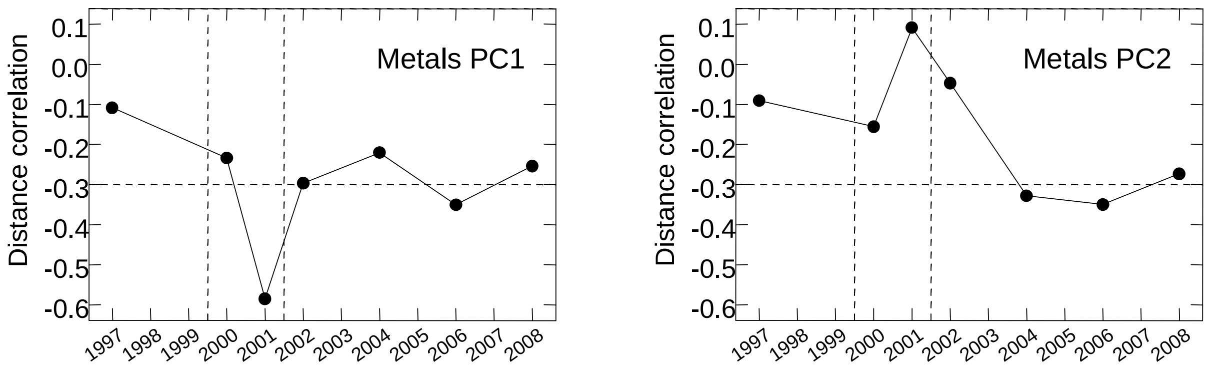

Figure 5-21 Annual Distance Correlations (r_s) for Metals PC1 and PC2 (All Stations)

Medians for Metals PC1 in EEM years were similar to baseline (1997) medians (Figure 5-22). 80th percentiles did not change substantially from 1997 to 2002, but progressively increased from 2002 to 2008. Therefore, in recent years, there have been more high Metals PC1 scores, although that is not visually evident from the plot of individual values in Figure 5-22. 20th percentiles, medians and 80th percentiles for Metals PC2 scores in EEM years were usually above baseline (1997) values (Figure 5-22). However, any changes in both PC1 and PC2 over time in EEM years were small, especially in more recent years.

Differences in RM regression intercepts among years for Metals PCs were not significant (Table 5-14), consistent with the relatively small differences in medians in EEM years (Figure 5-22).

The overall FEZ distant gradient for Metals PC1 in EEM years was significant (Table 5-14), with PC1 scores decreasing with distance from the FEZ drill centres in every year, including 1997 (negative FEZ distance slopes in Figure 5-23). There was a significant difference in FEZ distance gradients for EEM years in 2000 and 2001 versus 2002 to 2008, with distance slopes generally steeper in 2000 and 2001 than in subsequent years.

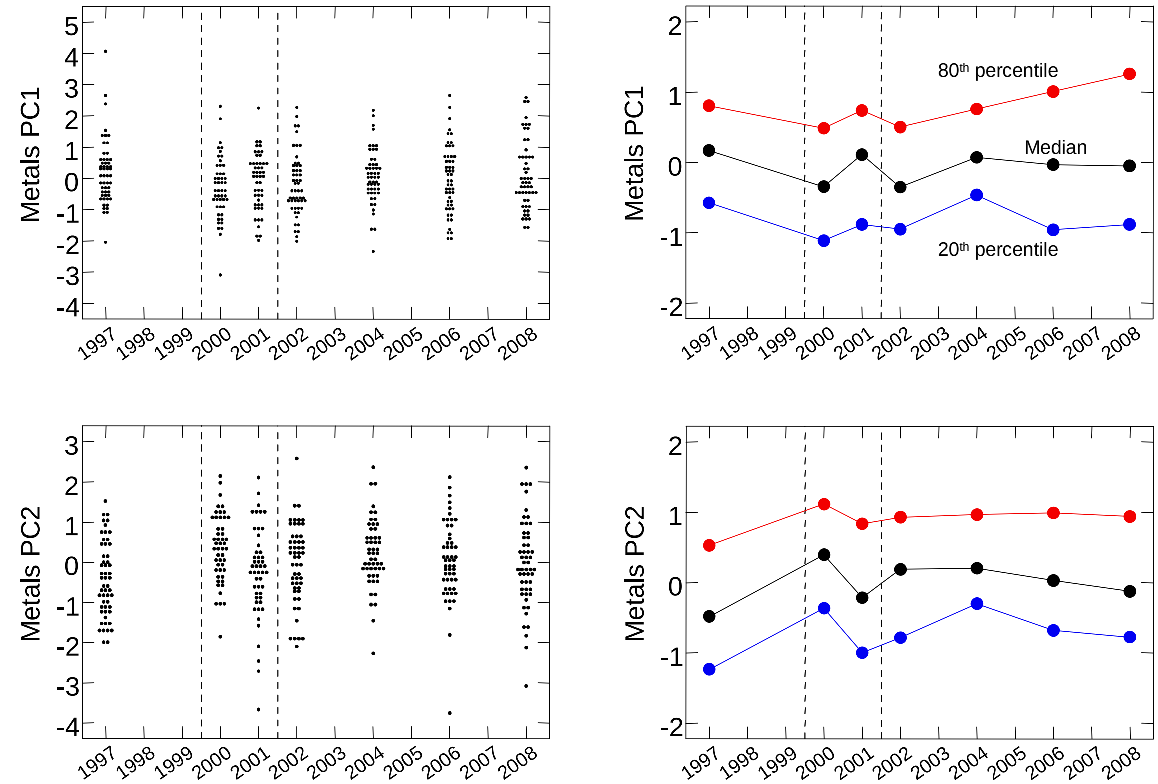

Figure 5-22 Annual Distributions, Medians, and 20th and 80th Percentiles for Metals PC1 and PC2 (All Stations)

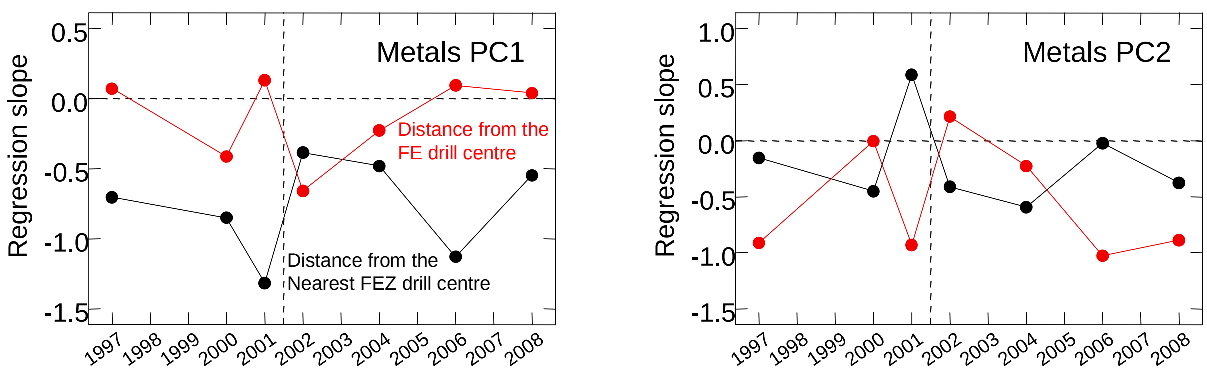

Figure 5-23 Multiple Regression Distance Slopes for Metals PC1 and PC2 (Stations 30(FE) and 31(FE) Excluded)

With stations 30(FE) and 31(FE) excluded, there were no significant changes in the FE distance gradient for Metals PC1 over time and the overall gradient was not significant (Table 5-14). FE distance slopes were steepest and negative in 2002 after drilling began at the FE drill centre, but returned to approximately 0 in recent years (Figure 5-23). Metals PC1 scores increased at station 30(FE) after drilling began at the FE drill centre, and were also high at station 31(FE) in 2008. However, there was otherwise little evidence of any effects of the FE drill centre on metals PC1 (Appendix B-4).

The overall FEZ distance gradient for Metals PC2 was not significant (Table 5-14). 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 (Table 5-14). FE distance slopes increased in strength from approximately 0 to negative (decrease with distance) from 2002 to 2008 (Figure 5-23). However, the distance gradient in 2001, before drilling began at the FE drill centre, was as strong as in 2006 and 2008 (Figure 5-23). With stations 30(FE) and 31(FE) included, results of RM regression tests of FE distance effects were similar to results with the two stations excluded (Appendix B-4).

Sulphur, Ammonia and Redox

Sulphur concentrations have been measured since 2001 and have decreased with distance from the nearest active drill centre in every year since then (Figure 5-24). The distance correlations were significant in every year except 2008. However, sulphur concentrations in 2008 were higher than in other years (Figure 5-25; values less than the highest RDL of 0.03% are plotted as ½ that RDL or 0.015%). Sulphur concentrations at station 30(FE) increased after drilling began at the FE drill centre, and concentrations there were the highest observed within every sample year from 2002 to 2008. Sulphur concentrations were also elevated at station 31(FE) and at several other stations near FEZ drill centres in 2004 and 2006.

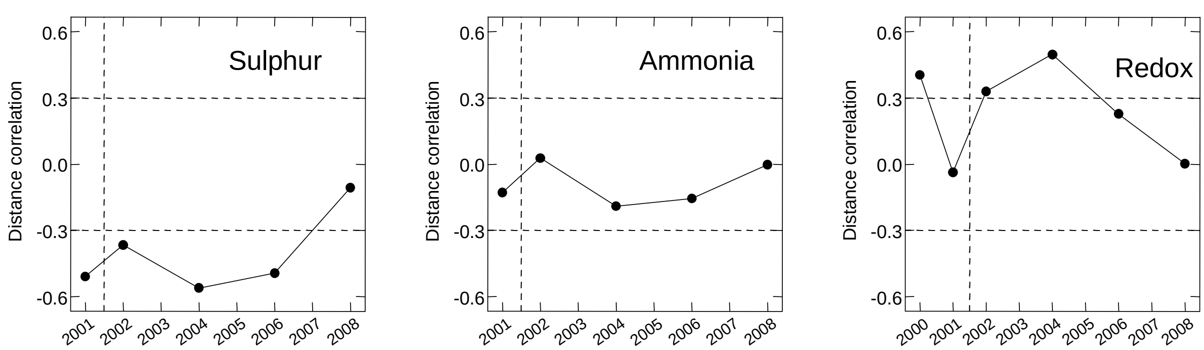

Figure 5-24 Annual Distance Correlations (r_S) for Sulphur, Ammonia and Redox (All Stations)

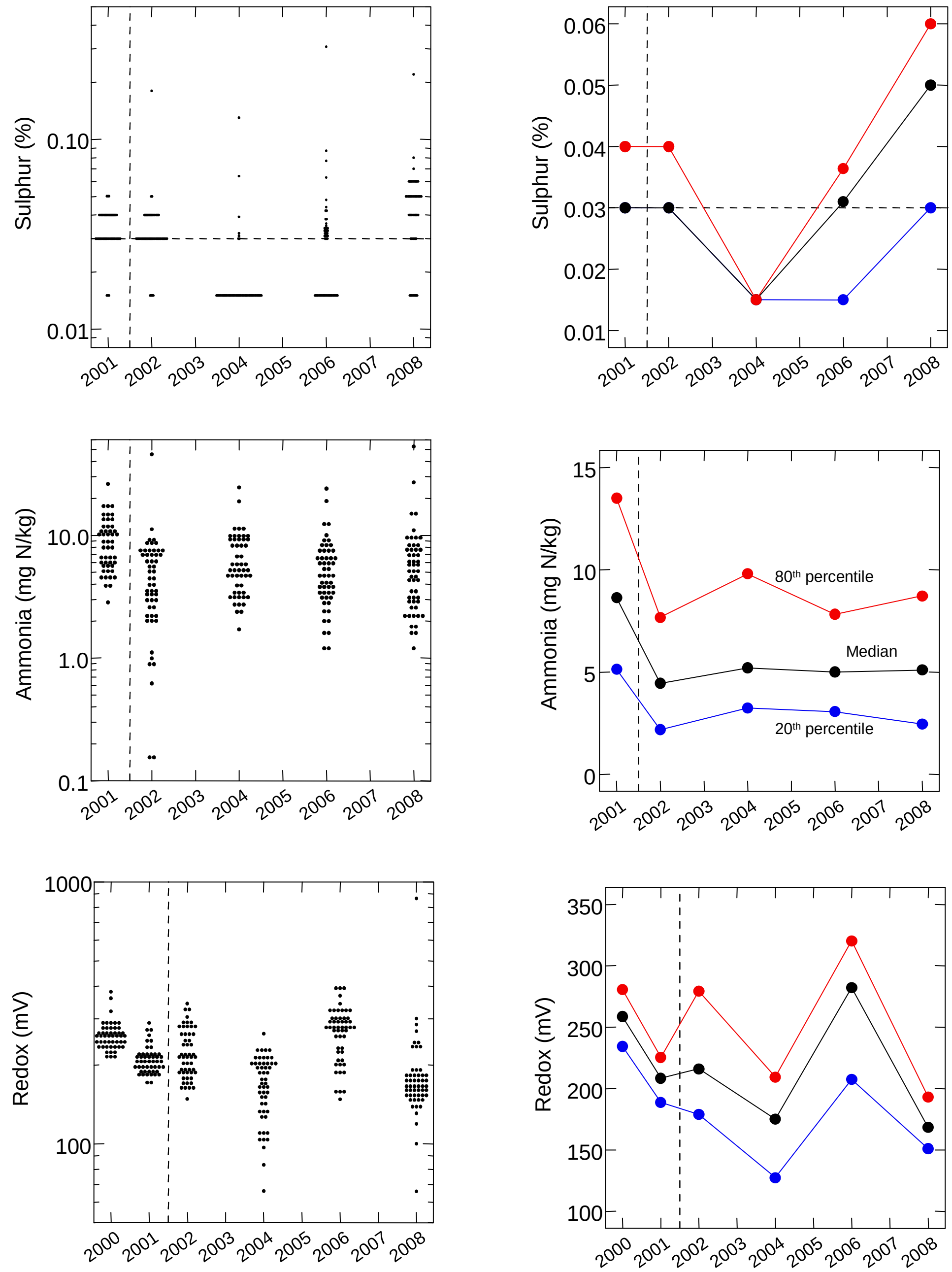

Figure 5-25 Annual Distributions, Medians, and 20th and 80th Percentiles for Sulphur (All Stations)

Ammonia concentrations, measured since 2001, did not decrease significantly with distance from the nearest active drill centre in any year (Figure 5-24). 20th percentile, median and 80th percentile ammonia concentrations in 2001 were approximately double values in subsequent years (Figure 5-25). As a result, differences in RM regression intercepts between 2001 versus 2002 to 2008 were significant (Table 5-14). Despite the weak non-parametric distance correlations, the overall FEZ distance gradient for ammonia was significant in RM regression analyses (Table 5-14), with distance slopes negative in every year (Figure 5-26). There was no evidence that drilling at the FE drill centre elevated ammonia concentrations near that drill centre. Ammonia concentrations at stations 30(FE) and 31(FE) did not increase from 2002 to 2008. Instead, the ammonia concentration at station 30(FE) in 2002 was the lowest observed in any year (i.e., a negative outlier) and there was a significant overall increase in ammonia concentrations with distance from the FE drill centre when stations 30(FE) and 31(FE) were included in RM regression analyses (Appendix B-4).

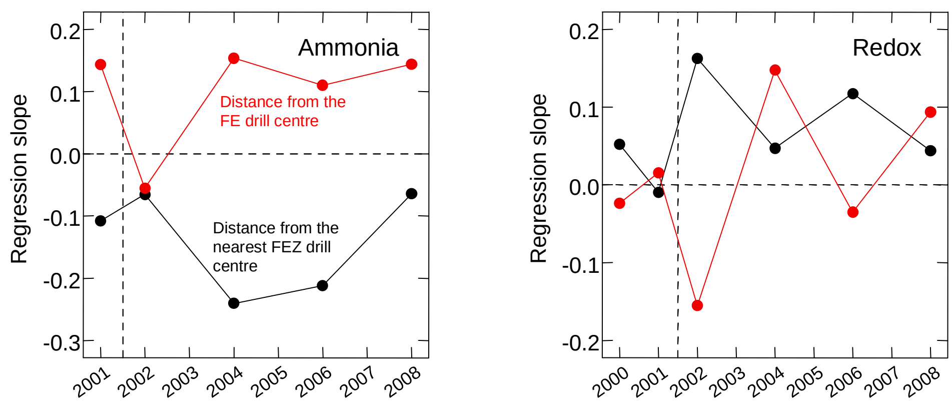

Figure 5-26 Multiple Regression Distance Slopes for Ammonia and Redox (Stations 30(FE) and 31(FE) Excluded)

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 5-24). For redox, positive rather than negative correlations may be indicative of adverse project-related effects, since low values (reducing conditions) are of primary concern and could be associated with discharge of drill cuttings.

Median and 20^{th} percentile redox values decreased from 2001 to 2004, increased in 2006, then decreased again in 2008 (Figure 5-25). 80^{th} percentiles were also greatest in 2006. In 2004 and 2008, the lowest values (<100 mV) occurred at station 30(FE), but there were other low values from 2004 to 2008 near FEZ drill centres. There was also one extreme high value in 2008, at the Southeast Reference (station 6(SE)).

RM regression intercepts for redox differed significantly among EEM years (Table 5-14). With both the FEZ and FE distance gradients changing significantly over time, the differences in regression intercepts were more similar to differences in 80th percentiles (i.e., greater in 2000, 2002 and 2006 than in other years) than differences in medians in Figure 5-25.

The overall FEZ distance gradient was significant for redox (Table 5-14), but the gradient changed significantly over time (Table 5-14). FEZ distance slopes were positive in all years except 2001 (Figure 5-26). FEZ distance gradients were significantly stronger in 2001 than in 2000, and also significantly stronger from 2002 to 2008 than in 2000 and 2001 (Table 5-14).

With or without stations 30(FE) and 31(FE), FE distance slopes for redox were approximately 0 in 2000 and 2001 (Figure 5-26). With the two stations excluded, FE distance slopes were negative in 2002, positive in 2004 and 2008 and approximately 0 in 2006. With stations 30(FE) and 31(FE) excluded, there were no net significant differences in FE distance gradients Before versus After drilling began at the FE drill centre. With stations 30(FE) and 31(FE) included, the distance slopes in 2002 and 2006 were approximately 0, and the difference in FE distance gradients Before versus After drilling was significant (Appendix B-4).

5.4.2 TOXICITY

5.4.2.1 Analysis of 2008 Data

Appendix B-5 provides Microtox IC50s and amphipod survival results from 1997 to 2008. In 2008, Microtox IC50s ranged from 4,367 to >197,000 mg wet/L. IC50s were less than 197,000 mg wet/L (the highest concentration tested) in 15 (of 53) samples. Ten (10) of these 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 9 of the 10 samples.

Amphipod survival ranged from 57% to 97% in 2008. Survival was less than 70% in samples from stations 30(FE) and 38(FEZ), and these samples were considered toxic based on comparison to Control or Reference (1(SW) and 6(SE)) sediments according to Environment Canada (1998) interpretative guidance. Survival was 70% to 73% in samples from stations 26(FE), 39(FEZ) and 46(FEZ), and these samples were considered toxic based on comparison to Reference but not Control sediments.

Relationships With Sediment Physical and Chemical Characteristics

Microtox IC50s based on wet weight and amphipod survival were uncorrelated (r_s = 0.048; p >> 0.05) over all 53 samples. Samples from stations 38(FEZ) and 39(FEZ) were considered toxic to both test organisms, based on Environment Canada (2002) interpretative guidance.

Microtox IC50s were negatively correlated with all sediment physical and chemical variables except redox (Table 5-15), indicating that negative responses increased as values of those variables increased. IC50s were not significantly correlated with $>C_{10}$-C_{21} HCs. IC50s were significantly correlated with barium, but that correlation was weaker than correlations with many other variables (Table 5-15). IC50s were strongly negatively correlated with adjusted fines and strontium, as in past EEM years (Section 5.4.4.1). In 2008, IC50s were strongly and significantly correlated with Metals PC1 but not Metals PC2. In some other years, IC50s have been more strongly correlated with Metals PC2 than with Metals PC1 (Section 5.4.4.1). Correlations between IC50s versus sulphur and sulphide were significant but weak.

Table 5-15 Spearman Rank Correlations (r_s) Between Toxicity Test Responses and Sediment Physical and Chemical Characteristics (2008)

Physical/Chemical Variable	Microtox IC50 (wet weight)	Amphipod survival
$>C_{10}$-C_{21} HCs	–0.190	0.000
Barium	–0.373**	0.002
Sediment PC1	–0.453**	–0.052
% fines	–0.405**	–0.149
% adjusted fines	**–0.522*** **	–0.131
% gravel	–0.353*	0.061
TOC	–0.400**	0.039
Metals PC1	**–0.601*** **	–0.072
Metals PC2	–0.133	–0.073
Strontium	**–0.518*** **	–0.119
Sulphur	–0.339*	–0.030
Sulphide	–0.274*	–0.016
Ammonia	–0.120	–0.020
Redox	0.115	–0.003

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

All correlations between amphipod survival and sediment physical and chemical variables were weak (r_s = –0.15 to 0.06) and not significant (Table 5-15). The lowest survival (57%) occurred for station 30(FE), where $>C_{10}$-C_{21} HC and barium concentrations were highest, but the highest survival (97%) occurred at nearby station 31(FE), where $>C_{10}$-C_{21} HC and barium concentrations were second highest.

Distance Relationships

In 2008, Microtox IC50s were uncorrelated with distances from the drill centres (Table 5-16). Instead, the lowest values generally occurred at intermediate distances of approximately 1 to 3 km (Figure 5-27). The horizontal dashed lines in Figure 5-27 are the benchmarks of 50,000 and 98,500 mg wet/L, used in this report to define toxicity and negative responses, respectively. Based on Environment Canada (2002) interpretative guidance, the one value between the two benchmarks, from station 31(FE), was also considered toxic.

Table 5-16 Results of Rank-Rank Regressions of Toxicity Test Responses (Y) on Distance (X) Variables (2008)

***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 *dl* FE *d* constant**	***Y*-FE *dl* FEZ *d* constant**	***r* (=r_s)**
Microtox IC50	0.206	0.060	0.181	0.161
Amphipod survival	0.138	0.013	0.132	0.095

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

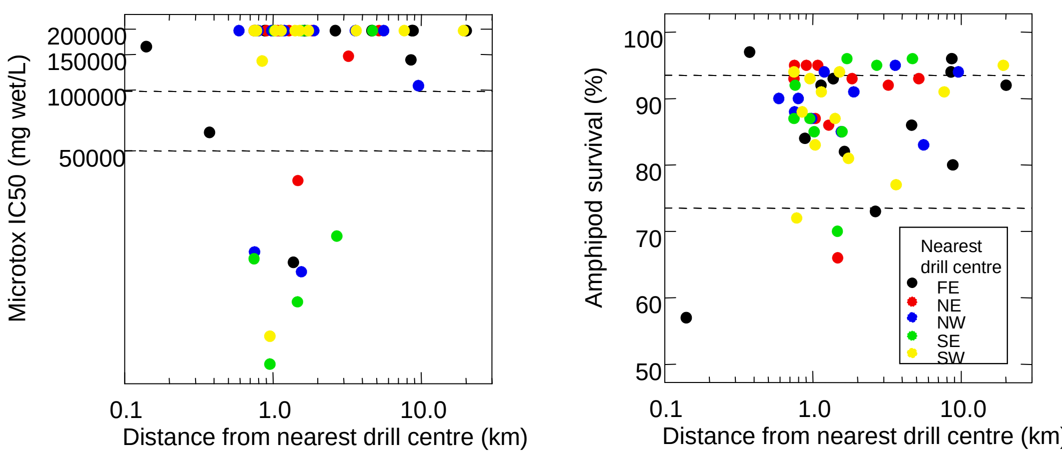

Figure 5-27 Distance Gradients for Toxicity Test Responses (2008)

In 2008, amphipod survival was uncorrelated with distances from drill centres (Table 5-16). The lowest survival (57%) occurred at station 30(FE), 0.14 km from the FE drill centre, and the highest survival (97%) occurred at station 31(FE), 0.37 km from the same drill centre (Figure 5-27). The horizontal dashed lines in Figure 5-27 are 73.5%, which separates toxic from non-toxic samples, and 93.5%, the Reference mean.

5.4.2.2 Comparison Among Years

Table 5-17 summarizes frequencies of Microtox IC50s less than 98,500 mg wet/L, the benchmark used to define negative responses, and value less than 50,000 mg wet/L, the benchmark used to define toxicity. 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 10% to 20% in 2004, 2006 and 2008. However, a decrease over time was less evident for toxicity, as frequencies of toxicity were 15% to 20% in EEM years except for 2001 (27%) and 2006 (11%).

Table 5-17 Frequencies of Samples with Negative Microtox Responses (1997 to 2008)

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
Total (All years)	363	86	24	57	16
Total (EEM years)	309	82	27	56	18

As in 2008, Microtox IC50s in past years were not strongly correlated with distances from the drill centres (Table 5-18). 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 also did not increase in strength after drilling began there prior to 2002 sampling.

Table 5-18 Spearman Rank Correlations (r_s) Between Microtox IC50s and Distance Measures (1997 to 2008)

Year	No. stations	Distance from:		
		Nearest active drill centre	Nearest FEZ drill centre	FE drill centre
1997	54	0.046	–0.071	0.143
2000	49	0.326*	0.350*	0.219
2001	49	0.178	0.178	0.161
2002	53	0.174	0.202	0.196
2004	52	0.061	0.177	0.122
2006	53	0.023	0.089	0.079
2008	53	0.161	0.100	0.137

Notes: - *p ≤ 0.05; **p ≤ 0.01; ***p ≤ 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 2008, negative responses and toxicity in past EEM years occurred mostly at intermediate distances. Figure 5-28 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. 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). Median distances were slightly lower for stations with negative responses than for other stations, consistent with the weak positive correlations between IC50s and distance in EEM years (Table 5-18). 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.

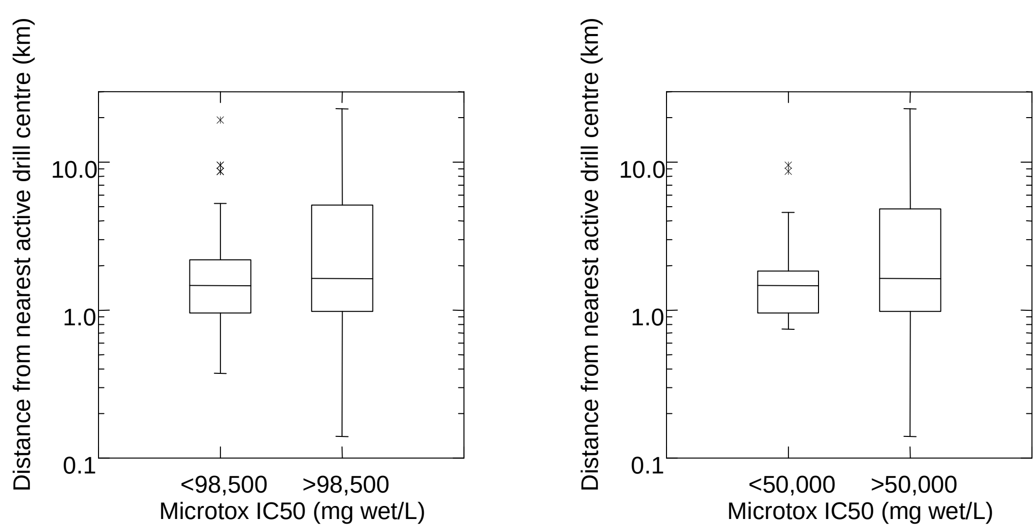

Figure 5-28 Distributions of Distances for Microtox Negative Responses and Toxicity (2000 to 2008)

Frequencies of Microtox toxicity (IC50s less than 50,000 mg wet/L) have been relatively constant in EEM years. Table 5-19 summarizes Microtox results for the 20 stations with IC50s less than 50,000 mg wet/L in at least one EEM year. Double solid circles indicate IC50s less than 50,000 mg wet/L, single solid circles indicate IC50s between 50,000 and 98,500 mg wet/L and open circles indicate IC50s greater than 98,500 mg/L. Nine (9) of the 20 stations listed in Table 5-19 were also sampled in baseline (1997), but baseline IC50s were greater than 98,684 mg/wet/L for eight of those nine stations (Station 52(FEZ), with IC50 = 50,537 mg wet/L in 1997 was the exception).

Table 5-19 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
Transect stations (*n*=192 samples)								
7(SE)*	FE	11.37	○	●●	○	○	○	○
9(SE)*	SE	2.69	●	●●	●	●●	●●	●●
11(SE)*	SE	0.95	●●	●●	●●	●●	○	●●
15(NE)*	NE	1.83	●●	●●	●●	●●	○	○
18(NW)*	NW	9.56	○	●●	●	○	○	○
29(FE)*	FE	0.88	●	●●	○	○	○	○
32(FE)*	FE	1.37	●●	●●	●●	●●	●●	●●
FEZ stations (*n*=117 samples)								
33(FEZ)	NW	0.75	●●	●●	●	●●	○	●●
37(FEZ)	NE	0.75	●●	●	●	○	○	○
38(FEZ)	NE	1.47	●●	●●	●	●●	○	●●
39(FEZ)	SE	1.46	○	○	○	○	○	●●
40(FEZ)	SE	0.76	○	○	○	○	●●	○
41(FEZ)	SE	0.75	●●	●●	●	○	○	●●
43(FEZ)	SW	1.41	○	○	●●	○	○	○
44(FEZ)	SW	0.95	●●	●●	●●	●●	●●	●●
46(FEZ)	SW	0.78	●	●●	●●	●●	○	○
48(FEZ)	SW	1.14	●●	○	○	NS	○	○
49(FEZ)	NW	1.55	●●	●●	●●	●●	●●	●●
51(FEZ)*	NE	1.28	NS	NS	●	○	●●	○
52(FEZ)*	SE	1.57	NS	NS	●●	●●	○	○

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

Toxicity occurred in sediments from stations 32(FE), 44(FEZ) and 49(FEZ) in all six EEM years (Table 5-19). Negative responses or toxicity occurred in four or five EEM years at stations 9(SE), 11(SE), 15(NE), 33(FEZ), 38(FEZ), 41(FEZ) and 46(FEZ). Therefore, 10 stations (approximately 20% of the stations sampled annually) accounted for 45 (80%) of the 56 toxic sediments noted over all EEM years.

The timing of toxicity generally did not coincide with the onset of drilling at the FEZ 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. Toxicity or negative responses only occurred at station 29(FE), 0.88 km from the FE drill centre, in 2000 and 2001, before drilling began at the FE drill centre**.**

5.4.3 BENTHIC COMMUNITY STRUCTURE

5.4.3.1 Overview

Over the seven sample years (1997, 2000, 2001, 2002, 2004, 2006 and 2008), 153 invertebrate families were collected (Table 5-20), excluding meiofauna (oligochaetes, protodrilids, copepods, ostracods, nematodes, nemerteans). Two families were collected only in Wash samples and were excluded from most analyses. Some of the “families” were not true taxonomic families but higher-level taxa (e.g., order or class).

Table 5-20 Gross Taxonomic Breakdown of Benthic Invertebrate Community Samples

Taxon		No. families (all years)	No. organisms (Elutriate samples)			
Phylum or Subphylum	Class or Order		2008 (*n*=53 stations)		2000, 2001, 2002, 2004, 2006 (*n*=245 stations)	
			No.	% of total	No.	% of total
Porifera		3	15	0.03	110	0.07
Cnidaria		7	68	0.12	1,148	0.70
Platyhelminthes	Turbellaria	1	3	0.01	5	0.00
Priapulida		1	0	0.00	1	0.00
Annelida	Polychaeta	34	47,569	85.28	141,316	85.69
Sipuncula		1	166	0.30	198	0.12
Mollusca	Polyplacophora	1	1	0.00	0	0.00
	Bivalvia	21	1,558	2.79	3,338	2.02
	Gastropoda	22	778	1.39	1,567	0.95
	Subtotal	44	2,337	4.19	4,905	2.97

Taxon		No. families (all years)	No. organisms (Elutriate samples)			
			2008 (*n*=53 stations)		2000, 2001, 2002, 2004 (*n*=245 stations)	
Phylum or Subphylum	Class or Order		No.	% of total	No.	% of total
Crustacea	Amphipoda	25	2,814	5.05	6,345	3.85
	Cirrepedia	1	600	1.08	3,786	2.30
	Cumacea	5	355	0.64	822	0.50
	Decapoda	5	12	0.02	45	0.03
	Isopoda	5	215	0.39	305	0.18
	Tanaidacea	1	1,165	2.09	3,478	2.11
	Subtotal	42	5,161	9.25	14,781	8.96
Chelicerata	Pycnogonida	1	8	0.01	0	0.00
Brachiopoda		1	0	0.00	4	0.00
Ectoprocta		1	0	0.00	1	0.00
Echinodermata		12	210	0.38	2,143	1.30
Urochordata		1	235	0.42	7	0.00
Hemichordata		4	5	0.01	304	0.18
Total		153	55,777		164,923	
Mean/Station			1,052		673	

In 2008, 57,777 benthic macro-invertebrates (i.e., excluding meiofauana) from 106 families were collected in 106 invertebrate samples from 53 stations (Table 5-20). Mean abundance per station was more than 50% greater than in previous years, an increase that occurred at most stations. Samples were dominated by polychaetes, which accounted for approximately 85% of total abundance in 2008 and previous years. Molluscs and crustaceans were the only other phyla accounting for more than 1% of total abundance in 2008 samples. Bivalves were the most abundant molluscs. Amphipods and Tanaidacea were the most abundant crustaceans.

In 2008 and previous years, invertebrate communities were dominated by three polychaete families: Spionidae, Cirratulidae and Syllidae (Table 5-21). These three families were collected at every station in every year and accounted for more than 60% of the total number of invertebrates collected in EEM Elutriate samples.

Table 5-21 Abundant Taxa (Families) in Benthic Invertebrate Elutriate Samples (2000 to 2008)

Taxon		**2008**		**2000, 2001, 2002, 2004, 2006**	
		% abundance (of 55,777 organisms)	**% occurrence (of 53 stations)**	**% abundance (of 164,923 organisms)**	**% occurrence (of 245 stations)**
POLYCHAETA	**SPIONIDAE**	42.45	100	34.62	100
POLYCHAETA	**CIRRATULIDAE**	12.48	100	17.40	100
POLYCHAETA	**SYLLIDAE**	8.37	100	12.81	100
Polychaeta	**Sabellidae**	3.47	94	1.81	86
Polychaeta	**Phyllodocidae**	3.45	100	3.44	99
Polychaeta	**Sigalionidae**	2.45	87	4.23	88
Polychaeta	**Paraonidae**	2.15	85	3.01	88
Tanaidacea		2.09	75	2.11	82
Polychaeta	Ampharetidae	1.90	81	0.23	42
Bivalvia	**Tellinidae**	1.74	85	0.88	69
Polychaeta	Polynoidae	1.64	98	0.66	80
Amphipoda	Stenothoidae	1.62	70	0.60	47
Gastropoda		1.13	62	0.56	38
Cirripedia	**Balanidae**	1.08	47	2.30	58
Polychaeta	**Maldanidae**	1.03	77	1.57	71
Polychaeta	**Orbiinidae**	1.01	70	1.35	72
Polychaeta	**Capitellidae**	0.99	98	1.25	89
Polychaeta	Opheliidae	0.96	62	0.50	61
Amphipoda	**Phoxocephalidae**	0.95	75	1.42	74
Amphipoda	Oedicerotidae	0.78	85	0.49	71
Polychaeta	Glyceridae	0.70	68	0.83	60
Polychaeta	Dorvilleidae	0.57	60	0.44	50
Polychaeta	Terebellidae	0.51	64	0.38	50
Bivalvia	Hiatellidae	0.51	92	0.56	80
Echinodermata	Ophiuroidea UID	0.12	28	0.71	39

Notes
- Bold caps indicates “dominants”, collected in all samples and accounting for more than 10% of the total number of organisms collected in Elutriate samples from 2000 to 2008.
- Bold indicates “sub-dominants”, or taxa other than Spionidae, Syllidae and Cirratulidae accounting for more than 1% of the total number of organisms collected.
- UID = Unidentified.

Table 5-21 also provides relative abundances and occurrences for all taxa accounting for at least 0.5% of total abundance in 2008 or from 2000 to 2006. Most of the other common families were also polychaetes. Tellinidae (mostly *Macoma*) and Hiatellidae (*Cyrtodaria* and *Hiatella*) were the dominant bivalve families (Table 5-21). Lepetidae (*Lepeta*) was the dominant gastropod family. Tanaidacea (order) was the most abundant crustacean. In recent years, most Tanaidacea have been identified as family Arthuridae. Stenothoidae (mostly *Metopa*) was the most abundant amphipod family in 2008 (and 2006). In previous years and over all EEM years combined, Phoxocephalidae (mostly *Harpinia* and *Phoxocephalus*) was the dominant amphipod family. The family Phoxocephalidae includes the west coast amphipod *Rhepoxynius abronius*, which is used in laboratory toxicity tests. Ophiuroidea (order) that could not be identified to lower taxonomic levels (Appendix B-3) was the most abundant echinoderm. These were mostly juveniles, probably of the genus *Ophiura* and family Ophiuridae (dominant ophiuroid adults). Echinarachnidae (*Echinarachnius;* sea spiders) were the most abundant echinoderms routinely identified to family or lower taxonomic levels, accounting for 0.25% of the total number of organisms collected in EEM Elutriate samples.

Figure 5-29 plots NMDS axis scores for Elutriate samples from 2000 to 2008 (total = 298 stations). The stress coefficient, a measure of the fit between the original pair-wise Bray-Curtis (B-C) distances between stations and distances between those stations in the NMDS plots, was 0.16. Stress values can range from 0 (perfect fit) to 1 (no fit). A stress coefficient of 0.16 indicates a reasonable two-dimensional fit to the 44,253 original B-C pair-wise distances among the 298 stations. Distances between stations in the two-dimensional plots reflect community differences as % differences, since the NMDS was based on relative abundances. In Figure 5-29, the vertical and horizontal dashed lines indicate NMDS1 = 0 and NMDS2 = 0, respectively. The origin (NMDS1 = NMDS2 = 0) represents the “average” community over all stations and years.

In Figure 5-29, stations are colour-coded based on distances to the nearest drill centre. Community composition varied widely within distance classes, especially among stations more than 2 km from active drill centres (blue and yellow circles). Over time, there has been a net increase in NMDS1 scores (right shift along NMDS1 axis), especially for stations within 1 km of drill centres (black circles).

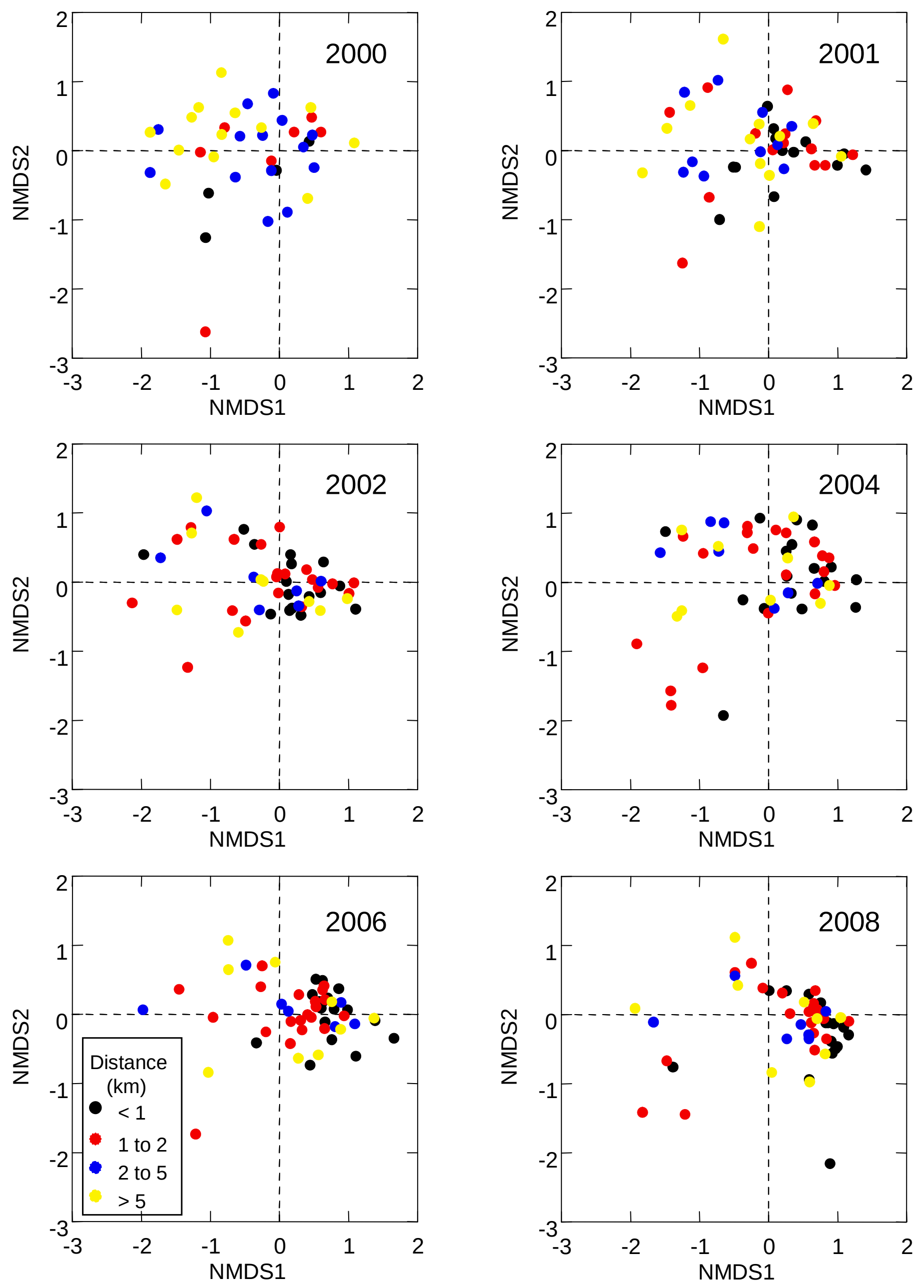

Figure 5-29 Non-Metric Multidimensional Scaling Plots Based on Relative Abundances of Invertebrate Taxa (2000 to 2008 Elutriate Samples)

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 2006)

Figure 5-30 plots Spearman rank correlations (r_s) between relative abundances of individual families and NMDS axis scores. This is effectively a plot of differences among taxa and the weighting of taxa along the NMDS axes. There is an approximate correspondence between positions of taxa in Figure 5-30 and positions of stations in Figure 5-29. For example, stations in the lower left quadrant of Figure 5-29 (negative NMDS1 and NMDS2 scores) would have greater relative abundances of taxa in the lower left quadrant of Figure 5-30 (negative correlations with NMDS1 and NMDS2). Most taxa were too rare to have much influence on the NMDS analysis and differences in community composition, and were clustered near the centre of Figure 5-30 (i.e., r_s with both NMDS axes approximately 0).

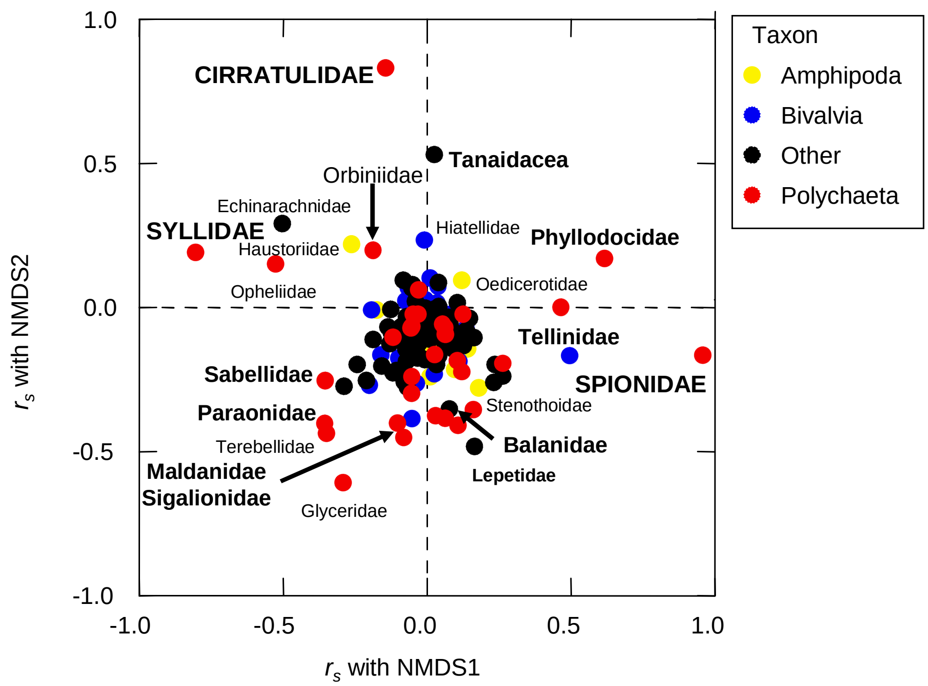

Figure 5-30 Spearman Rank Correlations (r_s) Between Family Relative Abundances and Non-Metric Multidimensional Scaling (NMDS) Axes (2000 to 2008 Elutriate Samples)

The three dominant polychaete families (Spionidae, Syllidae and Cirratulidae; bold caps in Figure 5-30 and Table 5-21) largely defined overall community differences along the NMDS axes among stations in Figure 5-29, and differences among taxa or groups of taxa in Figure 5-30. 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. 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) (bold in Figure 5-30 and Table 5-21). These two families were not strongly correlated with NMDS2 and their abundances would be expected to co-vary with Spionidae abundances.

NMDS2 was strongly positively correlated with relative abundances of the dominant Cirratulidae and the sub-dominant Tanaidacea, uncorrelated with relative abundances of Spionidae and Syllidae, and negatively correlated with abundances of several sub-dominant and lesser taxa. Therefore, NMDS2 represented a contrast between Cirratulidae/Tanaidacea versus most other taxa (i.e., Cirratulidae/ Tanaidacea dominance).

Polychaetes of the sub-dominant polychaete families Sabellidae and Paraonidae and the lesser polychaete families Terebellidae and Glyceridae formed a group of taxa in the lower left quadrant of Figure 5-30 (negative correlations with both NMDS1 and NMDS2). Therefore, communities at stations in the lower left quadrant of Figure 5-29 would have higher relative abundances of these four polychaete taxa and lower relative abundances of the dominant Spionidae and Cirratulidae. In other words, these stations would have more mixed (and usually more diverse) communities.

5.4.3.2 Analysis of 2008 Data

Summary Statistics

In 2008, total abundance varied by more than 10-fold among stations, with standard deviations (SD) approximately 50% of the mean (Table 5-22). Coefficients of Variations (CVs) were approximately 70% 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.

In 2008, standing crop varied almost 1,000-fold among stations, with a CV of 58% (Table 5-22). There were two extreme low values of 0.75 and 2.55 g wet/station at stations 30(FE) and 52(FEZ), respectively. Otherwise, standing crop was 10 to 100 g/station at eight stations, and greater than 100 g/station at 43 stations.

Table 5-22 Summary Statistics for Invertebrate Community Variables (2008)

Variable	Unit/Interpretation	Min	Max	Median	Mean	SD	CV
Summary measures							
Total abundance (*N*)	No. organisms/station	82	2,372	1,069	1,052	564	54
Standing crop (*B*)	g wet/station	0.75	521	185	201	117	58
Richness (*S*)	No. taxa/station	12	57	33	35	11	31
Adjusted richness (*S2*)	Observed : Expected *S*	0.54	1.38	1.04	1.01	0.19	19
NMDS1	Spionidae dominance	–1.93	1.16	0.62	0.31	0.80	
NMDS2	Cirratulidae/Tanaidacea dominance	–2.15	1.12	–0.11	–0.16	0.56	
Taxon abundances							
Spionidae	No. organisms/station	4	1,377	449	447	321	72
Cirratulidae	No. organisms/station	2	395	113	131	95	72
Syllidae	No. organisms/station	1	239	75	88	48	55
Orbiniidae	No. organisms/station	0	160	3	11	24	226
Paraonidae	No. organisms/station	0	179	7	23	36	159
Phyllodocidae	No. organisms/station	1	100	36	36	24	67
Tellinidae	No. organisms/station	0	61	3	10	16	155
Amphipoda	No. organisms/station	0	205	31	53	57	106
Echinodermata	No. organisms/station	0	25	2.0	4.0	4.9	123

Notes: - *n* = 53 stations.
- CV = Coefficient of Variation (SD as % of mean).

Richness and adjusted richness varied less among stations than abundances and standing crop (Table 5-22). In 2008, 12 to 57 taxa were collected per station, with more than 20 taxa collected at 49 of 53 stations. Mean and median adjusted richness values were approximately 1, indicating that richness relative to abundance in 2008 was similar to the "average" (adjusted richness = 1) over all EEM Elutriate samples.

In 2008, mean and median NMDS1 scores were positive, and mean and median NMDS2 scores were negative (Table 5-22). Therefore, communities in 2008 were shifted downwards and/or to the right in Figure 5-29, relative to earlier years and the overall average of NMDS1 = NMDS2 = 0. Although NMDS axis scores were driven primarily by the relative abundances of the three dominant polychaetes (Spionidae, Cirratulidae and Syllidae), there were some stations where NMDS scores were determined largely by the relative abundances of the sub-dominant polychaetes Orbiniidae, Paraonidae and Phyllodocidae.

Correlations Among Community Variables

Table 5-23 provides bivariate rank correlations among benthic invertebrate community summary measures for 2008 samples. Adjusting richness for abundance removed most of the positive correlation between raw richness and abundance.

Total abundance was also positively and significantly correlated with NMDS1 scores (Spionidae dominance) and negatively correlated with NMDS2 scores (Cirratulidae/Tanaidacea dominance). Total abundance was generally greater where Spionidae, which accounted for more than 40% of the organisms collected, were dominant, and also where Cirratulidae and Tanaidacea were less dominant.

Table 5-23 Spearman Rank Correlations (r_s) Among Primary Benthic Invertebrate Community Variables (2008)

	Total abundance (*N*)	Standing crop (*B*)	Richness (*S*)	Adjusted richness (*S2*)	NMDS1
Standing crop (*B*)	0.320*				
Richness (*S*)	**0.841*** **	0.297*			
Adjusted richness (*S2*)	0.235	0.186	**0.682*** **		
NMDS1	0.426**	0.180	0.154	–0.338*	
NMDS2	–0.317*	0.038	**–0.474*** **	–0.396**	–0.235

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

Standing crop was weakly but significantly positively correlated with total abundance and richness, and uncorrelated with other summary measures (Table 5-23).

Richness and adjusted richness were significantly negatively correlated with NMDS2 scores (Table 5-23). Communities associated with lower NMDS2 scores and lower relative abundances of Cirratulidae and Tanaidacea were generally more diverse communities with greater abundances and occurrences of other taxa (Section 5.4.3.1; Figure 5-30). Adjusted richness was also significantly negatively correlated with NMDS1 scores. Adjusted richness, or richness relative to total abundance, will generally be higher where the most abundant taxon (Spionidae) is less dominant.

Correlations (all positive) between abundances of the three dominant polychaete families and total abundance followed the same rank order as their relative abundances: Spionidae > Cirratulidae > Syllidae (Table 5-24). Abundances of Tellinidae and Phyllodocidae, which co-varied with Spionidae abundance, were also significantly positively correlated with total abundance. Amphipod abundance was significantly positively correlated with total abundance.

Table 5-24 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures versus Taxon Abundances (2008)

Taxon abundances	Summary measures					
	Total abundance (*N*)	**Standing crop (*B*)**	**Richness (*S*)**	**Adjusted richness (*S2*)**	**NMDS1**	**NMDS2**
Spionidae	**0.925*** **	0.337*	**0.687*** **	0.060	**0.623*** **	–0.208
Cirratulidae	**0.575*** **	0.127	0.339*	–0.166	0.142	0.409**
Syllidae	0.393**	–0.064	**0.456*** **	0.324*	–0.447**	–0.116
Orbiniidae	–0.015	0.313*	0.067	0.144	–0.128	0.254
Paraonidae	0.141	0.144	0.327*	0.376**	–0.250	–0.421**
Phyllodocidae	**0.550*** **	0.286*	0.178	–0.418**	**0.663*** **	0.128
Tellinidae	**0.668*** **	0.216	0.443**	–0.072	**0.633*** **	–0.165
Amphipoda	0.436**	0.214	**0.653*** **	**0.540*** **	–0.046	–0.166
Echinodermata	0.075	0.252	0.389**	**0.645*** **	–0.286*	–0.108

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

Standing crop was significantly positively correlated with Spionidae, Orbiniidae and Phyllodocidae abundances (Table 5-24). The larger Orbiniidae and Phyllodocidae, where abundant, may make a significant direct contribution, in terms of weight, to standing crop. The smaller but more abundant Spionidae may also make a direct contribution to standing crop. Abundances of Tellinidae and echinoderms, large and heavy organisms that should make a significant contribution to standing crop, were positively correlated with standing crop, but the correlations were weak and not significant.

Richness was positively and significantly correlated with abundances of all taxa except for Orbiniidae and Phyllodocidae (Table 5-24). These correlations were partly associated with the overall correlation between richness and total abundance. Adjusting richness for total abundance reversed the correlation for Phyllodocidae abundance, reduced correlations with Spionidae, Cirratulidae and Tellinidae abundances to approximately 0 and reduced the strength of positive correlations with Syllidae and amphipod abundances.

Correlations between absolute taxon abundances versus NMDS1 and NMDS2 scores in Table 5-24 were similar to correlations between relative abundances of the same taxa and the NMDS axes (Figure 5-30). Spionidae, Tellinidae and Phyllodocidae absolute and relative abundances were positively correlated with NMDS1. Syllidae absolute and relative abundances negatively correlated with NMDS1. Similarly, Cirratulidae absolute and relative abundances were positively correlated with NMDS2, and Paraonidae absolute and relative abundances negatively correlated with NMDS2. Overall amphipod abundance, and relative abundances of most individual amphipod families, were uncorrelated with the NMDS axes. Echinoderm abundance was also uncorrelated with the NMDS axes, and Echinarachnidae was the only individual echinoderm taxon strongly correlated with either NMDS axis (NMDS1; Figure 5-30).

Correlations With Sediment Physical and Chemical Characteristics

Table 5-25 provides rank correlations between benthic invertebrate community variables versus concentrations of >C_{10}-C_{21} HCs, barium, sulphur, sulphide and Sediment PC1 (a summary measure of other sediment physical and chemical characteristics).

Table 5-25 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs, Barium, Sulphur, Sulphide and Sediment PC1 (2008)

Community variable	>C_{10}-C_{21} HCs	Barium	Sulphur	Sulphide	Sediment PC1
Summary measures					
Total abundance (*N*)	0.336*	**0.467*** **	–0.002	0.284*	**0.542*** **
Standing crop (*B*)	–0.103	–0.059	0.109	0.016	0.100
Richness (*S*)	0.092	0.305*	–0.150	0.250	0.430**
Adjusted richness (*S2*)	–0.323*	–0.123	–0.255	0.043	0.015
NMDS1	**0.606*** **	**0.550*** **	0.179	0.350*	**0.543*** **
NMDS2	–0.254	–0.330*	0.084	**–0.458*** **	–0.361**
Taxon abundances					
Spionidae	0.422**	**0.507*** **	0.064	0.312*	**0.574*** **
Cirratulidae	0.277*	0.329*	0.185	0.155	0.385**
Syllidae	–0.220	–0.104	–0.343*	–0.206	–0.212
Orbiniidae	**–0.619*** **	**–0.578*** **	–0.061	–0.326*	–0.218
Paraonidae	–0.391**	–0.330*	–0.217	–0.010	–0.037
Phyllodocidae	**0.587*** **	**0.515*** **	0.272*	0.292*	**0.502*** **
Tellinidae	**0.649*** **	**0.579*** **	0.119	0.366**	**0.561*** **
Amphipoda	–0.274*	–0.032	–0.050	0.004	0.199
Echinodermata	**–0.468*** **	–0.319*	–0.243	–0.110	–0.164

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

Total abundance and NMDS1 (Spionidae dominance) were the only summary measures significantly positively correlated with >C_{10}-C_{21} HC concentrations (i.e., increased with increasing HC concentrations) (Table 5-25). Among the individual taxa, Spionidae, Cirratulidae, Phyllodocidae and Tellinidae, increased significantly in abundance with increasing >C_{10}-C_{21} HC concentrations (positive correlations in Table 5-25). In contrast, adjusted richness and abundances of Orbiniidae, Paraonidae, amphipods and echinoderms decreased significantly with increasing >C_{10}-C_{21} HC concentrations.

Positive correlations between benthic invertebrate community variables and barium were generally stronger, and negative correlations were generally weaker, than correlations between the same variables and $>C_{10}$-C_{21} HCs (Table 5-25). The correlations between community variables and barium reflect some natural cross-correlations between barium and other sediment physical and chemical characteristics positively correlated with community variables, as well as any direct or indirect project-related effects that may have occurred.

Syllidae (negative correlation) and Phyllodocidae abundances (positive correlation) were the only variables significantly correlated with sulphur concentrations and those correlations were weak ($0.01 < p < 0.05$).

NMDS1 scores, total abundance, Spionidae, Phyllodicidae and Tellinidae abundances were significantly positively correlated with sulphide concentrations. NMDS2 scores and Orbiinidae abundances were significantly negatively correlated with sulphide.

Total abundance, richness, NMDS1 and abundances of the dominant Spionidae and Cirratulidae and the sub-dominant Phyllodocidae and Tellinidae were significantly positively correlated with Sediment PC1 (Table 5-25).

Standing crop was uncorrelated with Sediment PC1. Richness was significantly positively correlated with Sediment PC1, but the correlation was removed when richness was adjusted for total abundance. NMDS1 scores, a measure of Spionidae dominance, was significantly positively correlated with Sediment PC1.

NMDS2 (Cirratulidae/Tanaidacea dominance) was significantly negatively correlated with Sediment PC1, despite the significant positive correlations between Cirratulidae abundance and both NMDS2 and PC1 (Table 5-25). Correlations between NMDS2 and sediment physical and chemical characteristics were often driven by differences in responses between Tanaidacea, rather than Cirratulidae, versus other taxa. (Appendix B-4 provides more detail and results for Tanaidacea and other taxa).

Sediment gravel and TOC content were the strongest individual physical and chemical correlates of most benthic invertebrate community variables (Table 5-26) and largely responsible for the strong correlations between community variables and Sediment PC1 in Table 5-25. Total abundance, Spionidae, Tellinidae and amphipod abundances and richness were significantly positively correlated with gravel content ($p < 0.01$); NMDS2 scores were significantly negatively correlated with gravel content at $p \leq 0.01$. In contrast, NMDS1 was the only community variable significantly correlated with fines content at $p \leq 0.01$, and only three other community variables (total abundance, Spionidae abundance and richness) were significantly correlated with fines content at $0.01 < p \leq 0.05$.

Table 5-26 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Sediment Particle Size, TOC, Metals, Ammonia and Redox (2008)

Community variable	Fines	Gravel	TOC	Metals PC1	Metals PC2	Ammonia	Redox
Summary measures							
Total abundance (*N*)	0.309*	**0.635*** **	**0.493*** **	0.298*	0.386**	0.345*	–0.043
Standing crop (*B*)	0.117	0.089	0.129	–0.022	–0.100	–0.115	0.061
Richness (*S*)	0.302*	**0.646*** **	0.296*	0.179	0.451**	0.319*	0.069
Adjusted richness (*S2*)	0.092	0.346*	–0.168	–0.061	0.250	0.017	0.202
NMDS1	0.385**	0.228	**0.639*** **	0.307*	0.266	0.192	–0.102
NMDS2	–0.229	–0.435**	–0.179	–0.188	–0.386**	–0.003	–0.083
Taxon abundances							
Spionidae	0.306*	**0.571*** **	**0.584*** **	0.332*	0.370**	0.317*	–0.057
Cirratulidae	0.220	0.244	0.422**	0.190	0.199	**0.459*** **	–0.062
Syllidae	–0.145	0.179	–0.289*	–0.035	–0.058	0.009	–0.026
Orbiniidae	–0.135	–0.136	–0.137	–0.219	–0.232	0.086	0.020
Paraonidae	–0.063	0.167	–0.081	–0.239	0.069	–0.039	–0.076
Phyllodocidae	0.241	0.219	**0.567*** **	0.233	0.160	0.238	–0.190
Tellinidae	0.221	**0.533*** **	**0.608*** **	0.237	0.305*	0.238	–0.096
Amphipoda	0.042	0.386**	0.092	–0.038	0.331*	0.345*	–0.050
Echinodermata	0.026	0.085	–0.203	–0.080	–0.079	–0.078	0.027

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

Total abundance, Spionidae, Cirratulidae, Phyllodocidae and Tellinidae abundances, as well as richness and NMDS1 scores, were significantly positively correlated with sediment TOC content (Table 5-26). In 2008, Syllidae abundance was the only community variable significantly negatively correlated with TOC, and that correlation was weak ($0.01 < p < 0.05$).

Correlations between community variables versus Metals PC1 and PC2 in Table 5-26 were generally weaker versions of correlations between the community variables and barium (Table 5-25). Metals PC1 was significantly positively correlated with total abundance, Spionidae abundance and NMDS1, but those correlations were significant only at $0.01 < p < 0.05$. Metals PC2 was significantly positively correlated with richness and total abundance, Spionidae, Tellinidae and amphipod abundances, and significantly negatively correlated with NMDS2. Four of these six correlations were significant at $p \leq 0.01$.

In 2008, total abundance, Spionidae, Cirratulidae, amphipod and Phoxocephalidae abundances were significantly positively correlated with ammonia concentrations (Table 5-26). There were few negative correlations between community variables and ammonia, and none were significant at $p \leq 0.01$. In past years, there have also been few negative correlations between ammonia and invertebrate community variables (Section 5.4.4.2; Appendix B-4). Community variables were also uncorrelated with redox levels in 2008.

In 2008, standing crop, and Orbiniidae, Paraonidae and echinoderm abundances, were not significantly correlated with Sediment PC1 (Table 5-25) or the individual sediment physical and chemical variables in Table 5-26.

Correlations With Toxicity Test Responses

In 2008, Microtox IC50s from laboratory toxicity tests were negatively correlated with most benthic community variables (i.e., toxicity and negative responses in the laboratory tests were generally greater at higher values of the field community variables) (Table 5-27). All correlations were weak, with only three (of 15) correlations significant at $p \leq 0.05$, and none significant at $p \leq 0.01$. None of the community variables, including amphipod abundance, was significantly correlated with amphipod survival in laboratory toxicity tests and all correlations were between $r_s = -0.2$ to 0.2 (Table 5-27).

Table 5-27 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables versus Sediment Toxicity Test Responses (2008)

Community variable	Microtox IC50	Amphipod survival
Summary measures		
Total abundance (*N*)	–0.329*	0.038
Standing crop (*B*)	–0.164	0.195
Richness (*S*)	–0.293*	0.031
Adjusted richness (*S2*)	–0.130	0.099
NMDS1	–0.142	0.002
NMDS2	0.133	–0.130
Taxon abundances		
Spionidae	–0.307*	0.024
Cirratulidae	–0.204	–0.176
Syllidae	–0.023	0.050

Community variable	Microtox IC50	Amphipod survival
Orbiniidae	0.169	–0.024
Paraonidae	0.195	0.105
Phyllodocidae	–0.014	–0.030
Tellinidae	–0.242	0.032
Amphipoda	–0.057	0.114
Echinodermata	–0.179	–0.088

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

Distance Regressions

Based on rank-rank regressions, partial correlations between benthic invertebrate community variables and distance from the nearest FEZ drill centre were generally stronger than partial correlations between the community variables and distance from the FE drill centre (Table 5-28). Figure 5-31 provides distance plots for summary measures. Figure 5-32 provides distance plots for taxon abundances. The rank-rank regressions reduced the influence of extreme low or high values for some community variables that occurred at station 30(FE), 0.14 km from the FE drill centre, and there was little evidence of effects from the FE drill centre beyond station 30(FE) (see below). For most 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.

Total abundance and abundances of the dominant polychaete taxa Spionidae and Cirratulidae decreased with distance from the nearest drill centre and the nearest FEZ drill centre, but only the decrease in Cirratulidae abundance with distance from the FEZ drill centres was significant (Table 5-28). Syllidae abundances increased significantly with distance from the FEZ drill centres but decreased significantly with distance from the FE drill centre, with no net significant increase or decrease with distance from the nearest drill centre. With abundances of Orbiniidae, Paraonidae, amphipods and echinoderms increasing with distance, and abundances of Phyllodocidae and Tellinidae decreasing with distance, distance effects on sub-dominant taxa probably had a limited net effect on distance effects on total abundance.

Table 5-28 Results of Rank-Rank Regressions of Benthic Invertebrate Community Variables (Y) on Distance (X) Variables (2008)

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*: *Y*-FEZ *d*/ FE *d* constant	Partial *r*: *Y*-FE *d*/ FEZ *d* constant	r (=r_s)
Summary measures				
Total abundance (*N*)	0.205	–0.159	–0.097	–0.208
Standing crop (*B*)	0.354*	0.069	0.331*	0.196
Richness (*S*)	0.176	0.096	–0.164	0.023
Adjusted richness (*S2*)	0.424**	0.414**	–0.195	0.356*
NMDS1	0.406*	–0.405**	0.127	–0.441**
NMDS2	0.220	–0.114	0.208	0.133
Taxon abundances				
Spionidae	0.247	–0.231	–0.044	–0.260
Cirratulidae	0.403*	–0.394**	–0.014	–0.266
Syllidae	0.400*	0.329*	–0.312*	0.134
Orbiniidae	**0.714*** **	**0.648*** **	0.355**	**0.723*** **
Paraonidae	0.470**	**0.469*** **	–0.060	0.443**
Phyllodocidae	**0.588*** **	**–0.587*** **	0.191	**–0.510*** **
Tellinidae	**0.539*** **	**–0.525*** **	–0.041	**–0.505*** **
Amphipoda	0.345*	0.334*	0.024	0.380**
Echinodermata	**0.528*** **	**0.514*** **	0.046	**0.509*** **

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

Total abundance and abundances of the three dominant polychaete taxa were lowest at station 30(FE), 0.14 km from the FE drill centre (far left circles in distance plots in Figures 5-31 and 5-32) but were intermediate to high at station 31(FE), 0.37 km from the FE drill centre. Orbiniidae, Paraonidae, amphipod and echinoderm abundances were all 0 at station 30(FE), but except for Orbiniidae abundance, not markedly lower at station 31(FE) than at other stations. Therefore, if there were any effects (i.e., reduced abundances) from the FE drill centre, they were generally restricted to station 30(FE).

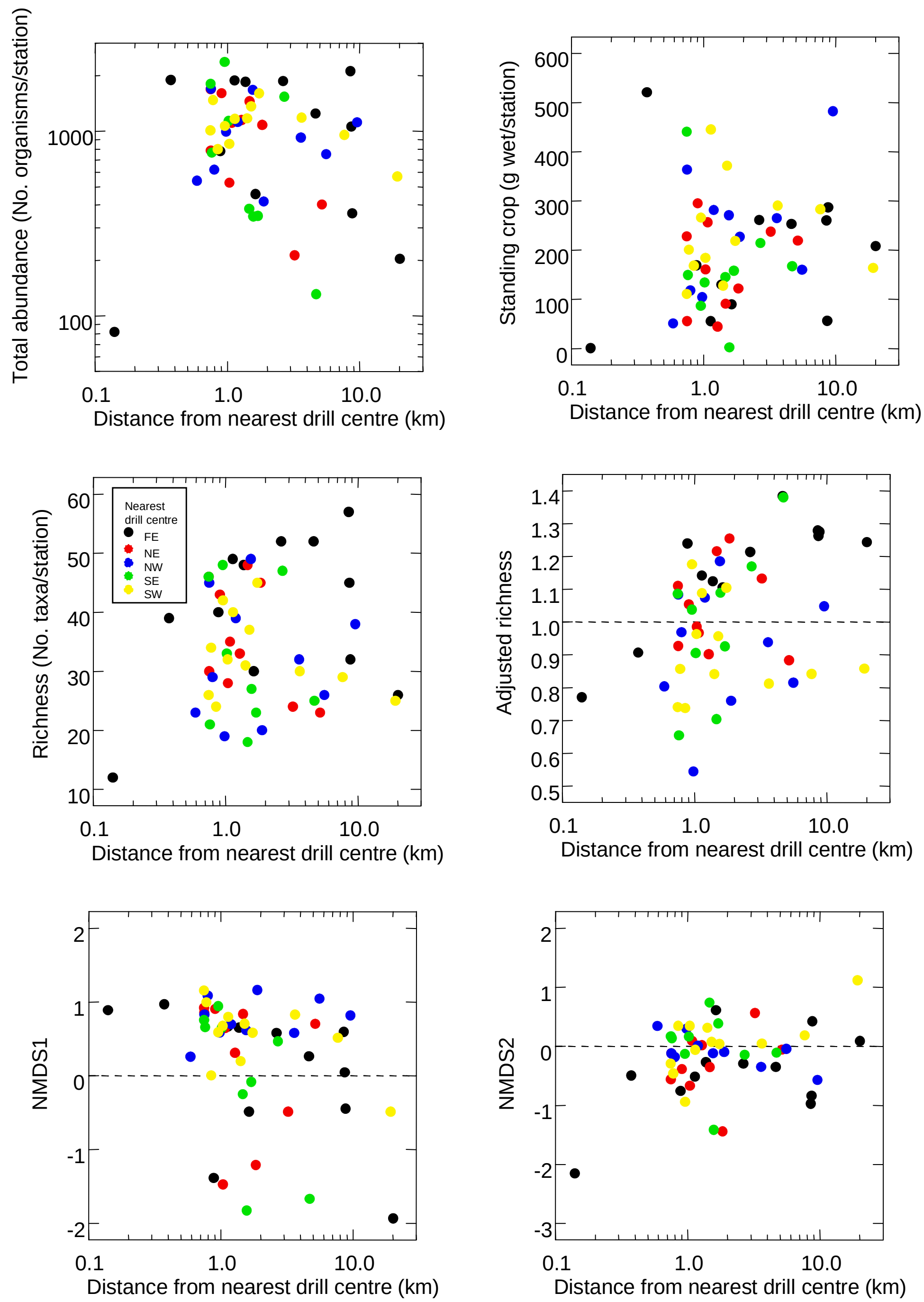

Figure 5-31 Distance Gradients for Benthic Invertebrate Summary Measures (2008)

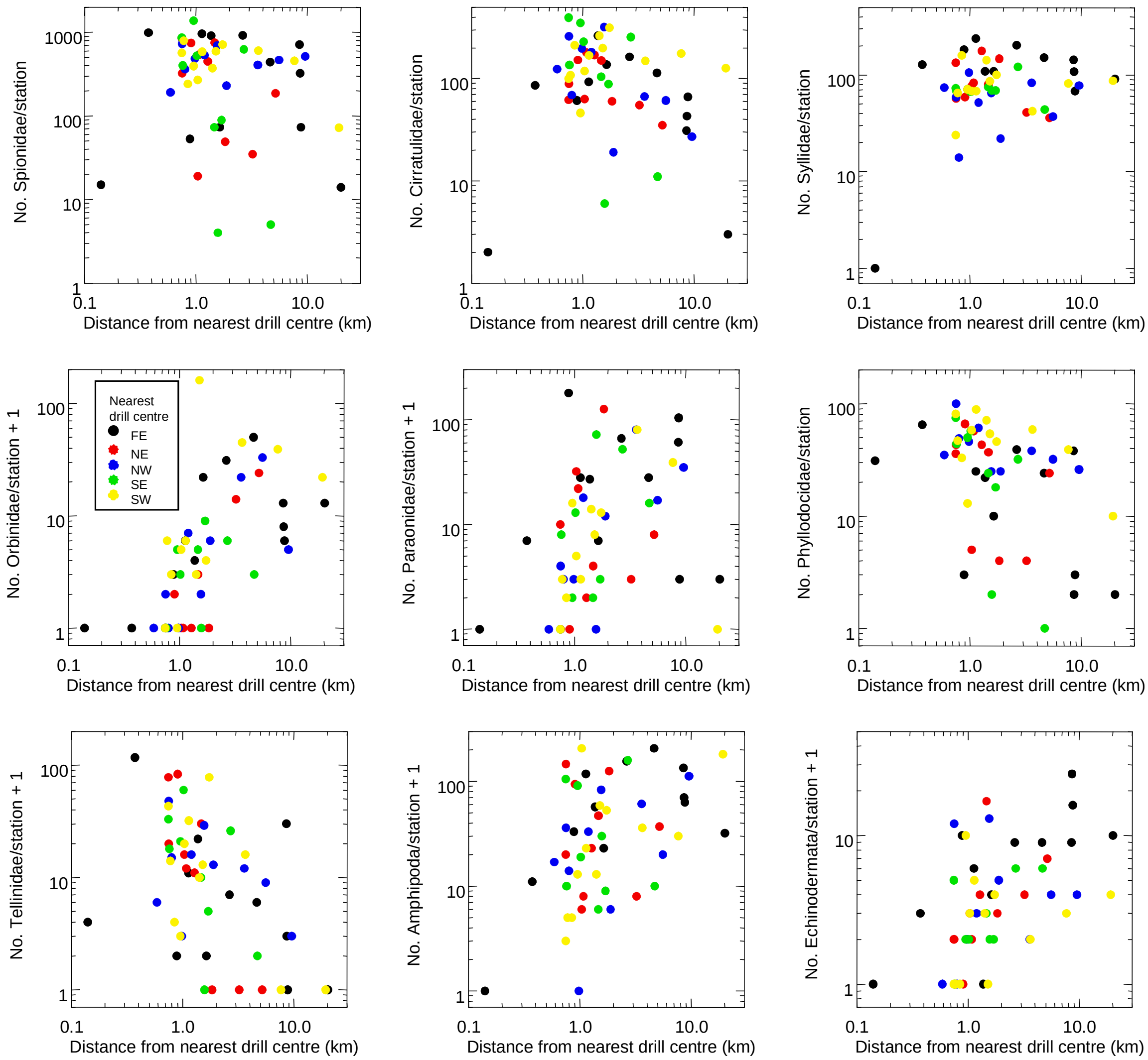

Figure 5-32 Distance Gradients for Benthic Invertebrate Taxon Abundances (2008)

In 2008, standing crop was significantly positively correlated with distance from the FE drill centre and not significantly correlated with distances from the nearest FEZ drill centre (Table 5-28). Standing crop has always increased with distance from the FE drill centre and, more generally, from East to West, even in baseline (1997) (Section 5.4.3.3).

In 2008, richness was not significantly correlated with distances from drill centres (Table 5-28). However, richness adjusted for total abundance increased with distance from the FEZ drill centres and distance from the nearest drill centre.

Richness was lowest at station 30(FE) (12 taxa collected), but adjusted richness (i.e., richness relative to abundance) was higher at that station than at some other stations because total abundance was also low (Figure 5-31).

NMDS1 scores (Spionidae dominance) decreased significantly with distance from the FEZ drill centres and from the nearest drill centre (Table 5-28). To some extent, this distance gradient was a function of decreases in Spionidae abundance (positively correlated with NMDS1) and increases in Syllidae abundance (negatively correlated with NMDS1) with distance. However, these were relatively weak correlations that were not significant. Decreases in NMDS1 scores with distance were also affected by the significant decreases in Phyllodocidae and Tellinidae abundances (both positively correlated with NMDS1) with distance. The NMDS1 score for station 30(FE) was higher than at most other stations (Figure 5-31) because Phyllodocidae were more abundant there than any other polychaetes, including Spionidae (Figures 5-32).

NMDS2 scores (Cirratulidae/Tanaidacea dominance) were not significantly correlated with distance measures (Table 5-28). Abundances of Cirratulidae decreased, and abundances of Tanaidacea increased, with distance from the nearest drill centre.

In 2008, distance correlations were strongest for Orbiniidae, echinoderms (positive correlations), Phyllodocidae and Tellinidae (negative correlations) (Table 5-28). All 16 abundances of 0 for Orbiniidae and all 10 abundances of 0 for echinoderms occurred at stations within 2 km of drill centres (Figure 5-32). In contrast, all 8 abundances of 0 for Tellinidae occurred at stations more than 1 km from drill centres, with 6 of those 0 abundances occurring at stations more than 2 km from drill centres.

5.4.3.3 Comparison Among Years

Baseline (1997) Wash Samples

Table 5-29 provides medians, minima, maxima and distance correlations (r_s) for selected benthic invertebrate community variables based on baseline (1997) Wash samples from 54 stations. Given that community variable values for baseline Wash samples versus EEM Elutriate samples were rarely directly comparable (see below), the baseline distance correlations in Table 5-29 were primarily useful for:

1. demonstrating the general point that significant natural distance gradients could occur for community variables; and
2. qualitative comparisons of the signs, if not magnitude, of baseline versus EEM distance correlations.

Table 5-29 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Distance Measures (1997 Wash Samples)

Variable	EEM Elutriate samples	Baseline (1997) Wash samples						
					r_s with distance from:			
	Median	Median	Minimum	Maximum	Nearest of NE, SW drill centres	Nearest FEZ drill centre	FE drill centre	Nearest drill centre
Summary measures								
Total abundance (*N*)	647	62	16	269	–0.276*	–0.263	0.149	–0.065
Standing crop (*B*)	170	174	11	395	0.092	0.092	**0.508*** **	0.338*
Richness (*S*)	30	14	4	33	–0.287*	–0.205	–0.240	–0.137
Taxon abundances								
Spionidae	216	2	0	13	–0.339*	–0.266	–0.034	–0.194
Cirratulidae	96	1	0	15	–0.039	0.137	–0.053	0.098
Orbiniidae	3	4	0	22	–0.115	0.007	0.235	0.164
Phyllodocidae	19	2	0	10	–0.426**	–0.246	0.009	–0.135
Bivalvia	11	5	0	18	0.295*	0.296*	0.409**	0.370**
Balanidae	2	11.5	0	210	–0.289*	–0.332*	0.131	–0.153
Amphipoda	18	3	0	18	–0.095	–0.095	–0.017	–0.090
Echinodermata	4	3	0	19	–0.094	–0.047	–0.056	0.105

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- Units are No. organisms/station for total and taxon abundances; g wet/station for standing crop; No. Taxa/station for richness.
- n = 54 baseline stations processed using the Wash recovery method; n = 298 EEM stations processed using the Elutriate recovery method.

The Wash method recovered fewer organisms, particularly smaller organisms, than the Elutriate method used to process most EEM samples in 2001 and all EEM samples since then (compare baseline Wash versus EEM Elutriate medians in Table 5-29). Median total abundances were 10 times greater in Elutriate samples than in Wash samples. Balanidae (barnacles) accounted for almost 50% of the organisms recovered in Wash samples versus 2% of the organisms recovered in Elutriate samples. Orbiniidae were more abundant than Spionidae, Cirratulidae and Syllidae (the three dominants in Elutriate samples) in the Wash samples. In general, abundances of larger/heavier organisms such as echinoderms, bivalves and Balanidae, plus standing crop (largely dependent on larger/heavier organisms), were the variables most comparable between baseline Wash and EEM Elutriate samples.

Table 5-29 excludes Syllidae, Paraonidae and Tellinidae because median abundances of those taxa in baseline Wash samples were 0 (i.e., the taxa were collected at less than 50% of stations). Adjusted richness and NMDS scores for baseline Wash samples are not provided because they were calculated based on Elutriate samples.

EEM Elutriate Samples

Figure 5-33 provides rank correlations (r_s) between invertebrate community summary measures and distance to the nearest active drill centre for Elutriate samples. Figure 5-34 provides distance correlations for taxon abundances. In each figure, the distance correlation (Y scale) is the same for all variables to facilitate comparison among variables. The NE and SW drill centres were active in 2000. Drilling began at the NW and SE drill centres before sampling in 2001 and drilling began at the FE drill centre before sampling in 2002 (indicated by the vertical dashed line between 2001 and 2002). The horizontal dashed lines in Figure 5-33 and similar figures indicate r_s = –0.3 and r_s = 0.3, which would be significant at p of approximately 0.05 for EEM years with 38 (2000) to 53 stations sampled and processed using the Elutriate recovery method in each year.

Total abundance decreased with increasing distance from drill centres in every EEM year but the distance correlation was only stronger than r_s = –0.3 and significant in 2004 (Figure 5-33). Distance correlations were also negative in all EEM years for Spionidae and Cirratulidae abundances, with the strongest correlations occurring in 2004 (Figure 5-34). In contrast, Syllidae abundances increased with distance in every EEM year, although distance correlations were weak (all $r_s \leq 0.2$) and not significant in any year. Baseline (1997) distance correlations were also significantly negative for total and Spionidae abundances, based on distances from the nearest of the NE and SW drill centres or the nearest FEZ drill centres (Table 5-29), suggesting that there was some natural tendency for total abundance and Spionidae abundance to decrease with distance from the centre of the Terra Nova development. Distance correlations for sub-dominants were a mix of positive and negative correlations, which would limit their net effect on distance correlations for total abundance.

Distance correlations for standing crop were near 0 to positive in EEM years (Figure 5-33). The strongest distance correlations (r_s = 0.2 to 0.4) occurred from 2004 to 2008, and were similar to the baseline (1997) correlation (r_s = 0.338) with distance to the nearest of the five drill centres (Table 5-29).

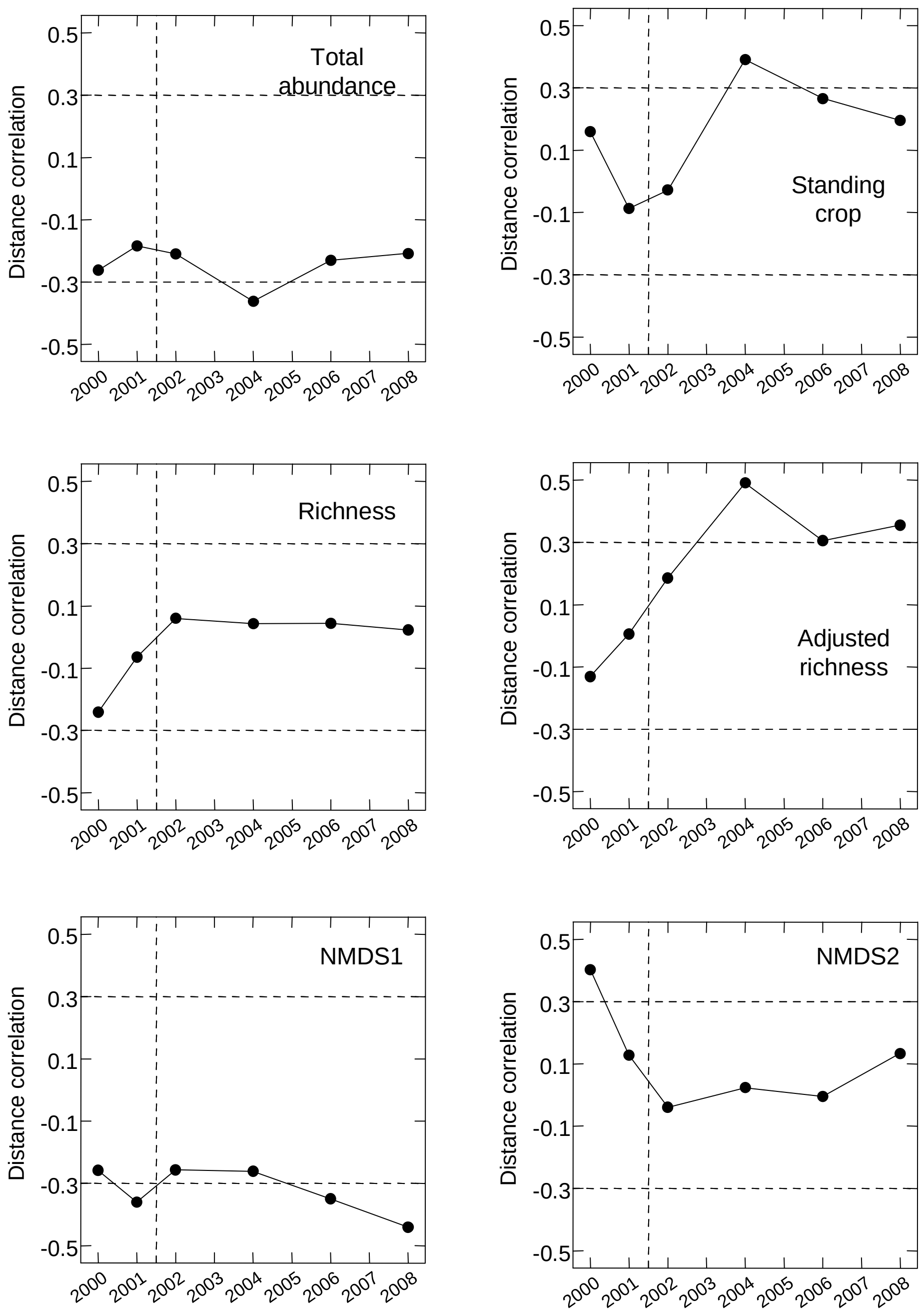

Figure 5-33 Annual Distance Correlations (r_s) for Benthic Invertebrate Community Summary Measures (Elutriate Samples from All Stations)

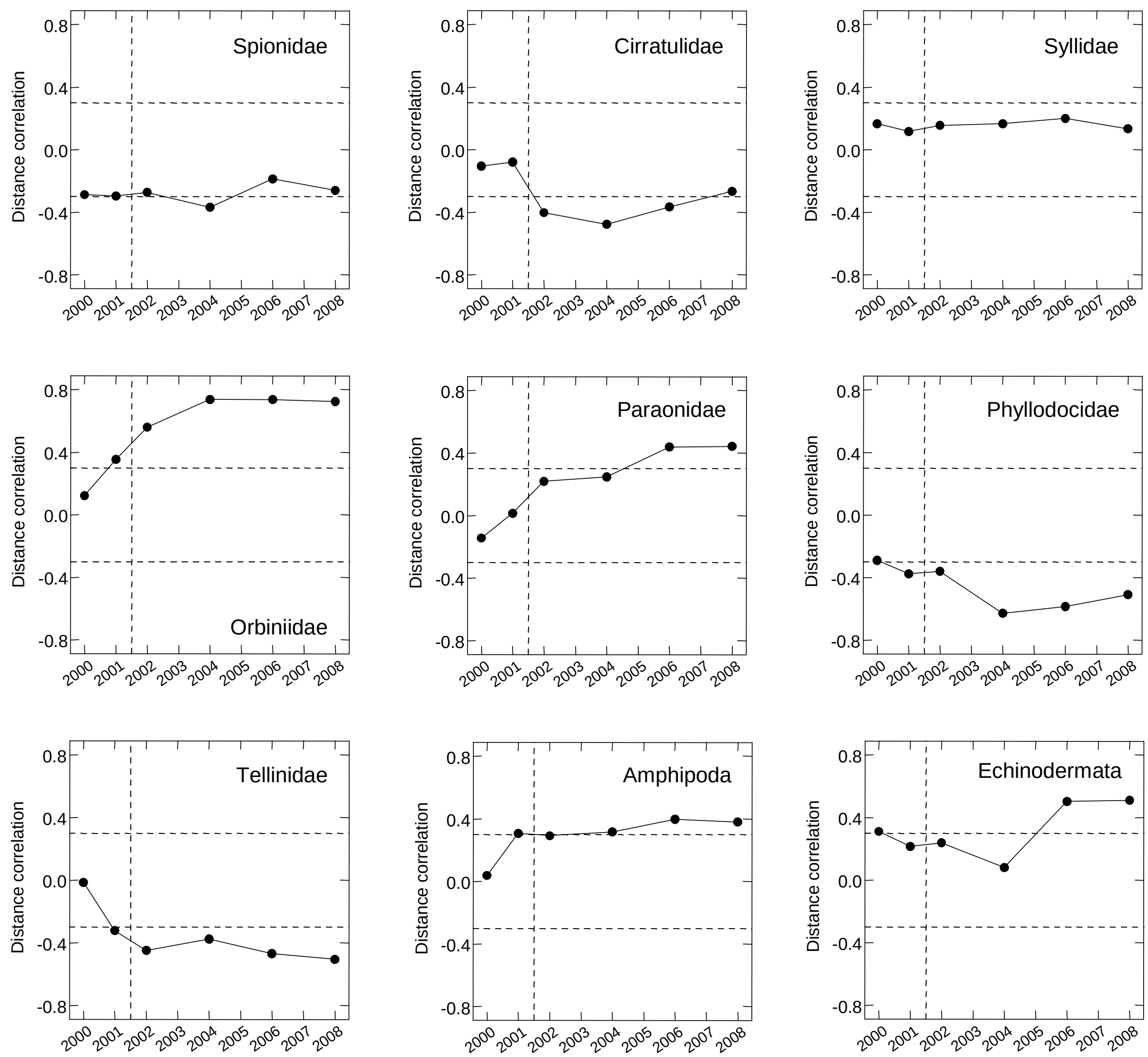

Figure 5-34 Annual Distance Correlations (r_s) for Benthic Invertebrate Taxon Abundances (Elutriate Samples from All Stations)

Distance correlations for richness were not significant in any EEM year, and decreased in strength from $r_s \approx -0.25$ in 2000 to $r_s = 0$ to 0.1 from 2002 to 2008 (Figure 5-33). Baseline (1997) distance correlations were negative (as in 2000), and significant based on distance to the nearest of the NE and SW drill centres (the drill centres active in 2000) (Table 5-29). Distance correlations for adjusted richness progressively increased from weakly negative in 2000 to positive and significant ($r_s \geq 0.3$) from 2004 to 2008 (Figure 5-33).

NMDS1 scores (Spionidae dominance) decreased with distance to the nearest active drill centre in every EEM year (Figure 5-33). The distance correlations were a function of the negative distance correlations for Spionidae, Phyllodocidae and Tellinidae abundances, all positively correlated with NMDS1, and the weak positive distance correlations for Syllidae abundance (Figure 5-34), which was negatively correlated with NMDS1.

NMDS2 scores (Cirratulidae/Tanaidacea dominance) were significantly positively correlated with distance in 2000 but not in subsequent years (Figure 5-33). Distance correlations for NMDS2 represented a mix of positive correlations for Tanaidacea abundance, negative correlations for Cirratulidae abundance and both positive and negative correlations for abundances of other sub-dominants negatively correlated with NMDS2 (e.g., Paraonidae and Balanidae; Figure 5-34 and Appendix B-4).

Among the sub-dominant taxa, distance correlations for Orbiniidae, Paraonidae, amphipods and echinoderms were approximately 0 to significantly positive and generally increased in strength over time (Figure 5-34). Distance correlations for Phyllodocidae and Tellinidae were 0 to significantly negative, again increasing in strength over time.

Total abundance increased from 2000 to 2008, with medians approximately doubling from 500 to 1,000 organisms/station (Figure 5-35). Median abundance of Spionidae and, to some extent, Cirratulidae also increased over time (Figure 5-36). For total abundance, Spionidae and Cirratulidae abundances, the greatest increases occurred in recent years (i.e., from 2004 to 2008). Syllidae abundances were greatest in 2002.

Medians and 80th percentiles for standing crop decreased from 2000 to 2002, with 2006 and 2008 values similar to those observed in 2000 (Figure 5-35). 20th percentiles remained relatively constant over time at approximately 100 g wet/station. Note that the overall median for EEM years was similar to the baseline median (Table 5-29). The Wash method should recover most of the larger and heavier organisms contributing to standing crop recovered by the Elutriate method.

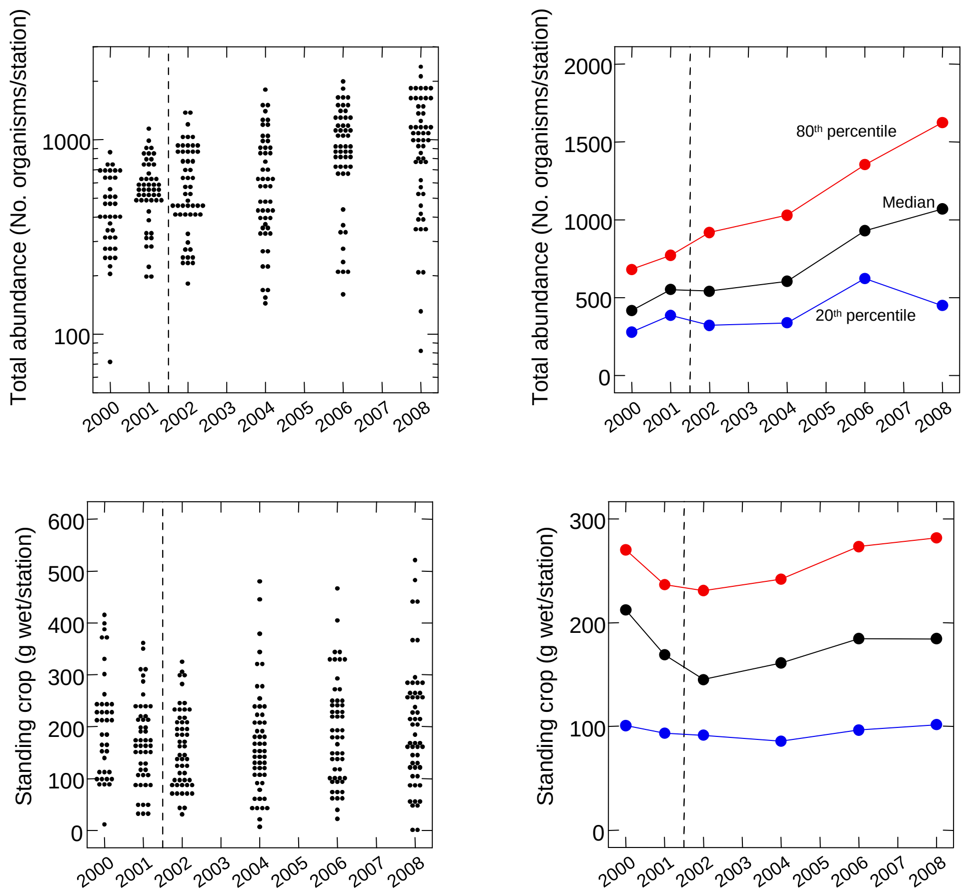

Figure 5-35 Annual Distributions, Medians and 20th and 80th Percentiles for Total Abundance and Standing Crop (Elutriate Samples from All Stations)

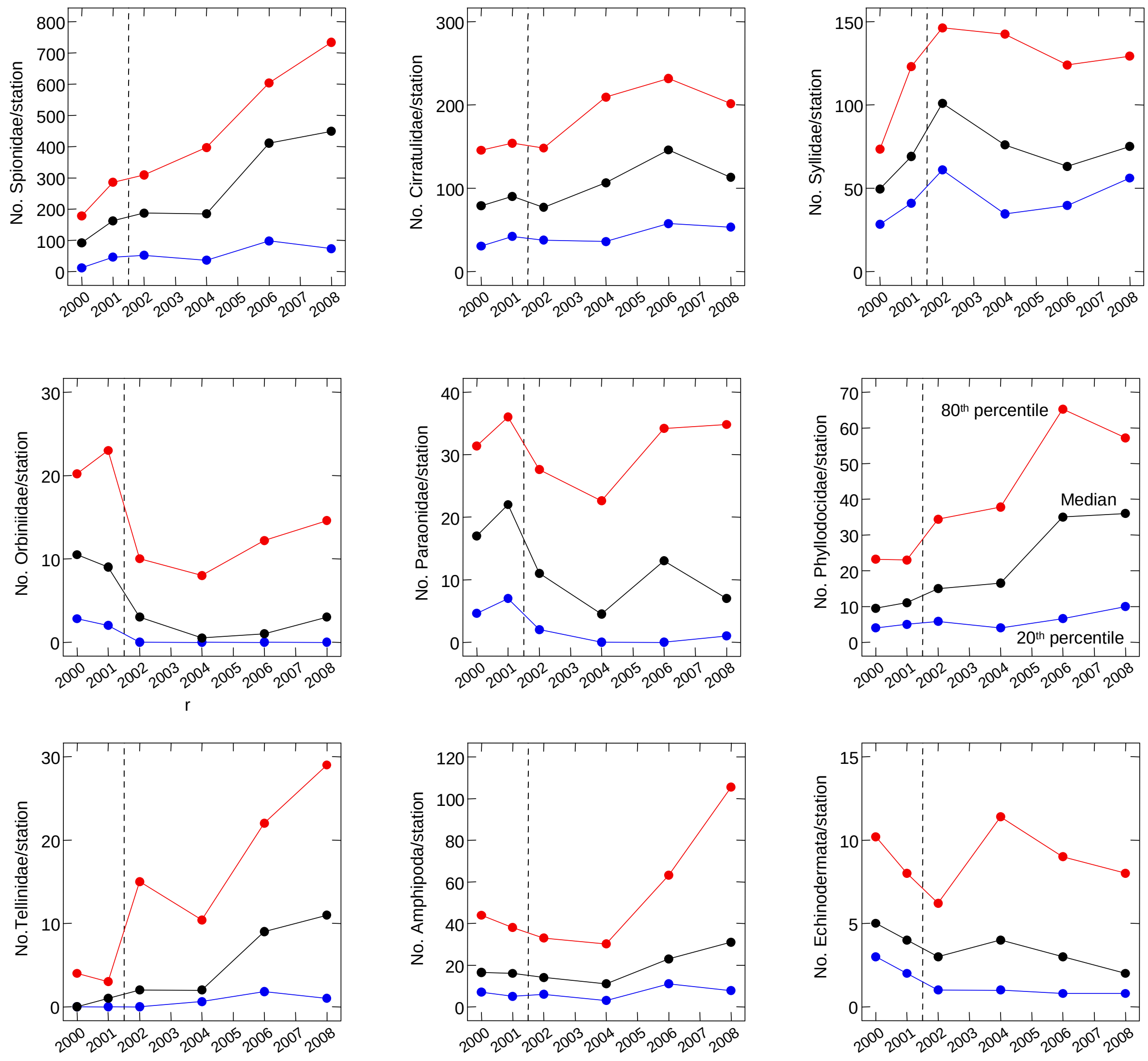

Figure 5-36 Annual Median and 20th and 80th Percentiles for Benthic Invertebrate Taxon Abundances (Elutriate Samples from All Stations)

Medians, 20th and 80th percentiles for richness decreased from 2000 to 2004, then returned to 2000 values by 2008 (Figure 5-37). Adjusted richness medians, 20th and 80th percentiles also decreased from 2000 to 2004, then increased in subsequent years, but not to 2000 values.

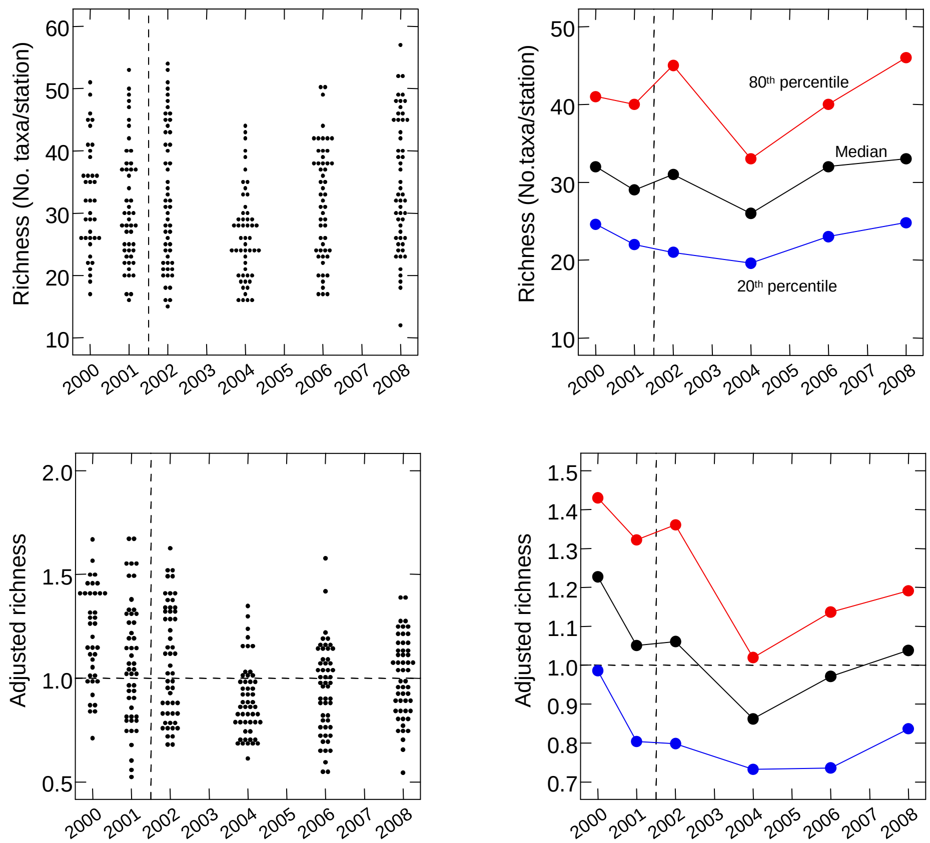

Figure 5-37 Annual Medians and 20th and 80th Percentiles for Richness and Adjusted Richness (Elutriate Samples from All Stations)

Medians and 20th percentiles for NMDS1 increased progressively over time in EEM years; 80th percentiles also increased, but to a lesser extent (Figure 5-38). There were fewer low (i.e., negative) NMDS1 scores in recent years (see distributions of individual values in Figure 5-38), and there was an upper limit to NMDS1 scores (approximately 1) as communities approached complete (i.e., 100%) dominance by Spionidae, Tellinidae and/or Phyllodocidae. Annual medians, 20th and 80th percentiles for NMDS2 did not change substantially over time.

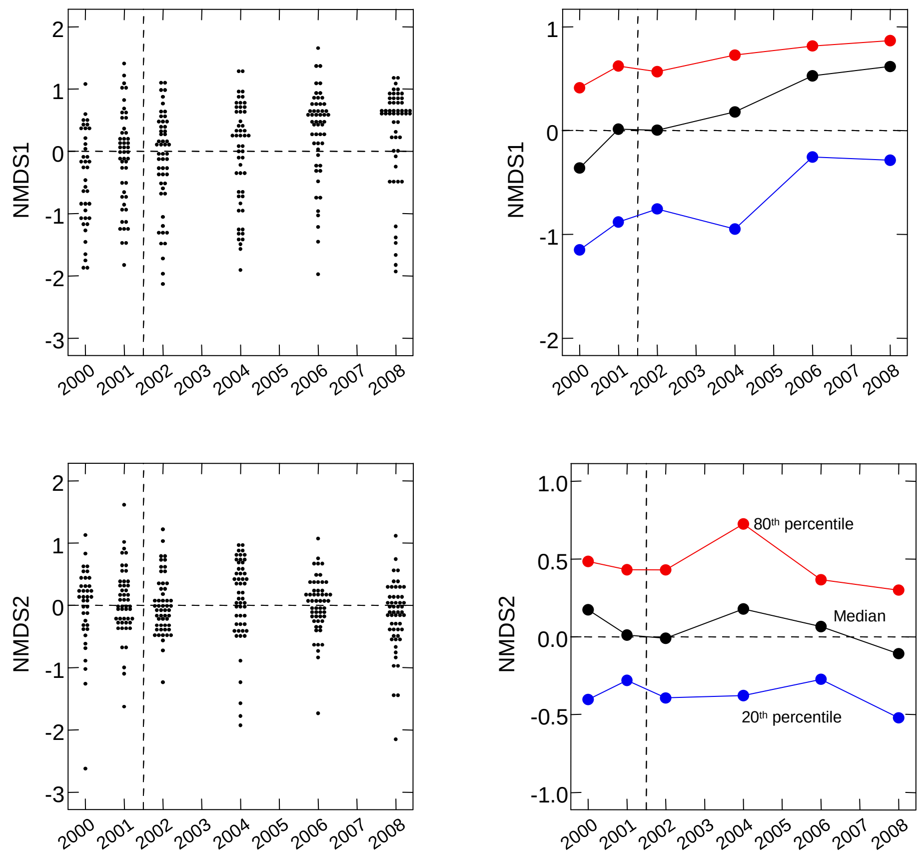

Figure 5-38 Annual Distributions, Medians and 20th and 80th Percentiles for NMDS1 and NMDS2 (Elutriate Samples from All Stations)

Median abundances of Orbiniidae, Paraonidae and echinoderms decreased after drilling began at the FE drill centre prior to 2002 sampling (Figure 5-36). Decreases in abundances of these three taxa were greatest at stations near active drill centres, as indicated by the increased strength of positive distance correlations over time in Figure 5-34.

Medians and 80th percentiles for amphipod abundance increased in 2006 and 2008 relative to previous years (Figure 5-36), although distance correlations did not change (Figure 5-34). The recent increases in amphipod abundance, especially 80th percentiles, were largely attributable to increased abundances of Oedicerotidae and Stenothoidae, two sub-dominant taxa largely unaffected by distance (Appendix B-4).

Medians and 80th percentiles for Phyllodocidae abundance increased approximately 3-fold between 2000 and 2008, with the greatest increases occurring in 2006 and 2008 (Figure 5-36). Median Tellinidae abundances per station increased from 0 in 2000 to approximately 10 in 2008; 80th percentiles increased from 3 to 4

Tellinidae/station in 2000 and 2001 to almost 30 Tellinidae/station in 2008. The increases in Phyllodocidae and Tellinidae abundance over time were greatest at stations near active drill centres, as the increased strength of distance correlations over time in Figure 5-34 indicates**.**

Table 5-30 provides results of RM regression analysis comparing benthic invertebrate community summary measures among years. Stations included were the 47 stations re-sampled every year and processed using the Elutriate recovery method. Station 30(FE) (re-sampled every year), 0.14 km from the FE drill centre, was excluded from the RM analyses because values for that station were often outliers after drilling began at the FE drill centre. 2000 was also excluded because some samples were processed using the Wash method in that year.

Appendix B-4 provides details on the RM models. For interpretation of RM regression results in Table 5-30 and elsewhere:

1. **The Among Stations terms** test relationships between multi-year means and the two distance (*X*) measures (FEZ and FE *d*). 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 *Y* values over time were similar at all or most stations, unless distance slopes also differ at $p \leq 0.01$. In the latter cases, changes over time may differ among stations and distances.
3. **The Within Stations Overall terms** test for *any* differences in intercepts or distance gradients among years.
4. **The Before versus After FE drilling contrasts** tests for a differences between 2000 and 2001 versus 2002 to 2008.
5. **The Trend (2002 to 2008) contrasts** test for a progressive increase or decrease in intercepts or distance gradients over time after drilling began at the FE drill centre and continued at the FEZ drill centres.

Results in Table 5-30 and elsewhere are presented as *F* values. $F > 1$ indicates added variance attributable to the term tested.

Table 5-30 Results (F Values) of RM Regressions Comparing Benthic Invertebrate Community Variables Among EEM Years (2001 to 2008)

Term	**Total Abundance (*N*)**	**Standing crop (*B*)**	**Richness (*S*)**	**Adjusted Richness (*S2*)**	**NMDS1**	**NMDS2**
Among Stations						
FEZ *d*	5.4*	0.0	0.4	8.2**	11.8**	0.0
FE *d*	0.5	**15.2*** **	1.6	1.9	3.3	1.1
Error 1	**6.7*** **	1.6*	**14.3*** **	**6.8*** **	**17.3*** **	**11.2*** **
Within Stations						
Overall						
Year	4.7**	3.3*	**8.9*** **	**6.9*** **	**9.3*** **	1.5
Year × FEZ *d*	1.1	1.3	0.9	1.9	0.851	1.6
Year × FE *d*	1.3	3.2*	2.5*	2.6*	2.6*	0.6
Before versus After FE Drilling (2001 vs 2002 to 2008)						
Year	3.7	0.0	2.1	7.2*	6.9*	0.0
Year × FEZ *d*	2.3	1.6	1.1	3.7	0.0	2.7
Year × FE *d*	0.1	0.1	2.3	0.8	1.9	0.1
Trend (2002 to 2008)						
Year	11.6**	0.6	7.7**	0.1	**40.0*** **	5.1*
Year × FEZ *d*	0.0	0.1	0.8	0.9	1.4	0.7
Year × FE *d*	0.1	0.0	3.5	2.6	8.2**	2.0

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- Distance variables (*X*), total abundance and adjusted richness were log-transformed.
- $n = 47$ stations (station 30(FE) excluded).
- *A*ll samples processed with the Elutriate recovery method.
- See Appendix B-4 for description and interpretation of terms in the RM regression models.

RM regression results for individual summary measures are discussed in more detail below, but there were some results common to all variables. Differences in regression intercepts among years were significant for all summary measures except NMDS2 (Table 5-30). With few changes in distance gradients significant at $p \le 0.01$, changes in intercepts over time generally indicated that increases or decreases occurred at all or most stations and paralleled time changes for medians in Figure 5-35. Carry-over effects were highly significant ($p \le 0.001$) for all summary measures except standing crop ($0.01 < p < 0.05$) (Table 5-30). Overall FEZ distance gradients were significant for some variables, but did not differ significantly among years for any variable. Except for standing crop, overall FE distance gradients (station 30(FE) excluded) were not significant. There were some significant changes in FE distance gradients over time, but differences between 2001 versus 2002 to 2008 (i.e., Before versus After drilling began at the FE drill centre) were not significant for any variable (Table 5-30).

RM regression intercepts for total abundance differed significantly among years (Table 5-30), with intercepts increasing from 2002 to 2008 (as did medians; Figure 5-35). Total abundance decreased significantly with distance from the FEZ drill centres over all EEM years from 2001 to 2008 (Table 5-30). Multiple regression slopes for distance from the FEZ drill centres were negative in every EEM year, including 2000 (Figure 5-39; the distance slopes for 2001 to 2008 exclude station 30(FE) and the distance slopes for 2000 exclude 11 of the 47 other RM stations sampled in later years). There were no significant differences in FEZ distance gradients from 2001 to 2008, despite continued drilling activity at the FEZ drill centres, and the distance slope in 2000, when only the NE and SW drill centres were active, was not weaker than slopes in later years (Table 5-30). The negative correlation between total abundance and distance from the FEZ drill centres in 1997 (Table 5-29) suggests that the EEM FEZ distance gradients may have been partly to largely natural rather than related to drilling activity at the FEZ drill centres.

With station 30(FE) excluded, the overall FE distance gradient for total abundance was not significant for 2001 to 2008 and there were no significant differences in FE distance gradients among years (Table 5-30). In 2000 and 2001, before drilling began at the FE drill centre, total abundances at stations 29(FE), 30(FE) and 31(FE), all within 1 km of the FE drill centre, were similar (Figure 5-40). After drilling began at the FE drill centre, total abundance was lower at station 30(FE) than at the other two stations in 2002, 2004 and 2008, although only the 2008 difference could be considered large.

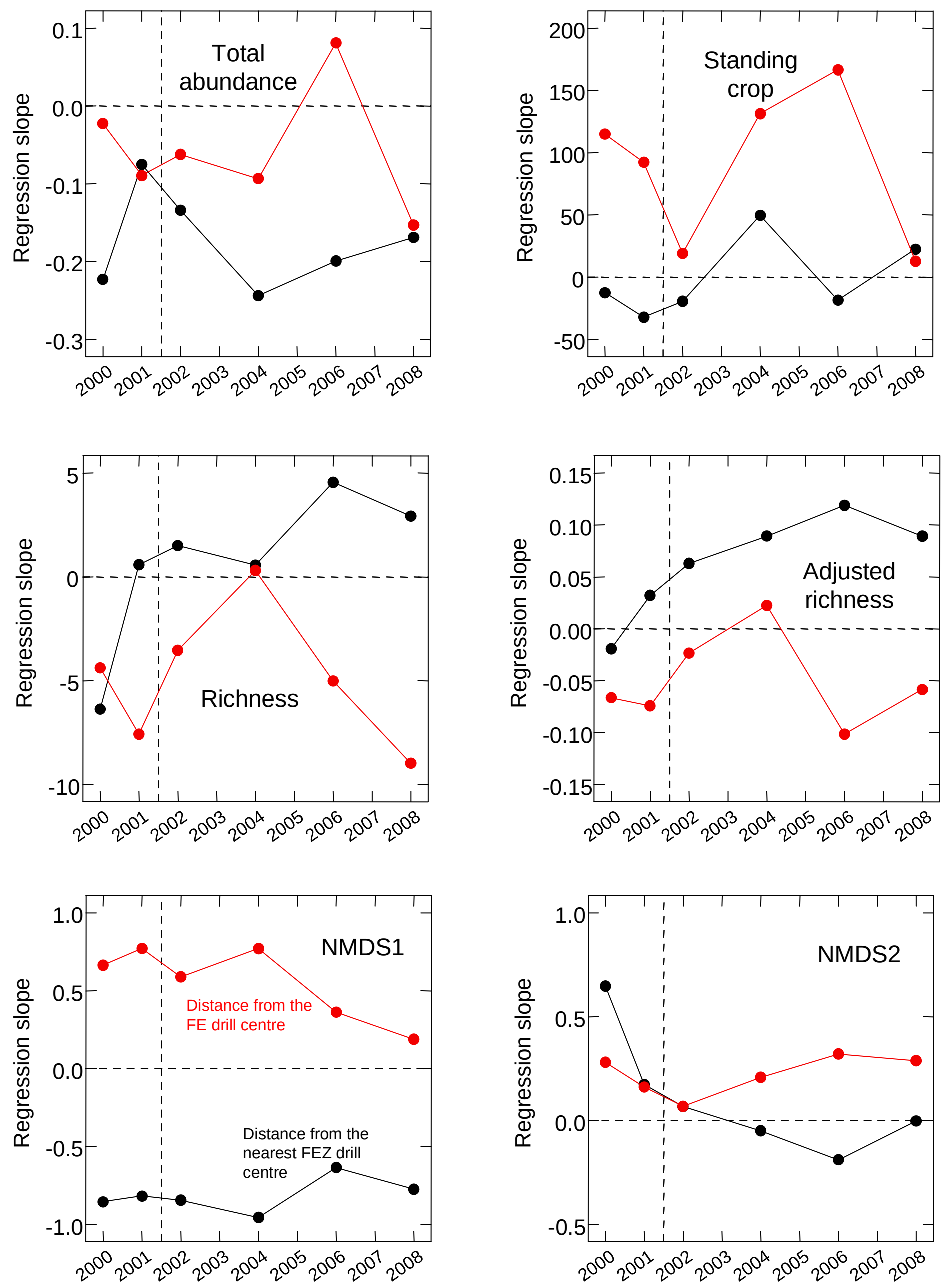

Figure 5-39 Multiple Regression Distance Slopes for Benthic Invertebrate Summary Measures (Elutriate Samples with Station 30(FE) Excluded)

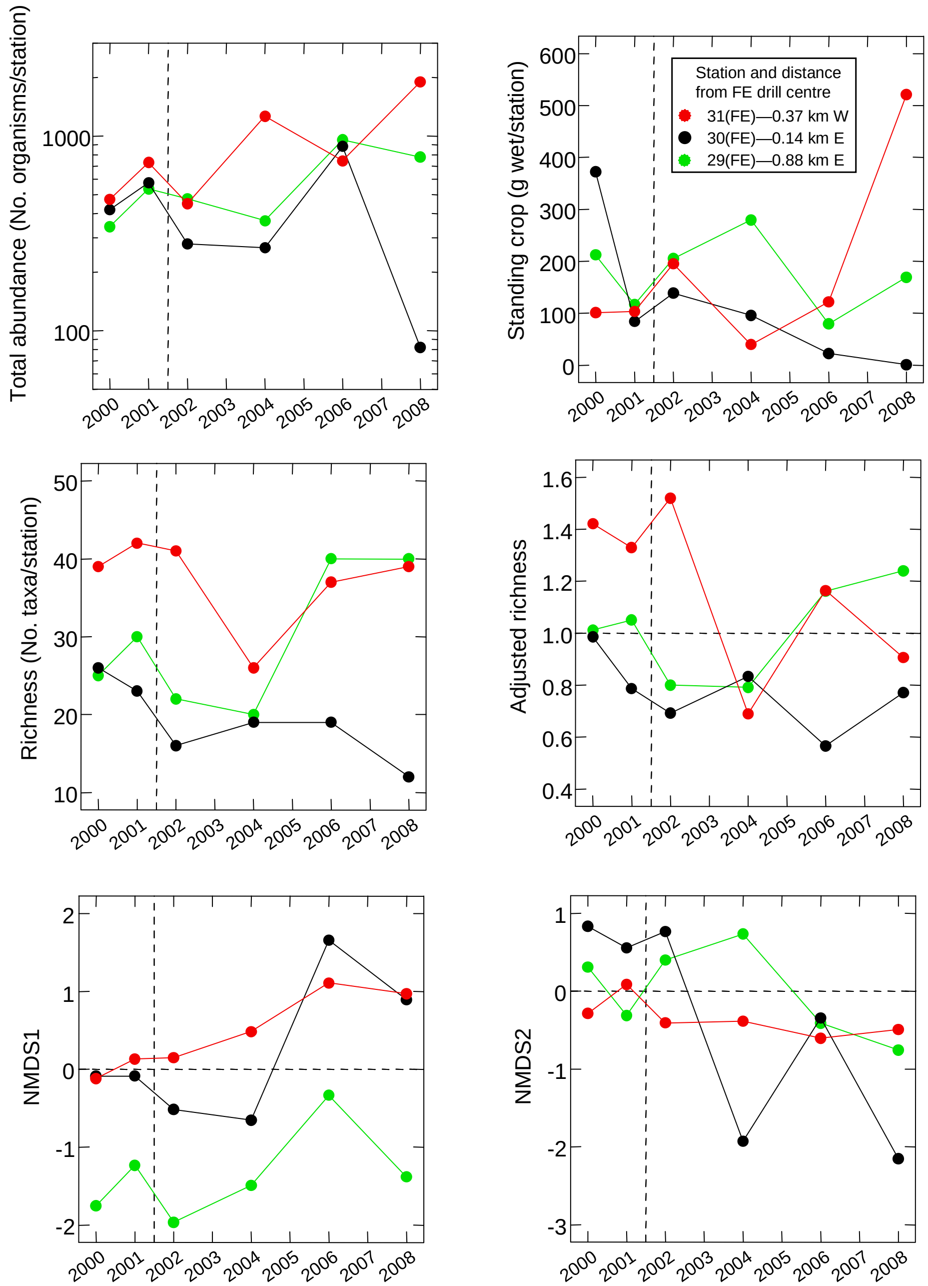

Figure 5-40 Benthic Invertebrate Community Summary Measure Values at the Three Stations Nearest the FE Drill Centre

Differences in regression intercepts among years and carry-over effects for standing crop were significant at $p < 0.05$, but weaker (lower F) than for most other summary measures (Table 5-30). The overall FEZ distance gradient for standing crop, and changes in that gradient over time, were not significant (Table 5-30). FEZ distance slopes for standing crop were positive in some EEM years and negative in others, and were generally weaker than FE distance slopes (Figure 5-39). There was also no correlation between standing crop and distance from the FEZ drill centres in 1997 (Table 5-29).

FE distance gradients for standing crop were highly significant ($p < 0.001$) over all EEM years from 2001 to 2008 (Table 5-30), with distance slopes positive in all years (Figure 5-39). The FE distance gradients differed significantly over time (Table 5-30), with gradients weaker in 2002 and 2008 than in other EEM years. The FE distance gradients were presumably natural, since they occurred in 2000 and 2001, before drilling began at the FE drill centre, and the gradient was also highly significant in 1997 (Table 5-29). The gradients were partly an East-West gradient, with standing crop decreasing from West to East. Standing crop was negatively and often significantly correlated with UTM Eastings in every year, including 1997.

If there were any effects of drilling at the FE drill centre on standing crop, they were restricted to station 30(FE), 0.14 km from the FE drill centre. From 2002 to 2008, standing crop at station 30(FE) progressively decreased from 130 to 0.75 g wet/station (Figure 5-40). The 2006 and 2008 values were the lowest observed in those years. In recent years, station 30(FE) was one of the few stations where both echinoderms and Tellinidae were rare or absent. Similar decreases did not occur at nearby stations 29(FE) and 31(FE), within 1 km of the FE drill centre (Figure 5-40).

Differences in regression intercepts among years for richness were significant at $p < 0.001$ for the years included in RM regression analyses (2001 to 2008; Table 5-30). Differences in regression intercepts among years and, specifically, the decrease between 2001 and later years, were significant for adjusted richness (Table 5-30; see also time profiles for medians in Figure 5-37).

The overall FEZ distance gradient, and changes in that gradient over time, were not significant for richness (Table 5-30). In contrast, the overall FEZ distance gradient was significant for adjusted richness, with distance slopes positive in all years except 2000 (Figure 5-39).

The overall FE distance gradient was not significant for either richness or adjusted richness (Table 5-30). Changes in the FE distance gradient were significant for both variables. FE distance slopes for both variables increased from negative in 2000 and 2001 to approximately 0 in 2004, then decreased in 2006 and 2008 to values comparable to 2000 and 2001 slopes (Figure 5-39). In EEM years, richness and adjusted richness at station 30(FE) were generally lower than at nearby stations 29(FE) and 31(FE) (Figure 5-40), probably partly to largely a natural and persistent small-scale difference (i.e., carry-over effect), especially in 2000 and 2001 before drilling began at the FE drill centre.

Regression intercepts for NMDS1 scores differed significantly among the years (2001 to 2008) included in RM regression analyses, with both the differences (increases) between 2001 and later years and the increasing trend from 2002 to 2008 significant (Table 5-30; see also Figure 5-38). In contrast, regression intercepts for NMDS2 did not differ significantly over all years included in RM analyses, although the trend (decrease) from 2002 to 2008 was significant (although not as evident for medians in Figure 5-38). Carry-over effects for NMDS1 were stronger than for any other summary measure (compare *F* values in Table 5-30).

The overall FEZ distance gradient for NMDS1 was significant (Table 5-30), as expected given that distance gradients for Spionidae, Phyllodocidae and Tellinidae abundances (positive correlates of NMDS1) were significant in most EEM years (Figure 5-34). FEZ distance slopes for NMDS1 were negative in all EEM years (Figure 5-39) and there were no significant differences in FEZ distance gradients among years (Table 5-30). In contrast, the overall FEZ distance gradient for NMDS2 was not significant (Table 5-30) and FEZ distance slopes were near 0 from 2001 to 2008 (Figure 5-39). FEZ distance slopes for NMDS2 were positive in 2000 and stronger than in later years, but still weaker than FEZ distance slopes for NMDS1.

Overall FE distance gradients for NMDS1 were not significant (Table 5-30), but there was a significant and progressive decrease in FE distance slopes (all positive) from 2002 to 2008 (Table 5-30; Figure 5-39). NMDS1 scores at station 29(FE), 0.88 km East of the FE drill centre, were consistently lower than NMDS1 scores at nearby stations 30(FE) and 31(FE) (Figure 5-40), which is an example of a strong small-scale carry-over effect. NMDS1 scores at stations 30(FE) and 31(FE) increased from near 0 in earlier years to approximately 1 in 2006 and 2008, consistent with the decrease in large-scale FE distance slopes from positive (i.e., lower values near the FE drill centre) to near 0. Therefore, NMDS1 scores for station 30(FE) would not be statistical outliers, although NMDS1 scores at that station have increased over time, primarily because Phyllodocidae and not Spionidae dominance increased from 2002 to 2008. In contrast, increases in NMDS1 scores at station 31(FE) and most other stations with higher NMDS1 scores were primarily a function of increased Spionidae dominance.

Overall FE distance gradients for NMDS2, and changes in those distance gradients over time, were not significant (Table 5-30). FE distance slopes were weakly positive in all years (Figure 5-39). NMDS2 scores decreased somewhat after 2002 at the three stations within 1 km of the FE drill centre, and values at station 30(FE) were the lowest values observed in 2004 and 2008 (Figure 5-40).

5.4.4 INTEGRATED ASSESSMENT

Given the large number of bivariate Spearman rank correlations (r_s) calculated and tested and the large sample sizes (especially for mean and overall correlations) for the integrated assessment of relationships among sediment components provided in this section, emphasis is on correlations significant at $p \leq 0.001$ (bold font in tables) and $|r_s| \geq 0.5$. Mean and overall correlations are provided in all cases as a measure of general long-term relationships, but these should be regarded with caution when $p \leq 0.01$ for tests of differences in correlations among years and/or when signs of correlations differ among years (van Belle and Hughes 1984).

5.4.4.1 Microtox Toxicity Test Responses versus Sediment Physical and Chemical Characteristics

Relationships with >C_{10}-C_{21} HCs

Table 5-31 provides bivariate Spearman rank correlations (r_s) between Microtox IC50s and toxicity[15] versus >C_{10}-C_{21} HC concentrations.

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[15] Toxicity is scored as 0/1 for non-toxic/toxic, with toxic samples defined as samples with IC50s < 50,000 mg wet/L).

Table 5-31 Spearman Rank Correlations (r_s) Between Microtox Toxicity Test Responses and Selected Sediment Physical and Chemical Variables (2000 to 2008)

Microtox response (*Y*)	***X* Variable**	**2000** *n*=49 stations	**2001** *n*=49 stations	**2002** *n*=53 stations	**2004** *n*=52 stations	**2006** *n*=53 stations	**2008** *n*=53 stations	**Diff. among years**	**Mean r_s**	**Overall r_s** *n*=309 stations
IC50	>C_{10}-C_{21} HCs	0.039	0.063	–0.353*	–0.174	–0.095	–0.190	NS	–0.123	–0.107
	Adjusted fines	**–0.608*** **	**–0.760*** **	**–0.571*** **	**–0.539*** **	–0.322*	**–0.522*** **	NS	**–0.550*** **	**–0.516*** **
	Strontium	**–0.749*** **	**–0.765*** **	**–0.626*** **	**–0.617*** **	–0.272*	**–0.518*** **	NS	**–0.587*** **	**–0.543*** **
	Metals PC1	–0.111	–0.452**	–0.401**	–0.160	–0.304*	**–0.601*** **	NS	**–0.340*** **	**–0.286*** **
	Metals PC2	**–0.564*** **	–0.396**	–0.444**	**–0.547*** **	–0.114	–0.133	NS	**–0.363*** **	**–0.348*** **
Non-toxic (*Y*=0) vs Toxic (*Y*=1)	>C_{10}-C_{21} HCs	0.005	–0.067	0.320*	0.195	0.101	0.194	NS	0.129	0.098
	Adjusted fines	**0.508*** **	**0.742*** **	**0.544*** **	**0.484*** **	0.337*	**0.480*** **	NS	**0.513*** **	**0.506*** **
	Strontium	**0.604*** **	**0.708*** **	**0.593*** **	**0.646*** **	0.296*	0.434**	NS	**0.544*** **	**0.541*** **
	Metals PC1	0.122	0.333*	0.379**	0.153	0.288*	0.394**	NS	**0.280*** **	**0.286*** **
	Metals PC2	**0.544*** **	**0.497*** **	0.355*	**0.562*** **	0.136	0.319*	NS	**0.399*** **	**0.387*** **

Notes:
- NS = $p > 0.05$; *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in *Y* among years is largely natural and unrelated to variance in *X* among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in *Y* among years is largely related to variance in *X* among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- For calculation of 2000, 2001 and 2002 correlations, IC50 > 98,684 mg wet/L (the highest concentration tested) were set at 98,684 mg/wet/L; for calculation of 2004, 2006 and 2008 correlations, IC50 > 197,000 (the highest concentration tested) were set at 197,000 mg wet/L; for calculation of the correlation over all years combined IC50 > 98,684 mg wet/L (including some IC50 < 197,000 mg wet/L in 2004, 2006 and 2008) were set at 98,684 mg wet/L.
- Sediments with IC50 < 50,000 mg wet/L were considered Toxic.
- Adjusted fines = fines as a % of fines + sand; gravel is excluded from Microtox tests.

Microtox IC50s and toxicity were not significantly correlated with $>C_{10}$-C_{21} HC concentrations in any year except 2002. Mean and overall correlations were not significant and correlations did not differ significantly among years (Table 5-31). The LOWESS trend line (solid line in Figure 5-41) for the overall relationship (i.e., all years combined) between IC50s and $>C_{10}$-C_{21} HCs was a flat line, indistinguishable from the dashed line at IC50 = 98,500 g wet/L. Figure 5-41 also plots the percentage of samples that were toxic versus median $>C_{10}$-C_{21} HC concentrations for 10 concentration classes. Frequencies of toxicity did not increase with increasing $>C_{10}$-C_{21} HC concentration. Fourteen (14) percent of samples at concentrations less than RDL of 0.3 mg/kg were toxic, comparable to the overall frequency of 18% over all EEM years. With mean and overall correlations between toxicity and concentration not significant, there were no significant differences in $>C_{10}$-C_{21} HC concentrations between toxic versus non-toxic samples.

Relationships with Other Sediment Physical and Chemical Characteristics

Microtox IC50s were significantly negatively correlated with, and toxicity significantly positively correlated with, adjusted fines at $p \leq 0.001$ in every year except 2006 (when few samples were toxic). Mean and overall correlations were also strong (i.e., $|r_s| \geq 0.5$) and highly significant ($p << 0.001$) (Table 5-31). Therefore, negative responses (IC50s less than 98,500 mg wet/L) and toxicity (IC50s less than 50,000 mg wet/L) were more common at higher adjusted fines levels. Figure 5-41 suggests a threshold relationship over all years combined, with negative responses and toxicity rare at fines levels less than 1.5% but relatively common at higher levels[16].

Metals PC1 and PC2 scores were positively correlated with strontium (Section 5.4.1.1) and usually significantly correlated with Microtox responses in EEM years (Table 5-31). However, with one exception in 2008, Microtox responses were always more strongly correlated with strontium than with either Metals PC. Based on these results, the strong relationships between Microtox responses and strontium (highly significant in most years, with mean and overall $|r_s| \geq 0.5$) were probably not a function of overall metal concentrations, but a function of some other correlate of strontium (assuming that strontium does not directly affect Microtox). Regardless of the cause of the relationships between Microtox responses and strontium, negative

[16] The relationship between IC50s and adjusted fines may be more linear than the solid LOWESS trend line and data suggest. Some IC50s from 2004 to 2008 plotted as 98,500 g wet/L (approximately the highest concentration tested from 2000 to 2002) in Figure 5-41 were between that value and 197,000 g wet/L (the highest concentration tested in later years). More generally, IC50s greater than the highest concentrations tested may have occurred at low fines levels, but would not be measurable.

responses and toxicity were largely restricted to strontium concentrations greater than 40 mg/kg (Figure 5-41).

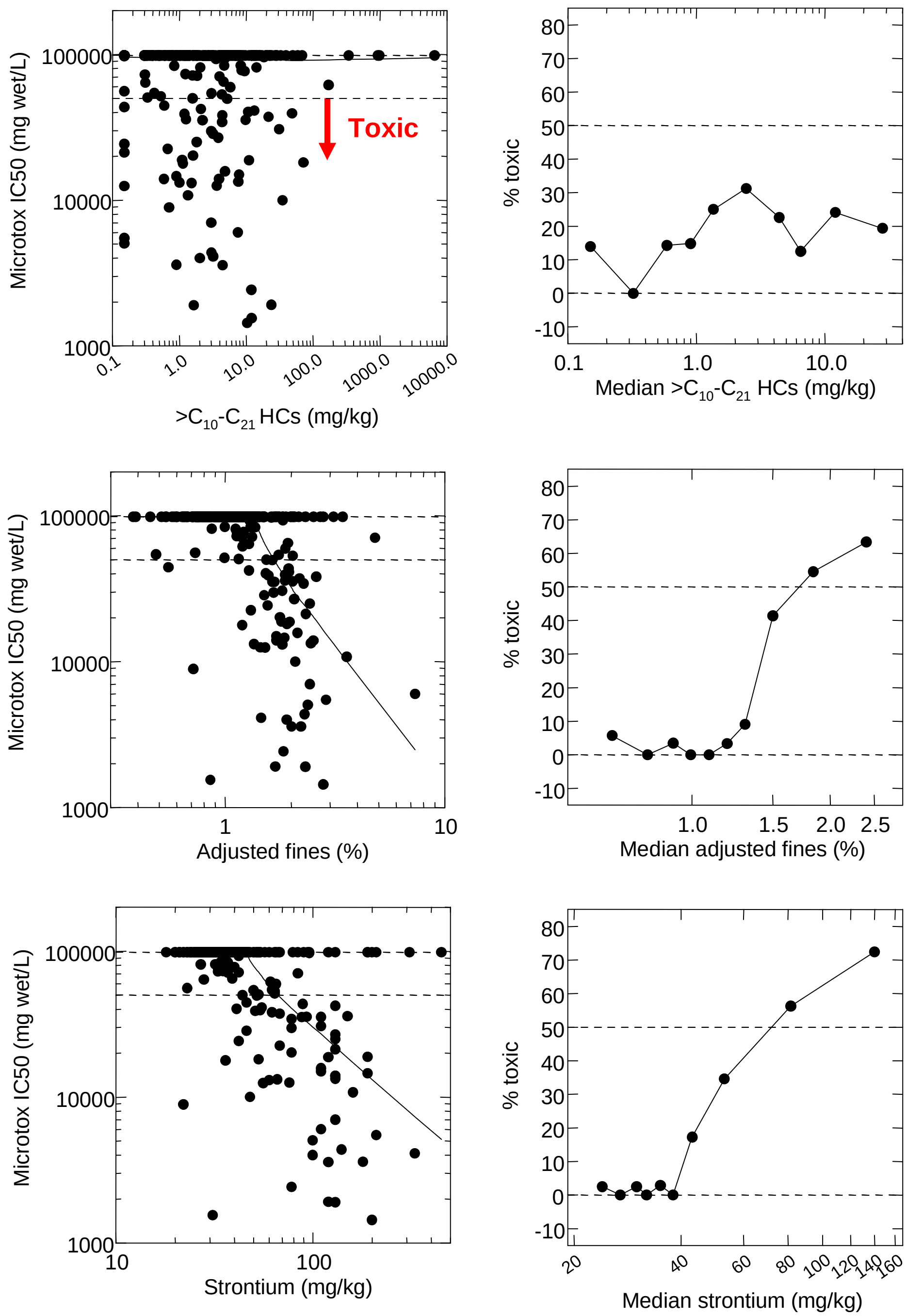

Figure 5-41 Relationships Between Microtox Toxicity Test Responses versus >C_{10}-C_{21} HCs, Adjusted Fines and Strontium (2000 to 2008)

Relationships between Microtox toxicity versus adjusted fines and strontium were further explored using a logistic multiple regression model with adjusted fines and strontium as *X* variables. Results are provided in Appendix B-4. Over all EEM years and samples combined, toxicity increased significantly ($p < 0.001$) with increasing fines and strontium levels, as expected given the rank correlations in Table 5-31. Adding either distance from the nearest drill centre or $>C_{10}$-C_{21} concentrations as *X* variables to the logistic regressions did not substantially improve the fit or predictive value of the models, and the effects of distance and HCs were of marginal significance (*p* approximately 0.05). Furthermore, the models suggested that toxicity increased with increasing distance to the nearest drill centre and decreased with increasing HC concentrations once fines and strontium effects were accounted for.

5.4.4.2 Benthic Invertebrate Community Structure versus Sediment Physical and Chemical Characteristics

Relationships with $>C_{10}$-C_{21} HCs

Table 5-32 provides Spearman rank correlations between benthic invertebrate community variables and $>C_{10}$-C_{21} HC concentrations for Elutriate samples. Total abundance increased significantly with increasing $>C_{10}$-C_{21} HC concentrations (Table 5-32; Figure 5-42). Abundances of the dominant Spionidae and Cirratulidae, and the sub-dominant Phyllodocidae and Tellinidae, also increased significantly with increasing $>C_{10}$-C_{21} HC concentrations. However, abundances of several other taxa decreased with increasing $>C_{10}$-C_{21} HC concentrations, which reduced the strength of relationships between total abundance and $>C_{10}$-C_{21} HCs. NMDS1 scores (not shown in Figure 5-42) also increased significantly with increasing $>C_{10}$-C_{21} HC concentrations since NMDS1 scores reflected high abundances of Spionidae (and also Tellinidae and Phyllodocidae) relative to abundances of most other taxa.

Correlations between Tellinidae abundance and $>C_{10}$-C_{21} HCs differed significantly among years and were stronger from 2002 to 2008, when Tellinidae were reasonably abundant, than in 2000 and 2001, when Tellinidae were relatively rare at most stations.

Table 5-32 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs (2000 to 2008 Elutriate Samples)

Community variable	2000 *n*=38 stations	2001 *n*=49 stations	2002 *n*=53 stations	2004 *n*=52 stations	2006 *n*=53 stations	2008 *n*=53 stations	Diff. among years	Mean r_s	Overall r_s *n*=298 stations
Summary measures									
Total abundance (*N*)	0.204	0.234	0.335*	0.439**	0.278*	0.336*	NS	**0.310*** **	**0.308*** **
Standing crop (*B*)	–0.010	0.157	–0.024	–0.278*	–0.141	–0.103	NS	–0.072	–0.091
Richness (*S*)	0.003	–0.066	0.053	–0.006	–0.021	0.092	NS	0.011	–0.016
Adjusted richness (*S2*)	–0.120	–0.170	–0.125	**–0.526*** **	–0.332*	–0.323*	NS	**–0.274*** **	**–0.296*** **
NMDS1	0.423**	**0.538*** **	0.386**	0.345*	0.395**	**0.606*** **	NS	**0.449*** **	**0.399*** **
NMDS2	–0.148	0.022	–0.022	0.002	–0.003	–0.254	NS	–0.065	–0.027
Taxon abundances									
Spionidae	0.385*	0.462**	0.433**	**0.469*** **	0.257	0.422**	NS	**0.405*** **	**0.372*** **
Cirratulidae	0.179	0.169	0.455*	**0.596*** **	0.387**	0.277*	NS	**0.354*** **	**0.383*** **
Syllidae	–0.314	–0.249	–0.218	–0.243	–0.202	–0.220	NS	**–0.237*** **	**–0.195*** **
Orbiniidae	0.150	–0.304*	**–0.687*** **	**–0.720*** **	**–0.672*** **	**–0.619*** **	***** **	**–0.508*** **	**–0.624*** **
Paraonidae	0.060	–0.099	–0.168	–0.241	–0.354*	–0.391**	NS	**–0.213*** **	**–0.270*** **
Phyllodocidae	0.525**	0.467**	**0.565*** **	**0.759*** **	**0.661*** **	**0.587*** **	NS	**0.599*** **	**0.573*** **
Tellinidae	–0.114	0.269	**0.525*** **	0.442**	**0.609*** **	**0.649*** **	**	**0.424*** **	**0.432*** **
Amphipoda	–0.022	–0.359*	–0.195	–0.323*	–0.431**	–0.274*	NS	**–0.278*** **	**–0.327*** **
Echinodermata	–0.391*	–0.393**	–0.330*	–0.086	**–0.490*** **	**–0.468*** **	NS	**–0.359*** **	**–0.328*** **
No. *p* ≤ 0.001	0	1	3	5	4	5	0	12	12
No. |r_s| ≥ 0.5	1	1	3	4	3	4		2	2

Notes:
- NS = $p > 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in *Y* among years is largely natural and unrelated to variance in *X* among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in *Y* among years is largely related to variance in *X* among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- No. community variables = 15.

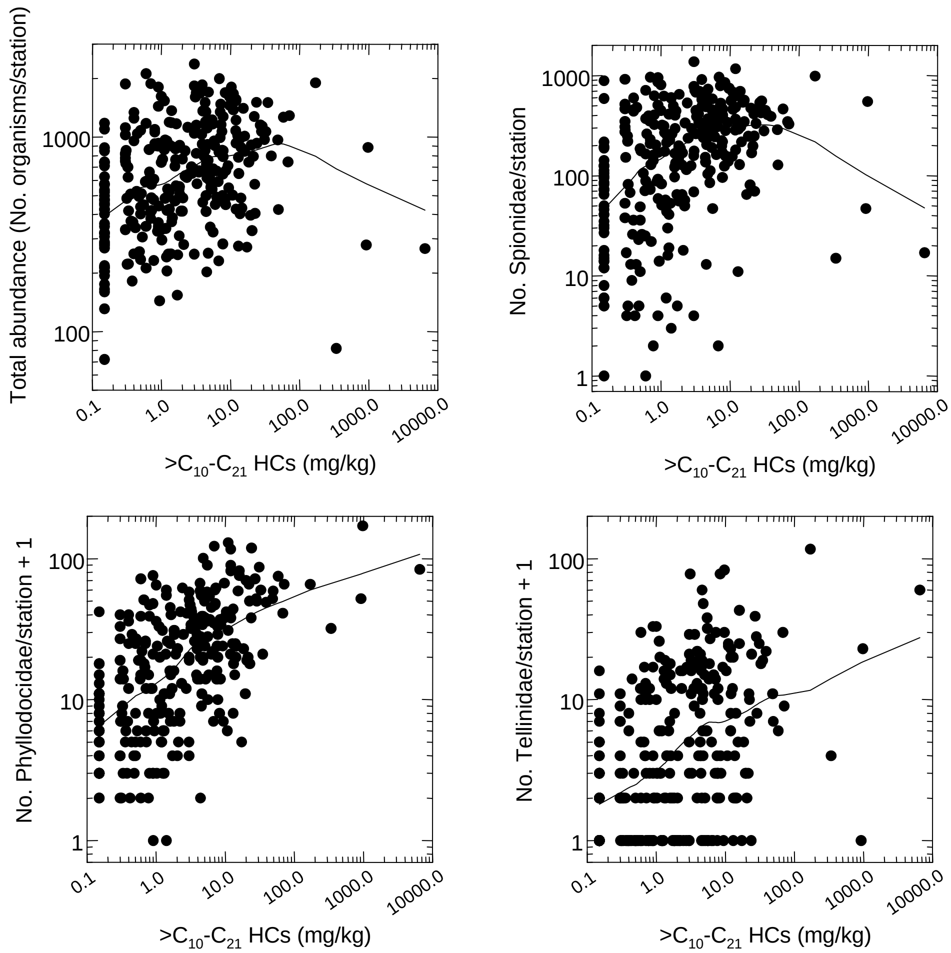

Figure 5-42 Relationships Between Total Abundance and Spionidae, Phyllodocidae and Tellinidae Abundances versus >C_{10}-C_{21} HCs (2000 to 2008 Elutriate Samples)

Adjusted richness (i.e., richness relative to abundance) decreased with increasing >C_{10}-C_{21} HC concentrations (Table 5-32), as expected given that total abundance but not richness increased with increasing >C_{10}-C_{21} HC concentrations. The concentration-response relationship for adjusted richness was relatively weak (mean and overall r_s approximately –0.3), but most values at >C_{10}-C_{21} HC concentrations greater than 10 mg/kg and all values at concentrations greater than 100 mg/kg were less than the overall median adjusted richness of 1 (Figure 5-43). Abundances of the dominant Syllidae and the sub-dominants Orbiniidae, Paraonidae, amphipods and echinoderms also decreased with increasing >C_{10}-C_{21} HC concentrations. Concentration-response relationships for Orbiniidae abundances differed significantly among years, and were much stronger from 2002 to 2008 than in earlier years.

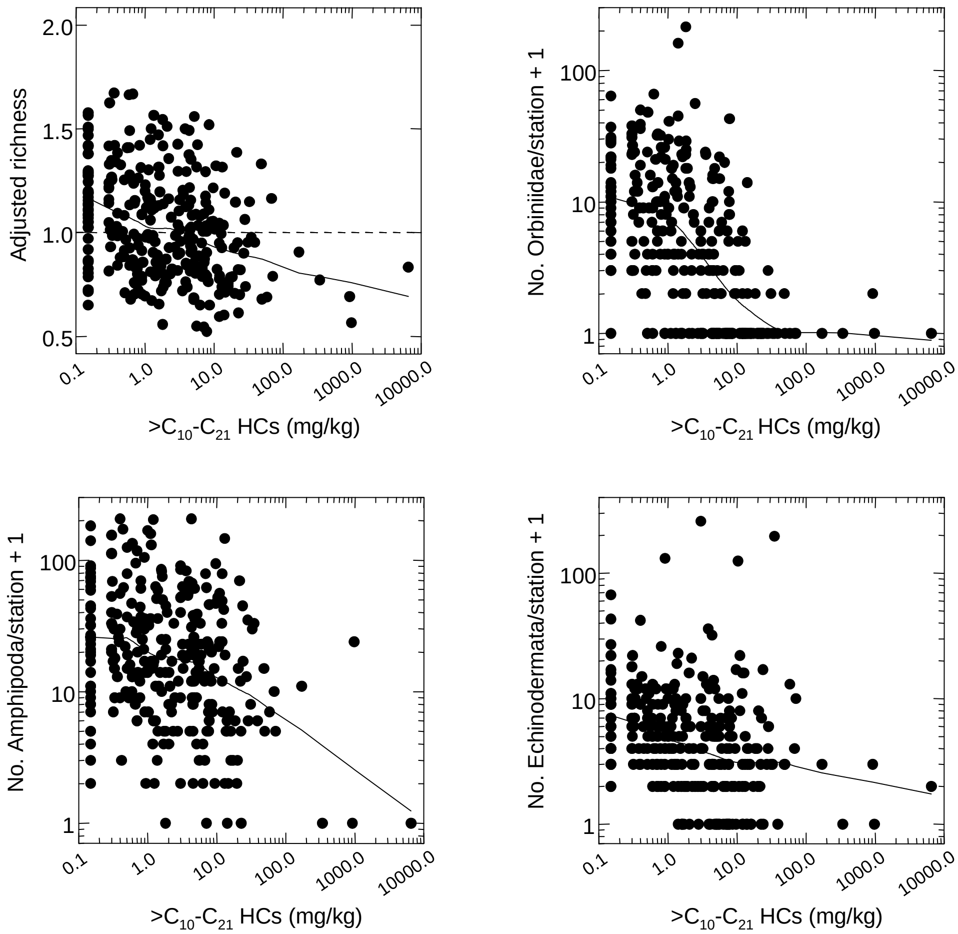

Figure 5-43 Relationships Between Adjusted Richness and Orbiniidae, Amphipod and Echinoderm Abundances versus >C_{10}-C_{21} HCs (2000 to 2008 Elutriate Samples)

Relationships with Other Sediment Physical and Chemical Characteristics

Tables 5-33 and 5-34 provide Spearman rank correlations (r_S) between benthic invertebrate community variables versus sediment fines and gravel content. Correlations for baseline (1997) Wash samples for selected community variables are also provided for qualitative comparison to correlations for EEM Elutriate samples.

Table 5-33 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Fines Content (2000 to 2008 Elutriate Samples)

Community variable	**1997 Wash samples**	**Elutriate samples**								
		2000	**2001**	**2002**	**2004**	**2006**	**2008**	**Diff. among years**	**Mean r_s**	**Overall r_s**
		***n*=38 stations**	***n*=49 stations**	***n*=53 stations**	***n*=52 stations**	***n*=53 stations**	***n*=53 stations**			***n*=298 stations**
Summary measures										
Total abundance (*N*)	0.400**	0.466**	0.237	**0.503**	0.242	0.427**	0.309*	NS	**0.361*** **	0.137*
Standing crop (*B*)	–0.048	–0.142	–0.116	–0.159	–0.280*	0.035	0.117	NS	–0.087	–0.126*
Richness (*S*)	0.401**	**0.586*** **	**0.554**	0.294*	–0.023	0.340*	0.302*	NS	**0.328*** **	0.165**
Adjusted richness (*S2*)		0.514**	**0.486**	0.044	–0.230	0.049	0.092	**	0.138*	0.079
NMDS1		0.185	0.062	0.312*	0.116	0.228	0.385**	NS	**0.219*** **	0.081
NMDS2		–0.445**	**–0.528*** **	–0.215	–0.238	–0.245	–0.229	NS	**–0.308*** **	**–0.202*** **
Taxon abundances										
Spionidae	0.179	0.276	0.155	**0.523**	0.191	0.280*	0.306*	NS	**0.291*** **	0.081
Cirratulidae	–0.224	0.208	–0.131	0.276*	0.103	0.329*	0.220	NS	0.170**	0.054
Syllidae		–0.220	0.095	0.000	–0.045	0.015	–0.145	NS	–0.043	0.030
Orbiniidae	–0.166	–0.255	–0.232	–0.293*	–0.323*	–0.382**	–0.135	NS	**–0.271*** **	**–0.250*** **
Paraonidae		0.221	0.295*	0.106	–0.095	–0.181	–0.063	NS	0.035	–0.056
Phyllodocidae	–0.001	0.127	0.030	**0.487*** **	0.277*	0.441**	0.241	NS	**0.277*** **	0.136*
Tellinidae		0.494**	**0.545**	**0.534*** **	0.049	**0.459*** **	0.221	NS	**0.377*** **	0.158**
Amphipoda	0.062	0.385*	0.185	0.240	–0.146	0.138	0.042	NS	0.129*	–0.068
Echinodermata	–0.010	–0.056	0.015	–0.101	0.142	–0.044	0.026	NS	–0.001	0.079
No. $p \leq 0.001$	0	1	4	4	0	1	0	0	8	2
No. $\lvert r_s \rvert \geq 0.5$	0	2	3	3	0	0	0		0	0

Notes:
- NS = $p > 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in *Y* among years is largely natural and unrelated to variance in *X* among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in *Y* among years is largely related to variance in *X* among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- No. community variables = 9 for 1997, and 15 for EEM years.

Table 5-34 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Gravel Content (2000 to 2008 Elutriate Samples)

Community variable	1997 Wash samples	Elutriate samples								
		2000 *n*=38 stations	2001 *n*=49 stations	2002 *n*=53 stations	2004 *n*=52 stations	2006 *n*=53 stations	2008 *n*=53 stations	Diff. among years	Mean r_s	Overall r_s *n*=298 stations
Summary measures										
Total abundance (*N*)	0.300*	0.162	0.159	**0.687*** **	0.414**	**0.590*** **	**0.635*** **	**	**0.459*** **	**0.556*** **
Standing crop (*B*)	–0.252	–0.365*	–0.232	**–0.520*** **	–0.207	–0.185	0.089	NS	**–0.230*** **	–0.169**
Richness (*S*)	0.392**	**0.686*** **	**0.702*** **	**0.793*** **	0.318*	**0.699*** **	**0.646*** **	NS	**0.639*** **	**0.648*** **
Adjusted richness (*S2*)		**0.800*** **	**0.676*** **	**0.655*** **	0.006	0.440**	0.346*	**	**0.471*** **	**0.419*** **
NMDS1		–0.250	–0.217	0.119	0.124	0.091	0.228	NS	0.032	0.134*
NMDS2		**–0.582*** **	**–0.625*** **	**–0.558*** **	–0.316*	–0.435**	–0.435**	NS	**–0.486*** **	**–0.476*** **
Taxon abundances										
Spionidae	0.271*	–0.133	–0.092	**0.505*** **	0.306*	0.396**	**0.571*** **	***	**0.283*** **	**0.401*** **
Cirratulidae	0.002	–0.168	–0.243	0.338*	0.160	0.331*	0.244	**	0.129*	**0.210*** **
Syllidae		–0.023	0.224	0.249	0.171	0.277*	0.179	NS	0.189**	**0.215*** **
Orbiniidae	**–0.489*** **	**–0.542*** **	–0.388**	–0.292*	–0.292*	–0.209	–0.136	NS	**–0.297*** **	**–0.232*** **
Paraonidae		0.462**	**0.638*** **	0.373**	0.232	0.357**	0.167	NS	**0.364*** **	**0.315*** **
Phyllodocidae	0.037	–0.233	–0.183	0.248	0.161	0.262	0.219	*	0.098	**0.211*** **
Tellinidae		0.322*	0.354*	0.336*	0.049	**0.516*** **	**0.533*** **	NS	**0.354*** **	**0.392*** **
Amphipoda	0.311*	0.264	0.145	0.329*	0.159	0.374**	0.386**	NS	**0.279*** **	**0.337*** **
Echinodermata	–0.105	0.205	0.117	0.090	0.336*	0.334*	0.085	NS	**0.194*** **	0.175**
No. $p \leq 0.001$	1	4	4	7	0	3	4	1	11	12
No. $\lvert r_s \rvert \geq 0.5$	0	4	4	6	0	3	4		1	2

Notes:
- NS = $p > 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in *Y* among years is largely natural and unrelated to variance in *X* among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in *Y* among years is largely related to variance in *X* among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- No. community variables = 9 for 1997, and 15 for EEM years.

The correlations with fines content are provided primarily to show that those correlations were generally weaker than correlations with gravel content in EEM years. For example, there were fewer highly significant ($p \leq 0.001$) annual, mean and overall correlations for fines content than for gravel content, and correlations between individual community variables and gravel content were usually stronger than correlations between the same variables and fines content. Note also that overall correlations were weaker than mean correlations for fines but not gravel content. Fines content, but not gravel content, varied significantly among years (Section 5.4.1.2), but the significant variance among years for most community variables (see Section 5.4.3.3) was largely unrelated to the significant variance in fines content among years.

Most invertebrate community variables were positively correlated with gravel content within EEM years and over all years (Table 5-34). Total abundance, richness and adjusted richness were the variables most strongly positively correlated with gravel content, with relationships approximately linear on a log-log scale (Figure 5-44). Total abundance and richness were also significantly positively correlated with gravel content in baseline (1997) Wash samples.

NMDS2 scores (Cirratulidae/Tanaidacea dominance) were significantly negatively correlated with gravel content within every EEM year and over all years (Table 5-34). The significant relationships for NMDS2 occurred largely because Tanaidacea were one of the few taxa that were more abundant in sediment with higher sand content (Appendix B-4) and Cirratulidae were largely unaffected by particle size. Consequently, in sandy sediments, abundances of these two taxa increased relative to abundances of other taxa that generally preferred sediments with a higher gravel content. Most NMDS2 scores were below the overall median of 0 in sediments with gravel content approaching or exceeding 10% (Figure 5-44; sand content in these sediments would be less than 90%).

Orbiniidae abundance also decreased with increasing gravel content in every EEM year and in baseline Wash samples (Table 5-34). Relationships with gravel were generally weak, particularly in recent years, and the overall relationship in Figure 5-44 primarily indicates that zero and low Orbiniidae abundances occurred somewhat more frequently at higher gravel content. Standing crop was also significantly but weakly negatively correlated with gravel content.

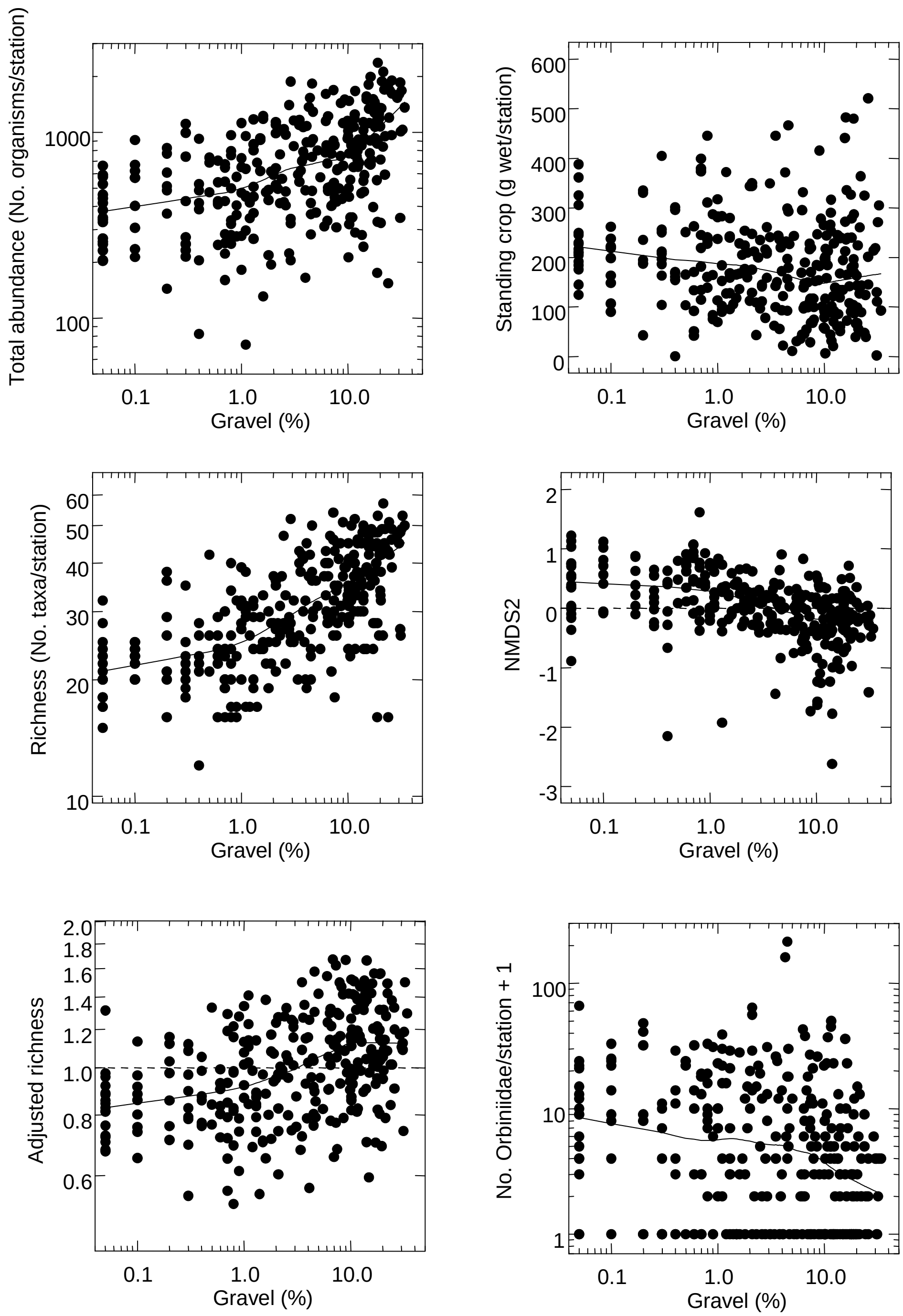

Figure 5-44 Relationships Between Selected Benthic Invertebrate Community Variables and Gravel Content (2000 to 2008 Elutriate Samples)

Table 5-35 provides Spearman rank correlations (r_s) between invertebrate community variables and sediment TOC content. Most significant correlations were positive. There was only one difference in correlations among years significant at $p \leq 0.05$ (Cirratulidae abundance) and none significant at $p \leq 0.01$. The strongest positive correlations (mean and overall $r_s > 0.5$) occurred for Spionidae, Tellinidae and Phyllodocidae abundances, and NMDS1 (Spionidae dominance). All four of these community variables, as well as total abundance, were also positively correlated with $>C_{10}$-C_{21} HC concentrations (Table 5-32), which may indicate both natural and project-related enrichment effects. Total abundance and Spionidae and Phyllodocidae abundances also increased significantly with TOC content in baseline (1997) Wash samples. Relationships between total abundance and Spionidae abundance versus TOC content were linear on a log-log scale (Figure 5-45).

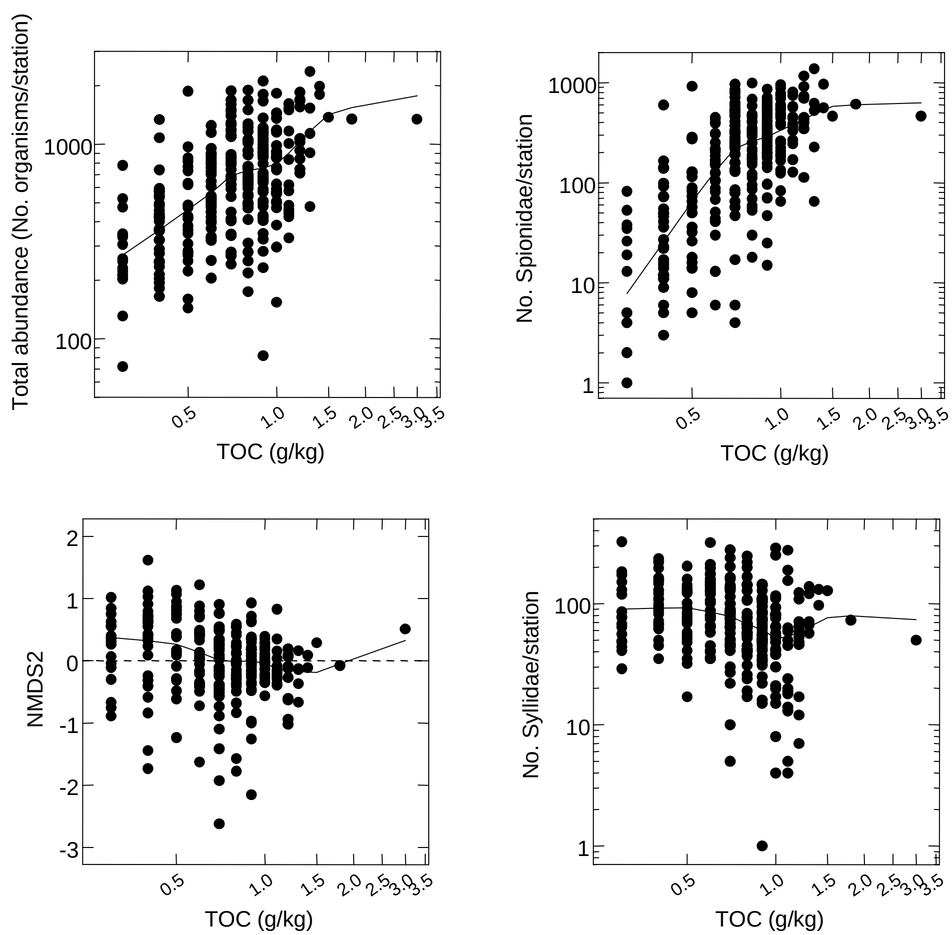

Figure 5-45 Relationships Between Selected Benthic Invertebrate Community Variables and TOC Content (2000 to 2008 Elutriate Samples)

Table 5-35 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and TOC Content (2000 to 2008 Elutriate Samples)

Community variable	1997 Wash samples	Elutriate samples								
		2000	2001	2002	2004	2006	2008	Diff. among years	Mean r_s	Overall r_s
		n=38 stations	n=49 stations	n=53 stations	n=52 stations	n=53 stations	n=53 stations			n=298 stations
Summary measures										
Total abundance (N)	**0.523*** **	**0.590*** **	0.372**	0.382**	0.343*	**0.620*** **	**0.493*** **	NS	**0.462*** **	**0.481*** **
Standing crop (B)	–0.007	0.056	0.234	–0.046	0.162	0.083	0.129	NS	0.103	0.121*
Richness (S)	0.342*	**0.550*** **	0.289*	0.243	0.183	0.309*	0.296*	NS	**0.300*** **	**0.266*** **
Adjusted richness ($S2$)		0.362*	0.180	0.078	–0.097	–0.170	–0.168	NS	0.013	–0.038
NMDS1		0.537**	**0.630*** **	**0.707*** **	**0.686*** **	**0.598*** **	**0.639*** **	NS	**0.638*** **	**0.674*** **
NMDS2		–0.248	–0.433**	–0.308*	–0.142	–0.134	–0.179	NS	**–0.238*** **	**–0.224*** **
Taxon abundances										
Spionidae	0.365**	**0.604*** **	**0.569*** **	**0.633*** **	**0.627*** **	**0.620*** **	**0.584*** **	NS	**0.607*** **	**0.632*** **
Cirratulidae	–0.216	0.323*	–0.091	0.150	0.172	**0.525*** **	0.422**	*	**0.251*** **	**0.285*** **
Syllidae		–0.478**	–0.410**	**–0.498*** **	–0.328*	–0.118	–0.289*	NS	**–0.347*** **	**–0.315*** **
Orbiniidae	–0.052	0.215	0.181	–0.059	–0.070	–0.280*	–0.137	NS	–0.040	–0.130*
Paraonidae		0.193	0.207	0.171	–0.074	–0.066	–0.081	NS	0.050	0.005
Phyllodocidae	0.280*	0.532**	**0.540*** **	**0.503*** **	**0.565*** **	**0.736*** **	**0.567*** **	NS	**0.576*** **	**0.602*** **
Tellinidae		0.497**	**0.500*** **	**0.615*** **	0.212	**0.679*** **	**0.608*** **	NS	**0.521*** **	**0.529*** **
Amphipoda	0.101	0.528**	0.267	0.440**	0.175	0.071	0.092	NS	**0.249*** **	**0.205*** **
Echinodermata	–0.128	–0.202	–0.238	–0.162	–0.256	–0.166	–0.203	NS	**–0.204*** **	**–0.200*** **
No. $p \leq 0.001$	1	3	4	5	3	6	5	0	11	11
No. $\lvert r_s \rvert \geq 0.5$	1	6	4	4	3	6	4		4	4

Notes:
- NS = $p > 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in Y among years is largely natural and unrelated to variance in X among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in Y among years is largely related to variance in X among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- No. community variables = 9 for 1997, and 15 for EEM years.

Syllidae and echinoderm abundances and NMDS2 (Cirratulidae/Tanaidacea dominance) were the only community variables with significant negative mean and overall correlations with TOC. Figure 5-45 plots relationships for NMDS2 and Syllidae abundance versus TOC, neither of which was strong compared to most positive relationships (e.g., for total and Spionidae abundances).

Appendix B-4 provides Spearman rank correlations (r_s) between benthic invertebrate community variables versus sulphur, ammonia and redox levels. Few mean and overall correlations were significant at $p \leq 0.001$ and none were strong (i.e., $|r_s| \geq 0.5$). Correlations with sulphur were generally weaker versions of correlations with $>C_{10}-C_{21}$ HCs.

5.4.4.3 Microtox Toxicity Test Responses versus Benthic Invertebrate Community Structure

Negative responses in Microtox toxicity tests (i.e., lower IC50s) in EEM years were not associated with negative benthic invertebrate communities responses. In fact, invertebrate communities were arguably healthier where lower IC50s and toxicity occurred. For example, IC50s decreased with increasing total abundance, richness and adjusted richness in every EEM year and over all years combined, although correlations between IC50s versus richness were weaker in more recent years than in earlier years (Table 5-36). As Figure 5-46 shows, total abundance, richness and adjusted richness values in sediments with IC50s < 98,500 mg wet/L were similar to or greater than values in sediments with IC50s ≥ 98,500 mg wet/L. Total abundance, richness and adjusted richness were also significantly positively correlated with toxicity, scored as 0/1 non-toxic/toxic, indicating that values of these community variables were significantly greater in toxic sediments (i.e., sediments with IC50s < 50,000 mg wet/L). Figure 5-47 provides distributions and medians for total abundance, richness and adjusted richness for toxic versus non-toxic sediments. Medians for total abundance and richness in toxic sediments (n = 55 stations) were approximately 50% greater than medians in non-toxic sediments (n = 243 stations). The difference in medians was smaller (approximately 25%) for adjusted richness.

Table 5-36 Spearman Rank Correlations (r_s) Between Microtox IC50s and Benthic Invertebrate Community Variables (2000 to 2008 Elutriate Samples)

Community variable	2000 *n*=38 stations	2001 *n*=49 stations	2002 *n*=53 stations	2004 *n*=52 stations	2006 *n*=53 stations	2008 *n*=53 stations	Diff. among years	Mean r_s	Overall r_s *n*=298 stations
Summary measures									
Total abundance (*N*)	–0.207	–0.181	**–0.668*** **	**–0.512*** **	–0.254	–0.329*	NS	**–0.368*** **	**–0.305*** **
Standing crop (*B*)	0.153	0.144	0.311*	0.151	0.110	–0.164	NS	0.115	0.142*
Richness (*S*)	**–0.560*** **	**–0.595*** **	**–0.659*** **	–0.358*	–0.165	–0.293*	NS	**–0.431*** **	**–0.426*** **
Adjusted richness (*S2*)	**–0.660*** **	**–0.564*** **	**–0.506*** **	–0.015	–0.038	–0.130	**	**–0.299*** **	**–0.296*** **
NMDS1	0.223	0.189	–0.023	0.076	–0.073	–0.142	NS	0.031	0.082
NMDS2	**0.603*** **	**0.531*** **	**0.462*** **	0.256	0.137	0.133	NS	**0.339*** **	**0.276*** **
Taxon abundances									
Spionidae	0.113	0.016	–0.407**	–0.216	–0.196	–0.307*	NS	–0.183**	–0.133*
Cirratulidae	0.120	0.154	–0.389**	–0.205	–0.141	–0.204	NS	–0.126*	–0.176**
Syllidae	–0.040	–0.209	–0.279*	–0.325*	–0.117	–0.023	NS	–0.171**	**–0.255*** **
Orbiniidae	**0.649*** **	0.333*	0.286*	0.262	0.093	0.169	NS	**0.281*** **	0.162**
Paraonidae	–0.425**	–0.352*	–0.253	–0.241	–0.041	0.195	*	–0.172**	–0.172**
Phyllodocidae	0.231	0.278	–0.129	–0.035	–0.063	–0.014	NS	0.032	0.017
Tellinidae	–0.316	–0.394**	–0.319*	–0.035	–0.305*	–0.242	NS	**–0.265*** **	–0.162**
Amphipoda	–0.231	–0.213	–0.317*	–0.198	–0.250	–0.057	NS	**–0.210*** **	–0.172**
Echinodermata	–0.150	–0.196	–0.198	–0.453**	–0.155	–0.179	NS	**–0.225*** **	**–0.289*** **
No. $p \leq 0.001$	4	3	4	1	0	0	0	8	6
No. $\lvert r_s \rvert \geq 0.5$	4	3	3	1	0	0		0	0

Notes:
- NS = $p > 0.05$; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**); No. community variables = 15.
- When signs of correlations differ among years, differences among years may be of more interest than general relationships over all years. Mean correlations are more appropriate and powerful measures of general relationships when variance in *Y* among years is largely natural and unrelated to variance in *X* among years. Overall correlations based on pooling all years are more appropriate and powerful measures of general relationships (and also more convenient for plotting) when variance in *Y* among years is largely related to variance in *X* among years.
- Annual r_s weighted by sample size (number of stations) for calculation of Mean r_s.
- For calculation of 2000, 2001 and 2002 correlations, IC50 > 98,684 mg wet/L (the highest concentration tested) were set at 98,684 mg/wet/L; for calculation of 2004, 2006 and 2008 correlations, IC50 > 197,000 (the highest concentration tested) were set at 197,000 mg wet/L; for calculation of the correlation over all years combined IC50 > 98,684 mg wet/L (including some IC50 < 197,000 mg wet/L in 2004, 2006 and 2008) were set at 98,684 mg wet/L.

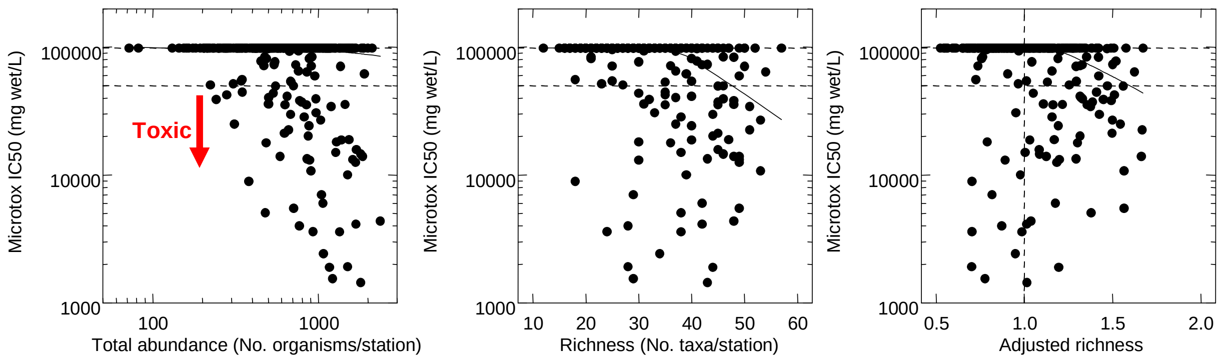

Figure 5-46 Relationships Between Microtox IC50s and Total Abundance, Richness and Adjusted Richness (2000 to 2008 Elutriate Samples)

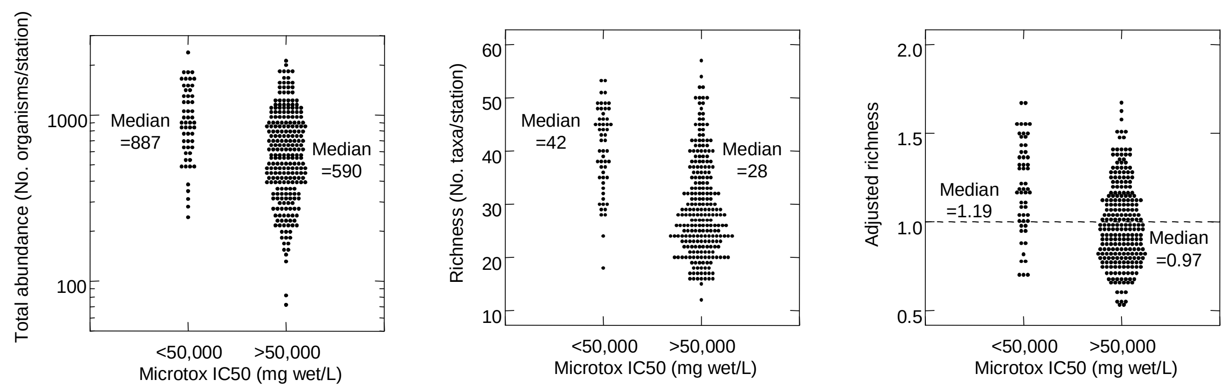

Figure 5-47 Distributions of Total Abundance, Richness and Adjusted Richness for Toxic versus Non-Toxic Samples in Microtox Toxicity Tests (2000 to 2008 Elutriate Samples)

Mean and overall correlations between IC50s and abundances of Spionidae, Cirratulidae, Syllidae, echinoderms, Paraonidae, amphipods and phoxocephalids were also negative and significant (although not always at $p \leq 0.001$) (Table 5-36), indicating that abundances of dominants and most sub-dominants were greater at stations where negative responses in Microtox toxicity tests occurred. IC50s were also negatively correlated with abundances of several other sub-dominants not included in Table 5-36 (Appendix B-4). The only significant positive mean and/or overall correlations between IC50s and community variables occurred for standing crop, NMDS2 (Cirratulidae/Tanaidacea dominance) and Orbiniidae abundance. The correlations between IC50s and standing crop were weak, with only the overall correlation significant at $p \leq 0.05$. The positive correlations between IC50s and NMDS2 occurred because IC50s were positively correlated with Tanaidacea abundance (mean and overall $r_s > 0.3$, $p < 0.001$; Appendix B-4), only weakly negatively correlated with Cirratulidae abundance (Table 5-36), and negatively correlated with abundances of most other taxa.

Table 5-37 provides bivariate rank correlations among gravel, TOC, adjusted fines and strontium for the 298 stations included in analyses of correlations between Microtox toxicity test responses and community variables. Most community variables were significantly positively correlated with gravel and/or TOC content (Section 5.4.4.2), and these two variables were significantly positively correlated with adjusted fines and strontium, two variables with significant adverse effects on Microtox (Section 5.4.2.1).

Table 5-37 Spearman Rank Correlations (r_s) Among Physical and Chemical Characteristics Used in Various Analyses of Benthic Invertebrate Community Variables (2000 to 2008 Elutriate Samples)

	Gravel	TOC	Adjusted fines
TOC	**0.358*** **		
Adjusted fines	**0.431*** **	**0.434*** **	
Strontium	**0.567*** **	**0.421*** **	**0.637*** **

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 298 stations.

5.5 SUMMARY OF FINDINGS

5.5.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

In 2008, as in previous years, Terra Nova sediments were predominantly sand (most samples were more than 90% sand). All but two fines content values were less than 2% and all TOC values were less than 1.5 g/kg.

>C_{10}-C_{21} HCs and barium were good indicators of drilling activity. Concentrations of >C_{10}-C_{21} HCs and barium generally increased over time after drilling began, although they were lower in 2008 than in 2006. >C_{10}-C_{21} HC and barium concentrations also decreased significantly with distance from drill centres in every EEM year. In 2008, maximum >C_{10}-C_{21} HC and barium concentrations (340 and 7,200 mg/kg, respectively) occurred at station 30(FE), located 0.14 km from the FE drill centre. Maximum concentrations also occurred at station 30(FE) in 2002, 2004 and 2006. In 2008, concentrations of >C_{10}-C_{21} HCs decreased to levels near RDL (0.3 mg/kg) within 3 km of drill centres. Concentrations of barium decreased to background levels (less than 190 mg/kg) within 1 to 2 km of drill centres.

In 2008, the highest fines content (3.2% and 7%) occurred at two stations within 1 km of drill centres. Fines content decreased with distance from drill centres in every sample year, including baseline (1997), and correlations with distance from the nearest active drill centre were significant in 2000, 2001, 2004 and 2006. Therefore, there was some evidence for project-related increases in fines content, mostly at stations within 1 km of drill centres.

In 2008, sulphur concentrations were elevated at Station 30(FE), 0.14 km from the FE drill centre, but there was no significant overall correlation between sulphur concentrations and distance from drill centres. In 2001, 2002, 2004 and 2006, sulphur concentrations decreased significantly with distance from drill centres. Sulphide concentrations decreased significantly with distance from drill centres in 2008.

Other sediment physical and chemical variables appeared unaffected by project activities. Values of most variables were greater in less sandy sediments, which generally occurred closer to the centre of the development. Therefore, some natural distance gradients existed, but these gradients did not change after drilling began.

Small-scale differences in sediment characteristics among stations also persisted over time (carry-over effects). For $>C_{10}$-C_{21} HCs and barium in particular, carry-over effects could represent localized project-related effects unrelated to distance. For most other variables (e.g., gravel, which was not and should not be affected by drill cuttings discharges), carry-over effects were natural.

5.5.2 TOXICITY

Microtox IC50s from laboratory toxicity tests were unrelated to distance from drill centres and to $>C_{10}$-C_{21} HC and barium concentrations in 2008 and most other EEM years. Instead, IC50s decreased and toxicity increased with increasing fines content and also with increasing strontium concentrations. Effects on Microtox were observed at 4 of 54 stations in 1997 versus 10 to 20 of approximately 50 stations in EEM years.

Survival of amphipods (*Rhepoxynius abronius*) in toxicity tests was reduced to less than 75% at 5 of 53 stations sampled in 2008 and these samples were considered toxic based on Environment Canada (1998) interpretative guidance. One of those samples was from station 30(FE), 0.14 km from the FE drill centre; the other four samples were from stations approximately 1 to 3 km from drill centres (i.e., the mid-range of sample distances). Over all stations, amphipod survival in 2008, and previous years, was not significantly correlated with distance from drill centres. As in past EEM years, survival in most samples was greater than 80% (the standard for Reference sediments).

5.5.3 BENTHIC COMMUNITY STRUCTURE

Benthic invertebrate communities in the Terra Nova area have always been dominated by polychaetes (more than 80% of total abundance) and, specifically, by three polychaete families: Spionidae, Cirratulidae and Syllidae. These three families have collectively accounted for more than 60% of total abundance. The most abundant sub-dominant taxa included several other polychaete families, Tanaidacea (crustaceans), Balanidae (barnacles) and Amphipoda (crustaceans). Phoxocephalidae, Oedicerotidae and Stenothoidae were the most abundant amphipod taxa. Tellinidae (mostly *Macoma*) were the most abundant bivalves and Ophiuroidae (mostly juveniles) were the most abundant echinoderms.

5.5.3.1 2008 Assessment

In 2008, total abundance and abundances of Spionidae, Cirratulidae, Phyllodocidae and Tellinidae increased significantly with increasing concentrations of $>C_{10}$-C_{21} HCs and barium. These taxa also decreased (although not always significantly) with distance from drill centres.

In contrast, richness relative to abundance (adjusted richness) and abundances of Orbiniidae, Paraonidae, amphipods and echinoderms decreased with increasing concentrations of $>C_{10}$-C_{21} HC and barium concentrations in 2008 and increased with distance from drill centres (again, not all correlations were significant).

Most invertebrate community variables were positively correlated with sediment gravel and TOC content in 2008. Correlations with other sediment physical and characteristics were generally weaker and not significant.

Standing crop and Orbinidae, Paraoinidae and echinoderm abundances were not significantly correlated with any sediment physical and chemical variables.

5.5.3.2 Multi-Year Assessment

In all sample years, including 1997 (baseline), standing crop was greater to the West than to the East (directional effect). Total abundance decreased with distance from the FEZ drill centres in all EEM years and in 1997. These distance gradients were generally weak within individual years and did not change over time in EEM years, despite increased drilling activity at the FEZ drill centres. Spionidae, Cirratulidae, Phyllodocidae and Tellinidae abundances also decreased with distance from drill centres in EEM years. The distance gradients for Phyllodocidae and Tellinidae abundances in recent years were strong and highly significant. Median abundances of the two taxa in 2006 and 2008 were approximately three times abundances in earlier EEM years, with most of the increases occurring near drill centres.

In contrast, richness relative to abundance (adjusted richness) and abundances of Orbiniidae, Paraonidae, amphipods and echinoderms generally increased with distance from drill centres in EEM years (as in 2008), with distance gradients for adjusted richness and Orbiniidae, Paraonidae and echinoderm abundances increasing in strength over time. Median Orbiniidae abundance per station decreased from approximately 10 in 2000 and 2001 to near 0 in later EEM years, with 0 abundances occurring more frequently within 1 to 2 km of drill centres than at more remote stations.

Distance gradients, and changes in these gradients over time, for invertebrate community variables were mostly associated with the FEZ drill centres. There was little evidence of large-scale effects of the FE drill centre. Values of some community variables were reduced at station 30(FE), 0.14 km from the FE drill centre, in one or more years after drilling began.

Carry-over effects (persistent spatial differences unrelated to distance) were highly significant ($p \leq 0.001$) for total abundance, richness, diversity and multivariate measures of community composition. Carry-over effects for standing crop were weaker and significant only at $0.01 < p < 0.05$.

5.5.4 INTEGRATED ASSESSMENT

Integrated assessments of relationships among sediment components (physical and chemical characteristics, toxicity and benthic invertebrate community structure) over all six EEM years were generally consistent with results for 2008.

Over all EEM years, Microtox IC50s decreased significantly and toxicity increased significantly with increasing sediment fines content and strontium concentrations and were unrelated to $>C_{10}$-C_{21} HC concentrations.

Lower IC50s and toxicity in Microtox tests were not associated with negative benthic invertebrate communities responses. In fact, total abundance, richness, adjusted richness (i.e., richness adjusted for abundance; a measure of diversity) and abundances of most dominant and sub-dominant taxa were greater in sediments with lower IC50s than in sediments with higher IC50s.

Total abundance and abundances of several dominant and sub-dominant taxa increased with increasing >C_{10}-C_{21} HC concentrations in all or most EEM years and over all EEM years combined.

Abundances of other taxa (e.g., Orbiniidae and amphipods) decreased significantly with increasing >C_{10}-C_{21} HC concentrations but increased significantly with increasing TOC concentrations.

Most community variable values were positively correlated with gravel and/or TOC content. However, abundances of Syllidae and echinoderms were negatively correlated with both gravel and TOC content.