Hibernia Southern Extension Environmental Effects Monitoring Program – Year Two (2015)

Volume I – Interpretation

To:	Hibernia Management Development Company
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From:	Amec Foster Wheeler Environment & Infrastructure A Division of Amec Foster Wheeler Americas Limited

EXECUTIVE SUMMARY

The Hibernia Program is committed to conducting an environmental effects monitoring (EEM) program designed to detect changes in the surrounding environment that may be attributed to the project (HMDC, 2013). The Hibernia Southern Extension (HSE) EEM program consists of sediment and commercial fish sampling components to assess the chemistry and toxicity of sediment quality, and the health, size and body burden chemistry of fish (as per Table 3.1). There is no produced water monitoring program for HSE as all fluids are managed and processed on the Hibernia Platform (HMDC, 2013).

The baseline characterization of the HSE production field was conducted in 2011 and the first year of the Environmental Effects Monitoring (EEM) program was completed in 2014 after the initiation of drilling in January of that year (HMDC, 2015a).The Year 2 (2015) EEM program for HSE was conducted as part of its three-year monitoring program during drilling operations (HMDC, 2013). No accompanying EEM surveys were required for the Hibernia Platform for 2015 based on the established EEM schedule for that project.

SEDIMENT SAMPLING PROGRAM

For the sediment sampling program, samples were collected from the seafloor from pre-established coordinates originally specified in the EEM design plan (HMDC, 2013). The established sediment sampling stations are arranged at approximately 250, 500 and 1,000-meter distances from the drill centre along the cardinal radials (north, south, east and west) projecting from the excavated drill centre (EDC). The Near-field stations have been repositioned slightly in each survey year since the 2011 baseline program to accommodate the installation of subsea infrastructure associated with development of the EDC at HSE. There are also an additional two sediment sampling Reference Areas common to all Hibernia programs (Hibernia Platform and HSE); one located approximately 16 km north of the Hibernia Platform (station 1-16000), and a second sediment sampling reference area located approximately 16 km west of the Hibernia Platform (station 7-16000). Relative to HSE, these Hibernia Reference Areas (16 km HRAs) are 26.8 km (station 1-16000) and 23.9 km (station 7-16000) away from the EDC. Subsequent to the 2011 baseline survey, an additional four stations on an eastern radius 6,000 meters away from the EDC on the eastern side were also established. They were added to the HSE EEM program in 2014 following the onset of drilling to enable examination and quantification of potential cumulative effects of the whole Hibernia program (Hibernia Platform and HSE simultaneously) in addition to potential changes for each drill centre location individually (HMDC, 2013, 2015a).

Sediment samples are subjected to a suite of laboratory analyses to quantify analytes including: particle size, total metals, barium (both total and weak-acid leachable), hydrocarbons (total petroleum hydrocarbons (TPHs), PAHs and alkyl PAHs), total inorganic carbon (TIC), total organic carbon (TOC), sulphide and ammonia as nitrogen (-N). To assess the potential toxicity of sediment samples to living organisms, three bioassays are conducted including a Microtox solid phase test, juvenile polychaete growth and survival assay and amphipod survival assay.

BIOLOGICAL SAMPLING PROGRAM

For the biological sampling program, commercial fish were sampled on a separate cruise within the same season. Sample collection was completed onboard a fisheries research vessel equipped with a Campelen trawl. The target commercial fish species was American plaice (*Hippoglossoides platessoides*) which were collected within a two km radius off the HSE EDC along with a reference site located 50 km northwest of the Hibernia Platform (50 km HRA). As prescribed in the Hibernia Management and Development and Company Ltd. (HMDC) Design Plan (HMDC, 2013), a minimum of seven tows were conducted at each location and 50 American plaice 25 cm in length or greater collected. For every fish collected, the length and weight of the whole fish was recorded, condition of each fish assessed, and sexual maturity was indexed. Subsamples of organs and tissues were collected for analytical evaluation of chemical body burden in tissues, health parameters (for evidence of microscopical lesions and/or anomalies in gill and liver tissues), and taste. Taste tests were conducted using a panel for qualitative assessment of fish fillets harvested from the study area (HSE) versus the 50 km reference area. By-catch data from trawls was also recorded.

Both the sediment and biological sampling programs were analysed statistically to assess for significant project-related changes or differences in detected concentrations of analytes according to survey year and/or distance or sampling area. Where applicable, analytes and assay results are examined for correlations between detected parameters and/or assay results.

SEDIMENT CHEMISTRY RESULTS

The predominant sediment type at HSE is sand (mean of all HSE stations 80%), followed by gravel, clay and silt respectively. Since the 2011 baseline survey, the proportion of sand in sediment samples within the Near-field (≤ 1000 m) appears to be increasing in each successive survey program. Sand has been negatively correlated with every sediment chemistry analyte examined in 2015, and is less commonly associated with elevated concentrations of organic matter (Sparkes et al., 2015).

In the 2015 HSE EEM sediment program, weak acid extractable barium was the only analyte to have a significant project-related effect when examined at the Whole-field level. Barium, weak acid leachable barium and fuel range hydrocarbons indicated a project-related effect in the Near-field. Other general trends observed that were not significantly Project-related were a decrease in overall mean concentration of several metal analytes compared to 2014, including aluminium, iron, and manganese. Metal analytes with higher overall mean concentrations in 2015 compared to 2014 EEM values included: chromium, lead, strontium, uranium and vanadium. Most notable were increases in mean barium concentrations which had a 6-fold greater maximum detected level in 2015 compared to 2014 and similarly an approximate 3-fold increase for weak-acid extractable barium since the previous (2014) EEM survey. Spatially, the highest concentrations for all of these analytes were co-localized at stations W-250, N-250 and E-250 in 2015 with the exceptions of strontium and uranium.

The spatial abundance of fuel range hydrocarbons ($>C_{10}$-C_{21}), appears to have increased most notably around the EDC since the 2011 baseline survey and statistical analysis indicates this as a

Project-related effect. In addition, the spatial distribution of lube range hydrocarbons (>C_{21}-C_{32}) appeared to be largely similar to that of fuel range hydrocarbons in 2015 however, statistically it is not a Project-related effect. The stations proximal to the EDC that had the highest concentrations of hydrocarbons in the fuel and lube range included stations E-250, N-250 and W-250. Analyses of other organic analyte concentrations such as organic carbon, ammonia-N and sulphide were not determined to be a Project-related effect.

Multivariate analysis of sediment chemistry results showed the 250 m, 500 m, 6,000 m, and 16,000 m (all P values ≤0.05) Distance categories differed significantly from each other in all years, but 250 m only differed from 1000 m from 2014 onwards (e.g. statistically discernible changes in the Near-field have been detected), which coincides with the onset of West Aquarius drilling operations at HSE. Alterations in the Near-field compared to sample locations farther from operations are expected during drilling operations. For example, significant increases in barium and hydrocarbon analytes are typical at Near-field stations (within approximately 250 m) from offshore drilling operations (DeBlois, Paine, et al., 2014b; Pozebon, Lima, Maia, & Fachel, 2005; Trefry et al., 2013).

SEDIMENT TOXICITY RESULTS

Overall, despite changes in sediment chemistry characteristics, the results of sediment toxicity assays indicate no significant project-related effects. Rather, according to amphipod and polychaete assay results, the quality of sediment around HSE appears to be consistent (Figure 6.1, 6.2) or improving (Figures 6.3-6.6) relative to baseline. The amphipod toxicity test in particular is considered a more reliable assay as it has also been shown to identify effects from sediments that are highly contaminated with fuel range hydrocarbons (>C_{10}-C_{21}) and barium associated with Synthetic-Based Muds (SBMs) at other offshore production fields in the area (e.g. Terra Nova) (Whiteway et al., 2014). In contrast, Microtox continues to have unpredictable results around the Near-field that are not correlated to any specific parameter between years. However, similar observations pertaining to Microtox have been reported for other EEM programs in the region. Specifically, the lack of association between Microtox toxicity results and associated discharges from offshore operations, such as differences in fines and strontium around the Terra Nova production field, have called into question the usefulness of this assay for environmental monitoring (Whiteway et al., 2014). Other offshore oil and gas monitoring studies also describe Microtox test results as “inconclusive” (Radovic et al., 2012).

HSE 2015 BIOLOGICAL SURVEY RESULTS

The overall catch rates of American plaice from the 50 km HRA compared to the catch rates around HSE have varied since baseline and were highest in 2014. Although the catch rates of American plaice decreased in 2015 compared to 2014, they were very similar to catch rates of 2011 (Figure 8.3). The 50 km HRA has consistently had slightly higher catch rates relative to HSE (Figure 8.3) and the majority of larger fish sampled were females (Figure 8.4). This pattern is likely representative of the sexual dimorphism in size for this species (Swain & Morgan, 2001). In addition, the greater proportion of larger male and female fish sampled were collected in proximity to the HSE field.

BODY BURDEN

Ten sets of tissue samples were collected from the livers and fillets of American plaice at each of the surveyed areas. Each fillet sample represented an individual fish while liver samples were composites from seven individuals per sample.

Detectable metals greater than or equal to (≥) the reportable detection limit (RDL) in liver tissues in 2015 included arsenic, cadmium, cobalt, copper, iron, manganese, selenium, silver, vanadium, zinc and mercury from both HSE and the 50 km HRA samples. However, zinc was the only analyte based on statistical analysis to show a project-related effect.

All composite liver samples from HSE contained detectable concentrations of fuel ($>C_{10}$-C_{21}) and lube range hydrocarbons ($>C_{21}$-C_{32}) in 2015. At the 50 km HRA, eight of ten composite liver samples had detectable concentrations of fuel range hydrocarbons and all had detectable levels of lube range hydrocarbons, consistent with previous years.

In fillet tissues sampled in 2015 there was a notable reduction in the number of metal analytes detected; only arsenic, mercury, selenium and zinc were observed. Comparatively, chromium, iron, manganese and nickel, had been detected in a single specimen from HSE in 2014. No fuel range ($>C_{10}$-C_{21}) hydrocarbons were detected in filet samples from HSE in 2015. Two fillet samples out of ten in the HSE area had lube range ($>C_{21}$-C_{32}) hydrocarbons detected at concentrations of 24 and 26 mg/kg (relative to an RDL of 15 mg/kg); none was detected from 50 km HRA samples.

TAINT TEST

For the 2015 EEM program sensory evaluation panellists were not able to qualitatively discriminate American plaice filet samples derived from fish collected from the HSE study area versus the 50 km HRA.

FISH HEALTH

Comparison of morphometrics of American plaice sampled between each surveyed area demonstrated the size of male fish surveyed in 2015 was largely similar between the two areas. Statistically significant differences included the Hepatosomatic Index (HSI) was greater among HSE males compared to those collected from the 50 km HRA, and females from HSE were slightly older and larger compared to those from the 50 km HRA.

Gross pathology of the surveyed fish found no indications of disease, abnormalities or lesions. A few parasitic copepods were noted on gills as well as nematodes (roundworms) in some of the viscera. Similar to the 2014 EEM survey (HMDC, 2015), the hematology (blood-smear) samples collected during the 2015 EEM biological cruise were not suitable for analysis.

Analysis of liver enzyme ethoxyresorufin-O-deethylase (EROD) activity on combined maturity stages (separately for each gender) found no significant difference between male or female livers collected from HSE and the 50 km HRA.

There were no significant differences observed between the prevalence of gill or liver pathologies at either HSE or the 50 km HRA in 2015.

CONCLUSION

Overall, project-related effects observed in the sediment monitoring program are consistent with results observed at other offshore oil and gas development installations that show localized changes among key sediment analytes. Specifically, barium, weak acid leachable barium and fuel range hydrocarbons (>C_{10}-C_{21}) have indicated a project-related effect in the Near-field; however, these analytes are all associated with drill cuttings deposition (DeBlois, Paine, et al., 2014b; Pozebon, Lima, Maia, & Fachel, 2005; Trefry et al., 2013). The results of the fish health surveys and body burden analyses reveal that in general, there are no significant differences observed between fish collected from HSE compared to those collected from the 50 km HRA. Moreover, fish from either sampling area were organoleptically indiscernible. Therefore, all three null hypotheses of the HSE EEM program– HSE's drilling operations will not result in significant adverse environmental effects on marine fish, fish habitat, or taint of fish (HMDC, 2013) – are not rejected based on the 2015 HSE EEM survey.

GLOSSARY OF ACRONYMS

2D	Two-dimensional
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
CAPP	Canadian Association of Petroleum Producers
BACI	Before-After Control-Impact (study design)
CEFAS	UK Centre for Environment, Fisheries and Aquaculture Science
CCME	Canadian Council of Ministers of the Environment
cm	Centimetre
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada Nova Scotia Offshore Petroleum Board
CPUE	Catch Per Unit Effort
DFO	Fisheries and Oceans Canada
DISTLM	Distance-Based Multivariate Multiple Linear Regression
ECMP	Environmental Compliance Monitoring Plan
Eco-RBCA	Ecological Risk-Based Corrective Action
EDC	Excavated Drill Centre
EEM	Environmental Effects Monitoring
EQL	Estimated Quantification Limit
EROD	Ethoxyresorufin-O-deethylase
g	Gram
GESAMP	United Nations Group of Experts on Scientific Aspects of Marine Environmental Protection
GBS	Gravity Based Structure
GSI	Gonadosomatic index
HMDC	Hibernia Management and Development and Company Ltd.
HRA	Hibernia Reference Area (16 km for sediment and 50 km for commercial fish)
HSE	Hibernia Southern Extension
HSD	Honest Significant Difference (Tukey test)
HSI	Hepatosomatic index
ICES	International Council for the Exploration of the Sea
IC50	Inhibitory Concentration (at which 50% inhibition occurs)
IQR	Interquartile Range
kg	Kilogram
km	Kilometre
km^2	Square kilometre
L	Litre
m	Metre
m^3	Cubic metre
MARPOL	International Convention for the Prevention of Pollution from Ships
MFO	Mixed Function Oxygenase
mg	Milligram
ml	Millilitre
mm	Millimetre
MODU	Mobile Offshore Drilling Unit
NAD	North American Datum
NAF	Non-Aqueous Fluid
NEB	National Energy Board
NMDS	Non-metric Multidimensional Scaling
NRC	National Research Council
OCNS	Offshore Chemical Notification Scheme
OWTG	Offshore Waste Treatment Guidelines
P	Statistical probability level

PAH	Polycyclic Aromatic Hydrocarbons
PERMANOVA	Permutational Multivariate Analysis of Variance
ppm	Parts per million
QA/QC	Quality Assurance/Quality Control
RDL	Reportable detection limit
SBM	Synthetic-based mud
SD	Standard deviation
SETAC	Society of Environmental Toxicology and Chemistry
SPT	Solid Phase Test
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
UTM	Universal Transverse Mercator
WBM	Water-Based Mud
µg	Microgram

ACKNOWLEDGEMENTS

The 2015 HSE EEM program was conducted under contract to the Hibernia Management and Development Company Ltd. under the guidance of Kent Slaney, Environmental Advisor for HMDC, and managed by Dr. David Coté, Senior Ecologist and Project Manager and Kevin Baldwin as Senior Commercial Lead at Amec Foster Wheeler Environment and Infrastructure (Amec E&I), in St. John's, Newfoundland and Labrador Canada.

The biological survey program was conducted aboard the fisheries Research Vessel the *RV Nuliajuk* with Captain John Chidley and crew. Fish processing and sampling was conducted by Amec E&I personnel including Dr. David Coté, Justin So, Shaun Garland and Randy Norman. Fish health samples were processed and gill samples were analyzed by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University, and liver samples were analyzed by Dr. Rasul Khan, Department of Ocean Sciences, Memorial University of Newfoundland.

The sediment sampling program was conducted aboard the Atlantic Kingfisher with the assistance of her crew. Fugro Geoservices Inc. provided geopositional services for sediment collections by Robby Boland and Jason Dawe. Narcissus Walsh (Narwhal Environmental Consulting Services, St. John's Newfoundland and Labrador) provided logistical expertise for deployment and recovery of the boxcorer on deck. Amec E&I sampling crew included Dr. David Coté, James Loughlin, Justin So, Randy Norman and Brett Barter.

Laboratory quantification of chemical analytes in sediment and tissues as well as particle size analysis was conducted by Maxxam Analytics and managed by Michelle Hill (Newfoundland Canada and Halifax Nova Scotia). Sediment toxicity assays were performed by Petroforma Inc. and managed by Suzette Winters (St. John's Newfoundland and Labrador). Fish fillet taint testing was conducted by the Marine Institute of Memorial University and managed by Michelle Thomson (St. John's Newfoundland and Labrador).

Sediment quality, toxicity and fish tissue (body burden) data was analyzed by Drs. David Coté and Alexandra Eaves, along with Justin So and Dr. Jonas Roberts for fish health results. GIS technical support was provided by Juanita Abbott. Data compilation was conducted by Stephanie Smith and Matthew Gosse and Quality Assurance (QA) reviewed by Dr. Alexandra Eaves. The Volume I Interpretation report was written by Dr. Alexandra Eaves with support from Dr. David Coté and Justin So. The Volume II Methods and Results was compiled by Justin So and Shaun Garland. Senior Independent Review was conducted by James McCarthy and final formatting by Stephanie Smith.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Hibernia Management and Development Corporation Ltd. (HMDC) is committed to conducting an environmental effects monitoring (EEM) program to detect changes in the surrounding environment that may be attributed to its offshore Projects (HMDC, 2013). The baseline characterization of the Hibernia Southern Extension (HSE) production field was conducted in 2011 and the first year of the Environmental Effects Monitoring (EEM) program was completed in 2014 after the initiation of drilling in January of that year (HMDC, 2015). The Year 2 (2015) environmental EEM program for HSE was conducted as part of its three-year monitoring program during drilling operations (HMDC, 2013) and no accompanying survey was conducted for the Hibernia Platform in 2015 in accordance with the EEM schedule for that program.

1.1 Background

The Hibernia field is the longest operating offshore oil and gas production field in Atlantic Canada. It is located approximately 315 km offshore in 82 metres of water in the Jeanne d'Arc Basin on the Grand Banks, east of St. John's Newfoundland and Labrador, Canada (Figure 1.1). The Hibernia Field is in proximity to two other offshore oil and gas drilling operations, those of Terra Nova (operated by Suncor Energy) and White Rose (Husky Energy) (Figure 1.1). The Hibernia geological formation was originally estimated to contain approximately a billion barrels of oil from which the primary drilling centre, the Hibernia Platform is producing approximately 140,000 barrels of crude oil per day (Yeung et al., 2015; Hibernia, 2016a). This is the largest offshore oil production platform in Canada (Yeung et al., 2015). The Hibernia Platform is affixed on top of a gravity based structure (GBS) – a tall (111 meter) cement column constructed with internal chambers with a 1.3 million barrel capacity to store oil (Hibernia 2016a). The combined structure is positioned on the seabed and the topside structure stands 224 metres high and has the capacity to produce 230,000 barrels of crude oil per day as well as living accommodations for a crew of approximately 270 personnel (Hibernia, 2016a). The Hibernia Platform began producing oil in November 1997, and to further develop extended-reach sections of the reservoir, the Hibernia Southern Extension (HSE) excavated drill centre (EDC) has been designed as a subsea development with tiebacks to the Hibernia platform (Hibernia 2016b). Once completed, the HSE will extend Hibernia's oil reserves and operating life.

The HSE is located 7 km southeast of the Hibernia Platform (Figure 1.1). To avoid potential impacts from icebergs, the HSE EDC has been constructed as a 10 meter deep excavation in the seafloor and when drilling installation is complete, will consist of up to five production wells and up to six subsea water injection wells (Hibernia, 2016b). When completed, the water injection wells will be part of a single subsea water injection manifold for pressure maintenance and recovery (Hibernia, 2016b). The production wells are being drilled by extended reach from the Hibernia Platform, and the water injection wells are drilled from the semi-submersible mobile offshore drilling unit (MODU) the West Aquarius (HMDC, 2015b) (Figure 1.2). This HSE subsea development is tied back into the Hibernia Platform via a subsea stimulation and control umbilical as well as a flexible water injection pipeline (Figure 1.3). This EEM report is specific to the HSE portion of the project.

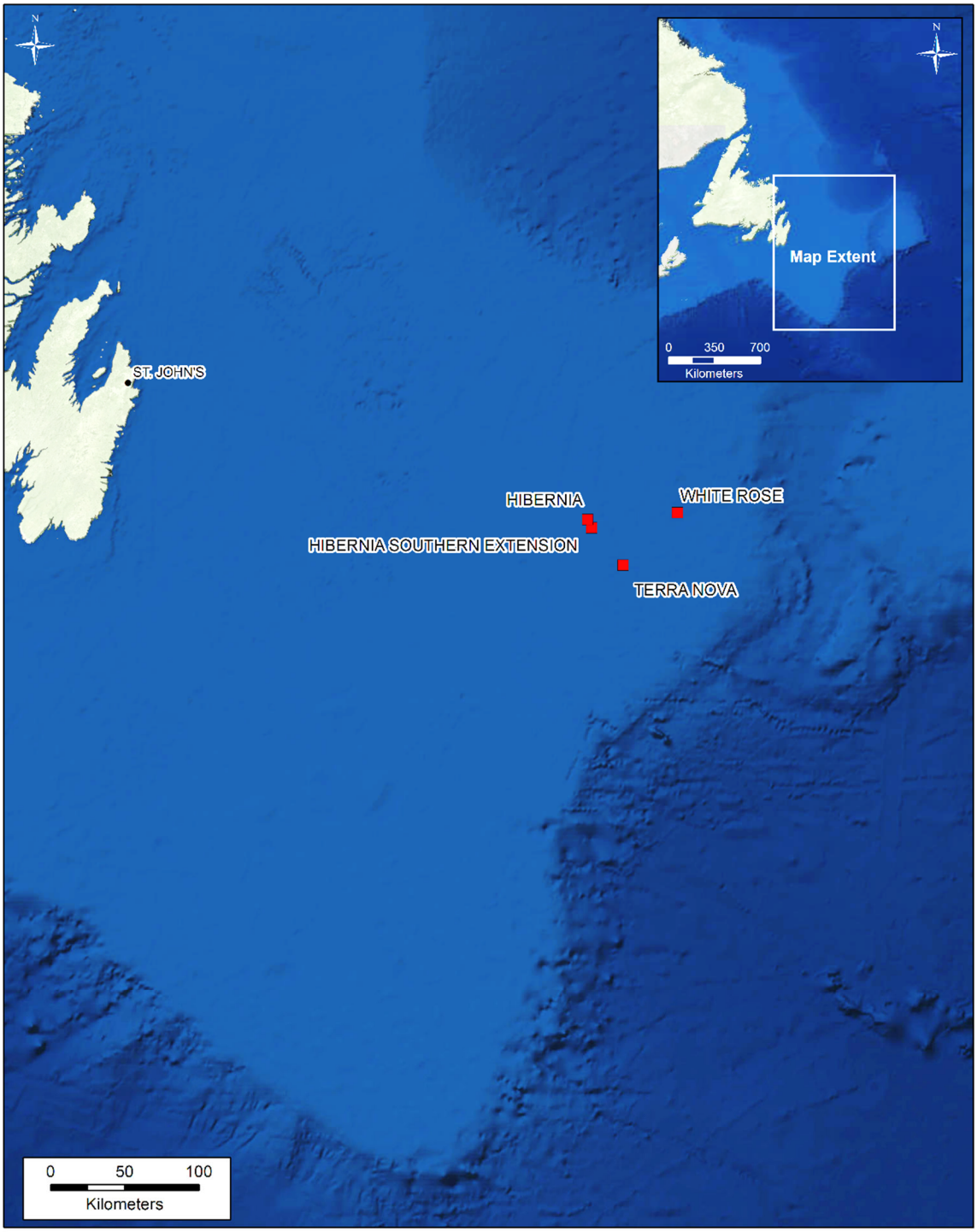


Figure 1.1 Location of the Hibernia production field in relation to St. John's, Newfoundland and Labrador, Canada (inset) and proximity to other offshore production operations on the Grand Banks.

Figure 1.2 West Aquarius semi-submersible mobile drilling unit at HSE in September 2015 with the MV Atlantic Merlin offshore supply vessel on the left, and sediment boxcore sampler being deployed overboard in the foreground on the right.

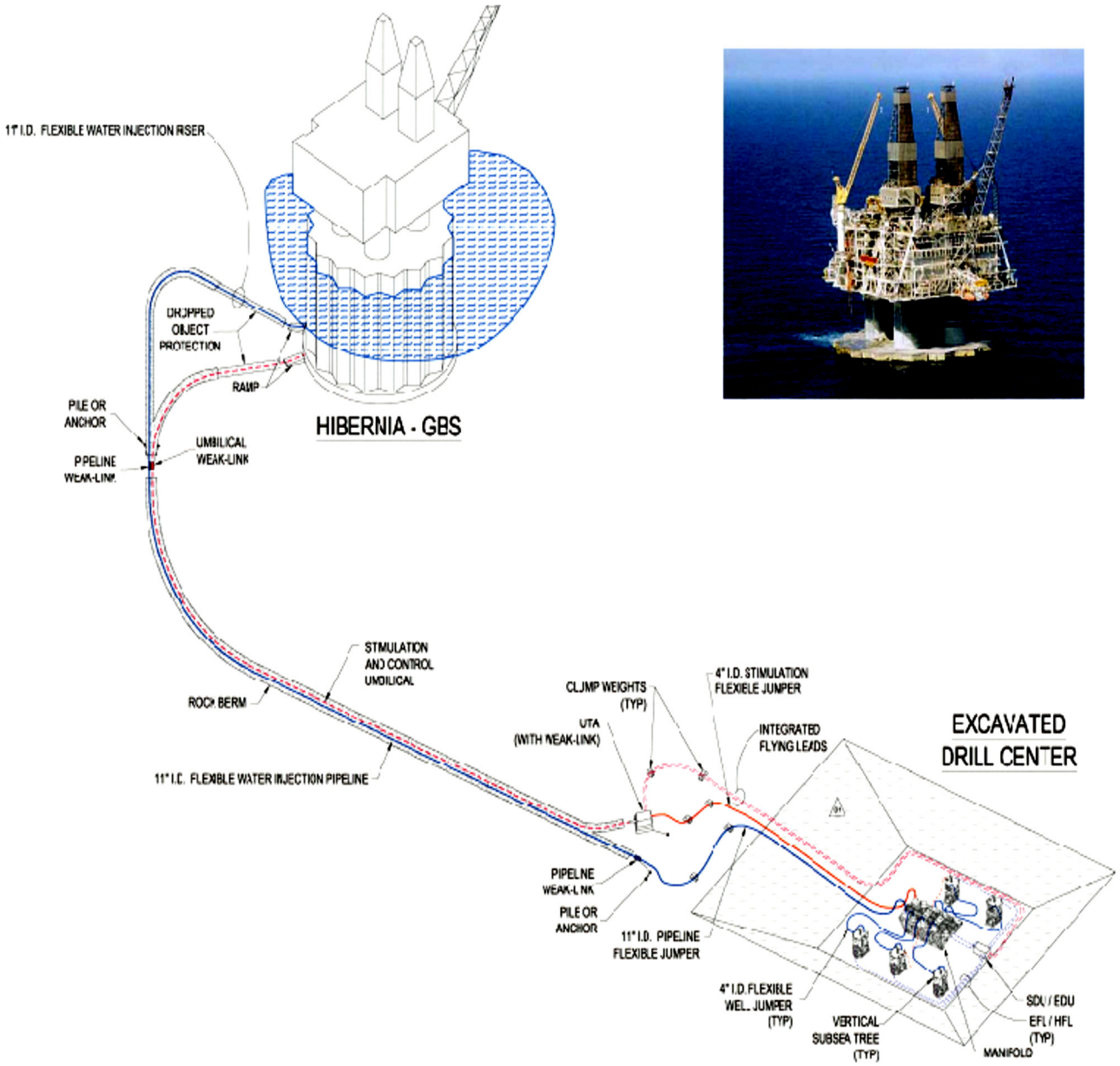


Figure 1.3 Diagram of HSE excavated drill centre and subsea tie-back system connecting to Hibernia Platform (shown in inset) (image from http://www.hibernia.ca/hse.html).

1.2 Project Commitments

The Hibernia Program is committed to conducting an environmental effects monitoring (EEM) program to detect changes in the surrounding environment that can be attributed to the project (HMDC, 2013). Thusly, a monitoring design plan has been adaptively revised, reviewed and approved by the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) that includes the prescriptive monitoring requirements for both the Hibernia Platform and the HSE in its most recent iteration (HMDC, 2013).

Overall, the EEM program is a component among a series of environmental protection initiatives outlined in the HMDC Operational Plan which includes Emergency Response Management and Environmental Compliance Monitoring (HMDC, 2013). As compliment to these other environmental protection initiatives, the EEM program serves two key functions; first, it is intended to detect changes in the receiving environment resulting from project activities during normal activities, and second, it is intended to confirm the effectiveness of discharge limits put forth in the Environmental Protection Plans of the project (HMDC, 2013).

1.3 HSE EEM Program Objectives

The program objectives are listed in the EEM program design plan as follows (HMDC, 2013):

- Fulfill regulatory information requirements and address legitimate public concerns;
- Provide early warning of potential project-induced environmental effects;
- Meets the needs of the project;
- Be scientifically defensible;
- Be cost-effective and make optimal use of equipment, technology and personnel;
- Use the data collected for assessment and where necessary to modify operational practices and procedures; and analyze and interpret data so that the results are understandable to both the public and non-scientists.

These objectives are intended to assess project related HSE activities as they relate to normal operations. In the event of a large accidental oil release, an event-specific Oil Spill EEM would be implemented, using similar monitoring tools, throughout the potentially affected area (HMDC, 2013).

Since the approval of its Environmental Assessment in 2010, monitoring milestones for HSE are as follows (HMDC, 2013, 2015a):

- 2011: initial baseline environmental survey program was conducted at HSE in July (biological cruise) and August (sediment cruise);
- 2014: drilling at HSE began in January (HMDC, 2015a);
- 2014: initial EEM survey at HSE was completed along with biennial Hibernia Platform EEM survey program;
- 2015: EEM surveys represent the first standalone survey of HSE. 2015 was not a planned monitoring year for the Hibernia Platform.
- 2016: the third year post-operational EEM program will be conducted at HSE along with the biennial Hibernia Platform survey program.

1.4 Evaluation and interpretation of the 2015 HSE EEM Monitoring Data

The strategy, methods and interpretation for the 2015 HSE EEM program are illustrated in Figure 1.4. Sample collection was conducted during two offshore programs; a biological sampling cruise to survey and sample fish and a physical cruise to collect benthic sediment samples. For the biological program, the targeted survey species is American plaice (*Hippoglossoides platessoides*), from which fish health sampling, taint (taste) and body burden (detection of

contaminants in fish tissues) are assayed and quantified. For the sediment program, benthic (seabed) samples are collected at pre-determined monitoring stations and are analyzed for particle size, detection of contaminants, and toxicity. All methods, sampling and data are subjected to quality assurance/ quality control (QA/QC) verification in the field, laboratories and during desktop analyses. The methods, results and interpretation of these analyses are defined and presented in the proceeding chapters of this report. The analysis provides statistical interpretation of the spatial and temporal trends that may be occurring in association with drilling activities at HSE. Moreover, particular emphasis is given to parameters that may be associated with drilling operations at HSE, such as barium and hydrocarbons (DeBlois, Paine, et al., 2014; Trefry et al., 2013; Whiteway et al., 2014).

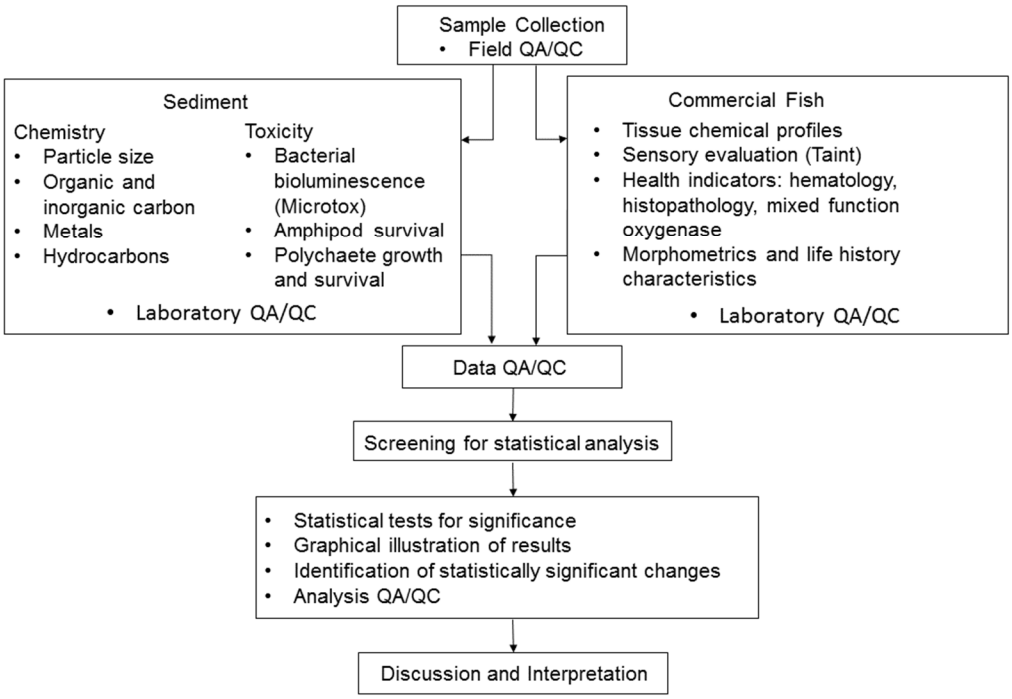


Figure 1.4 Framework for evaluating and interpreting Environmental Effects Monitoring Components (modified from HMDC, 2013, 2015a).

2.0 REGULATED / APPROVED DISCHARGES

Discharges associated with offshore production operations are monitored and reported in accordance with the recommended standards and practices for the treatment and disposal of waste materials associated with offshore petroleum drilling and production operations. These standards and practices are outlined in the Offshore Waste Treatment Guidelines (OWTG) (NEB, 2010). The OWTG are applicable to waste materials including effluents, emissions, solid wastes and discharge limits that are defined in an offshore operator's Environmental Protection Plan. These discharges are monitored according to Paragraph 9(j) of the *Drilling and Production Regulations* (NEB, 2010). Operations at HSE are required to comply with discharge levels and volumes on a continuous basis according to Operator's Environmental Compliance Monitoring Plan (a component of the Environmental Protection Plan). Additional annual requirements outlined in the EEM program are scheduled during the first three years of HSE production (HMDC 2013, HMDC 2015a).

2.1 Discharges at HSE

The National Energy Board (NEB) of Canada, Canada-Nova Scotia Offshore Petroleum Board (C-NSOPB) and Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) (2009) recommend the use of protocols developed by the UK Centre for Environment, Fisheries and Aquaculture Science (CEFASs) for assessing the hazard of chemicals in the Canadian offshore (DeBlois, Paine, et al., 2014). Based on the Offshore Chemical Notification Scheme (OCNS), ratings identifying hazard groups are established based on the chemical, physical and ecotoxicological properties of the products intended for use and disposal offshore; these categories range from most hazardous (category A) to least hazardous (category E) (DeBlois, Paine, et al., 2014).

There are three types of liquid and solid effluents that are generated and discharged into the receiving environment by the West Aquarius in compliance with C-NLOPB monitoring: drilling solids, bilge water and drainage water (HMDC 2015b).

2.2 Drilling Solids

Drilling solids (cuttings) are the particles produced when drilling subsurface rocky formations that are carried from the bottom of the well to the surface by drilling muds (Peralba et al., 2010). Drilling muds are injected into the well hole primarily to cool and lubricate the drill bit, remove cuttings, control backpressure (prevent blow-outs) and maintain the integrity of the hole to allow the installation of a casing (Holdway, 2002). How drilling solids are treated prior to discharge once the drilling mud is expelled from the upper drilling riser on the MODU depends on the nature of the drilling mud being used. There are two general types of drilling muds used at HSE; water based muds (WBMs) and non-aqueous fluids (NAFs). WBMs are generally used only for the top sections (conductor and surface sections) of the wells whereas NAFs are used for horizontal and deeper (intermediate and main sections) sections of wells and for horizontal sections of wells because of their better performance in unstable expandable clay formations (Canadian Association of Petroleum Producers, 2001; DeBlois et al., 2014b).

The primary constituents of WBMs are water, barium sulphate (a.k.a. barite or $BaSO_4$) as a weighting agent, and bentonite clay as a viscosifier (DeBlois, Paine, et al., 2014; Trefry et al., 2013). Depending on the composition of the bedrock formation being drilled, various salts and organic gels may also be added (Trefry et al., 2013). For example, sodium hydroxide (NaOH) and lime are included as a minor fraction (<10% of WBM) at the Terra Nova production field (DeBlois, Paine, et al., 2014). As WBMs are primarily water and barite, which is relatively inert (Whiteway et al., 2014), WBM cuttings are separated from the drilling fluids and discharged overboard (HMDC, 2015b) and barium is the main contaminant of WBM-on-drill cuttings (Whiteway et al., 2014).

In contrast, the primary constituents of NAFs are organic fluid, barite, saltwater, emulsifiers, gelificants and other chemical additives (reviewed by Peralba et al., 2010). The base (organic) fluid is Petro-Canada Puredrill IA-35LV (HMDC, 2015b), a synthetic isoalkane that is completely colorless, odorless, is readily biodegradable and non-toxic to humans and marine wildlife (Talalay and Pyne, 2017). Puredrill IA-35LV complies with US Food and Drug Administration Regulations for pharmaceuticals while in the form of oil and has the same molecular stability and non-reactivity that allows the material to be classed as food grade status for human consumption to assure low toxicity for marine organisms (HMDC, 2015b). It is composed of aliphatic hydrocarbons in the fuel range ($>C_{10}–C_{21}$) and contains no aromatic hydrocarbons (DeBlois, Paine, et al., 2014). This same base fluid is used at the Hibernia Platform (HMDC, 2015b), as well as the Terra Nova production field (DeBlois, Paine, et al., 2014).

Puredrill IA-35LV is also rated as a Category E product (least hazardous) in the Offshore Chemical Notification Scheme (OCNS) (DeBlois et al., 2014b). For disposal on the West Aquarius MODU, the-NAF-on-drilling solids (drilling solids) are physically separated from non-aqueous based drilling fluid (NAF) and treated using dryer technology for a 6.9g/100g oil on wet solids as a performance target prior to discharge (HMDC, 2015b). Samples are collected every twelve hours to quantify the oil on cuttings according to the MI Swaco procedure LW1-041 Synthetic On Cuttings: Test and Report for East Coast Canada (HMDC, 2015b). Drill cutting volumes are calculated from the daily drilling records and are based on the diameter of the drill bit and length of the drilled hole (HMDC, 2015b) (Table 2.1). Fuel range hydrocarbons ($>C_{10}–C_{21}$) and barium are the main contaminants from discharge of PureDrill AI-35LV associated cuttings (Whiteway et al., 2014).

Table 2.1 Estimated Volume of Discharge Cuttings by Hole Section from HSE in 2015

Hole Section	Discharged Cuttings Volume (m^3)		
	WIKK1	WIGG1-2	Average
1067 mm Interval (20% Washout)	105	102	104
660 mm Interval (20% Washout)	136	150	143
445 mm Interval (10% Washout)	309	303	306
311 mm Interval (5% Washout)	272	204	238
216 mm Interval (5% Washout)	13	11	12
216 mm Sidetrack Interval (5% Washout)	37	-	-

2.3 Bilge Water Collection

Bilge water is collected in a bilge water collection tank under normal operating conditions and is directed to an oil-water separation system from where the accumulated sludge is transported to shore for treatment and disposal (HMDC, 2015b). The treated water is discharged through a dedicated overboard line equipped with an in-line detector that continuously monitors oil content in water; discharge will automatically stop if oil content in excess of 15 mg/L of oil in water is detected consistent with the International Convention for the Prevention of Pollution from Ships (MARPOL) requirements (HMDC, 2015b).

2.4 Drainage Water

Deck drainage discharge may contain various contaminants such as cleaning detergents and dispersants, small amounts of hydrocarbons, and other chemicals such as lubricants (Yang, Khan, & Sadiq, 2011). On the West Aquarius, drainage waste is carefully controlled by two systems. The first is a clean drain system which collects precipitation and water runoff in areas of the MODU where hydrocarbon and other chemical spills do not occur, such as the weather deck periphery drains, and discharges directly to sea (HMDC 2015b). The second is a contaminated drain system which diverts hazardous (e.g., liquid mud/brine tank cleaning well test area and helicopter refueling skid) and non-hazardous (e.g., pipe storage areas, mud lab and mud pump room) area drains into segregated, separator chamber tanks for removal of solids. Any light fraction hydrocarbons that are detected within the system are to be separated and properly handled for disposal, similar to bilge water (HMDC 2015b). Any deck drainage that is to be discharged to sea, consistent with bilge water management, does not contain residual oil concentrations in excess of 15 mg/ L as described in the OWTG (HMDC, 2015b).

2.5 Other Discharges

Additional sources of effluent from the West Aquarius for which compliance monitoring is not required includes water-based drill cuttings, ballast water, cooling water, desalination brine as well as small amounts of subsea system operational discharges (such as approximately 0.44 m^3 of water-based biodegradable control fluid per well annually) (HMDC, 2015b). All chemicals that may potentially be released to sea are screened in accordance with the C-NLOPB offshore chemical selection guidelines and quantities released are reported annually as described in the West Aquarius Environmental Compliance Monitoring Plan (ECMP) (HMDC, 2015b).

2.6 Contamination versus Pollution

Discharges resulting in the presence of a substance in the marine environment at concentrations greater than background levels or greater than a pre-determined approved concentration is characterized as contamination in the marine receiving environment (Chapman, 2007). For a substance to be characterized as a contamination, it does not need to cause a biological effect. The term pollution is given to contamination that results in adverse biological effects (Chapman, 2007).

In order to determine whether any contaminant identified in samples might have a negative biological effect, its bioavailability is included within the assessment. Bioavailability of a contaminant can vary depending on several factors such as chemical form, modifying environmental factors, environmental niche and the behavioral and physiological reactions of exposed biota (Chapman, 2007). Therefore, the detection of chemical analytes (contaminants) in the environment alone does not identify a pollutant, rather effects-based measures such as bioavailability and toxicity assays are also required to determine pollution status (Chapman, 2007). Moreover, linkages must be established between environmental levels of exposure and internal levels of tissue contamination to indicate an injurious effect of a substance in the marine ecosystem (Van Der Oost, Beyer, & Vermeulen, 2003a). The use of biomarkers (changes in a biological responses) provide insight regarding potential mechanisms of contaminant effects on an organism (Van Der Oost et al., 2003a). The incorporation of such assays is included in the HSE EEM design to monitor for potential adverse environmental conditions and these are discussed in later chapters.

3.0 HIBERNIA SOUTHERN EXTENSION ENVIRONMENTAL EFFECTS MONITORING PROGRAM

3.1 Sampling Frequency, Survey Timing, and Boundaries

The baseline characterization of the Hibernia Southern Extension (HSE) production field was conducted in 2011 and the first year of the Environmental Effects Monitoring (EEM) program was completed in 2014 after the initiation of drilling in January of that year (HMDC, 2015a). The design of the HSE EEM program is consistent with that of the Hibernia Platform EEM program, and details of both are described in the Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring Plan (HMDC, 2013). There is no produced water monitoring program for HSE as all fluids are managed and processed on the Hibernia Platform (HMDC, 2013). The HSE EEM program consists of sediment and commercial fish sampling components to assess the chemistry and toxicity of sediment quality, and the health, size and body burden chemistry of fish (please see Table 3.1). This report describes the results of the Year 2 (2015) EEM program for HSE; the schedule history of the sampling program is summarized in Table 3.2. In general, the HSE EEM program is scheduled to be conducted annually for the first three years of production (since 2014), then on alternate years consistent with other EEM programs on the Grand Banks (HMDC, 2013). Detailed descriptions of sampling/subsampling methods and data reports are included in Volume II.

Table 3.1 Hibernia Southern Extension Environmental Effects Monitoring Program Sediment and Biological Sampling Program Component Parameters and Analysis

Program Component	Parameters	Analysis
Sediment Quality	Chemistry	Particle size, organic and inorganic carbon, metals, hydrocarbons, ammonia and sulphide concentrations
	Toxicity	Bacterial bioluminescence (Microtox), Amphipod survival, Polychaete growth and survival
Commercial Fish (American plaice)	Tissue Chemical Profiles	Body burden (metals, hydrocarbons, ammonia and sulphide concentrations)
	Sensory Evaluation	Taint / taste testing
	Health Indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity

Table 3.2 Hibernia Southern Extension Environmental Effects Monitoring Program Sediment and Biological Sampling Cruise History.

EEM Production Year	Sediment Cruise Dates	Biological Cruise Dates
2011 (Baseline)	August 01-06	July 07-12
2014 (Year 1 EEM)*	August 07-17	June 20-July 01
2015 (Year 2 EEM)	September 10-16	June 28-30
* Drilling at HSE commenced in January 2014 (HMDC, 2015a)		

3.2 Sediment Sampling Program

Samples of benthic marine sediment are collected from the seafloor from pre-established coordinates originally specified in the EEM design plan (HMDC, 2013). The sediment sampling stations are arranged at approximately 250-, 500- and 1,000-meter distances from the drill centre along the cardinal radials (north, south, east and west) projecting from the excavated drill centre (EDC). There are an additional two sediment sampling reference areas common to all Hibernia programs (Hibernia Platform and HSE); one located approximately 16 km north of the Hibernia Platform (station 1-16000), and a second sediment sampling reference area located approximately 16 km west of the Hibernia Platform (station 7-16000) (Figure 3.1). Relative to HSE, these Reference Areas are 26.8 km (station 1-16000) and 23.9 km (station 7-16000) away. Subsequent to the 2011 baseline survey (Figure 3.2), an additional four stations on a radius 6,000 meters away from the EDC on the eastern side were included (Figure 3.3). They were added to the HSE EEM program in 2014 following the onset of drilling to enable examination and quantification of potential cumulative effects of the whole Hibernia program (Hibernia Platform and HSE simultaneously) during EEM survey years when both production fields are surveyed (such was the case in 2014) in addition to potential changes for each drill centre location individually (HMDC, 2013; 2015).

The sample distances from the EDC are referred to as Near-, Mid- and Far-field respectively and are classified according to Table 3.3 (consistent with previous years). Since the 2011 baseline survey, the location of all the Near-field stations (within 1 km of the EDC) have been repositioned slightly to maintain safe working distances for deployment of the benthic sampling device in the vicinity of new subsea infrastructure installations (Figure 3.2-3.4). The coordinates of the 2015 EEM sampling stations are provided in Table 3.4. The distances of the EEM sampling stations relative to the original baseline sampling locations are summarized in Table 3.5. In a previous survey the suffix ‘-M’ had been added to the Near-field stations to denote them as being moved since baseline. As adjustments to locations are ongoing to accommodate new subsea installations this suffix has since been removed and the record of distances moved is instead provided as a summary in Table 3.4 as well as being depicted spatially in relevant outputs of this report.

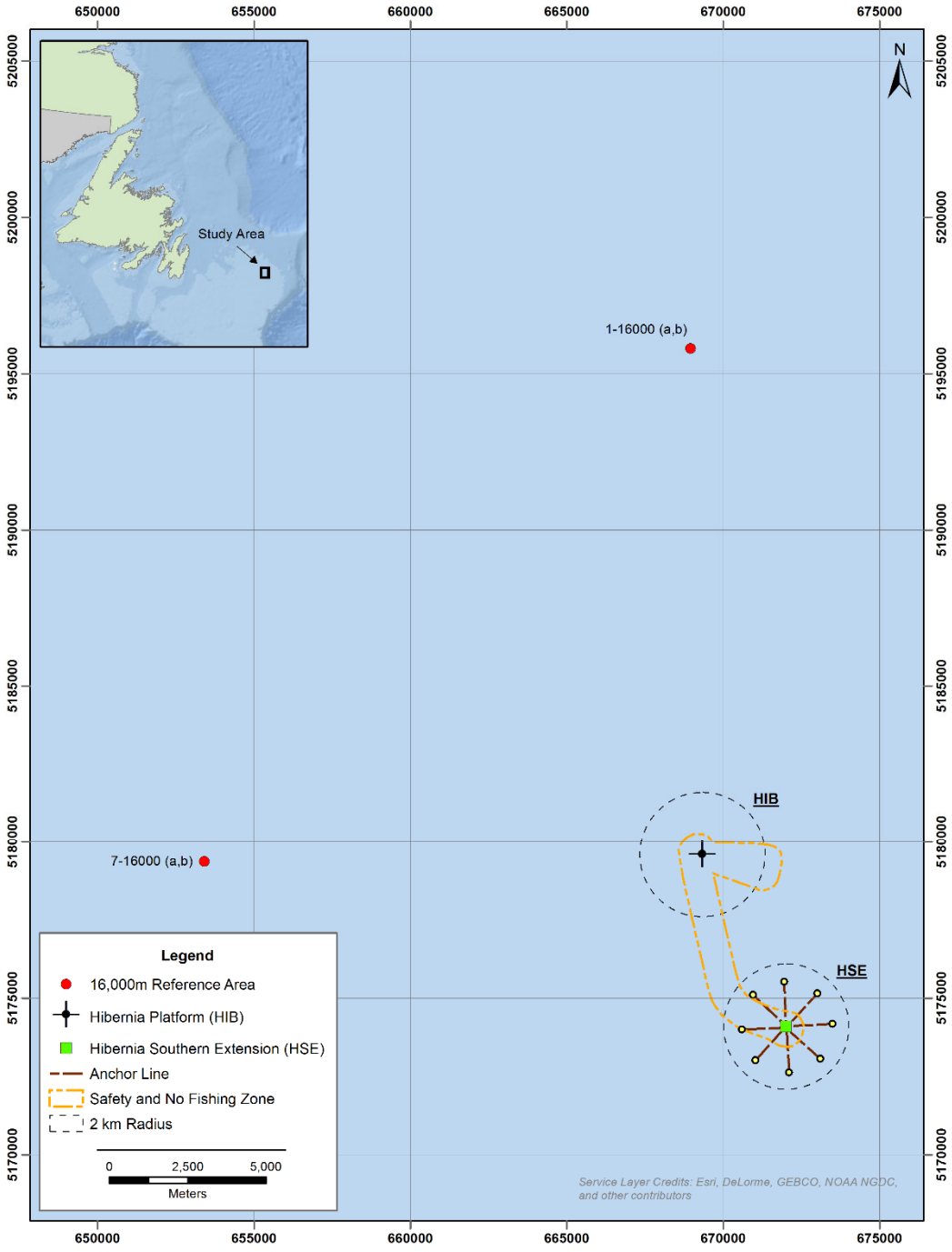


Figure 3.1 Locations of Hibernia Program areas: Hibernia Platform (HIB), Hibernia Southern Extension (HSE) and Reference Areas 16 km to the west and north of the Hibernia Platform.

Table 3.3 Field Distance Definitions for Hibernia Platform and Hibernia Southern Extension

Field distance descriptors[1]	Distance from Source[2]	Distance form Hibernia Platform	Distance from HSE
Near-Field	≤ 1000 m	250, 500, 1000m	250, 500, 1000 m
Mid-Field[3]	>1000 m to ≤ 3000 m	2000, 3000 m	-
Far-Field[4]	>4000m	6000 m	6000 m
[1] Whole-Field Analysis combines Near-, Mid-, and Far- for one Source, Cross-Field Analysis is a comparison between Hibernia Platform and HSE [2] Source being Hibernia Platform or HSE Drill Centre [3] Mid-Field prior to 2004 was defined as 1500-3000 m [4] Far-Field prior to 2004 was defined as 4000-8000 m			

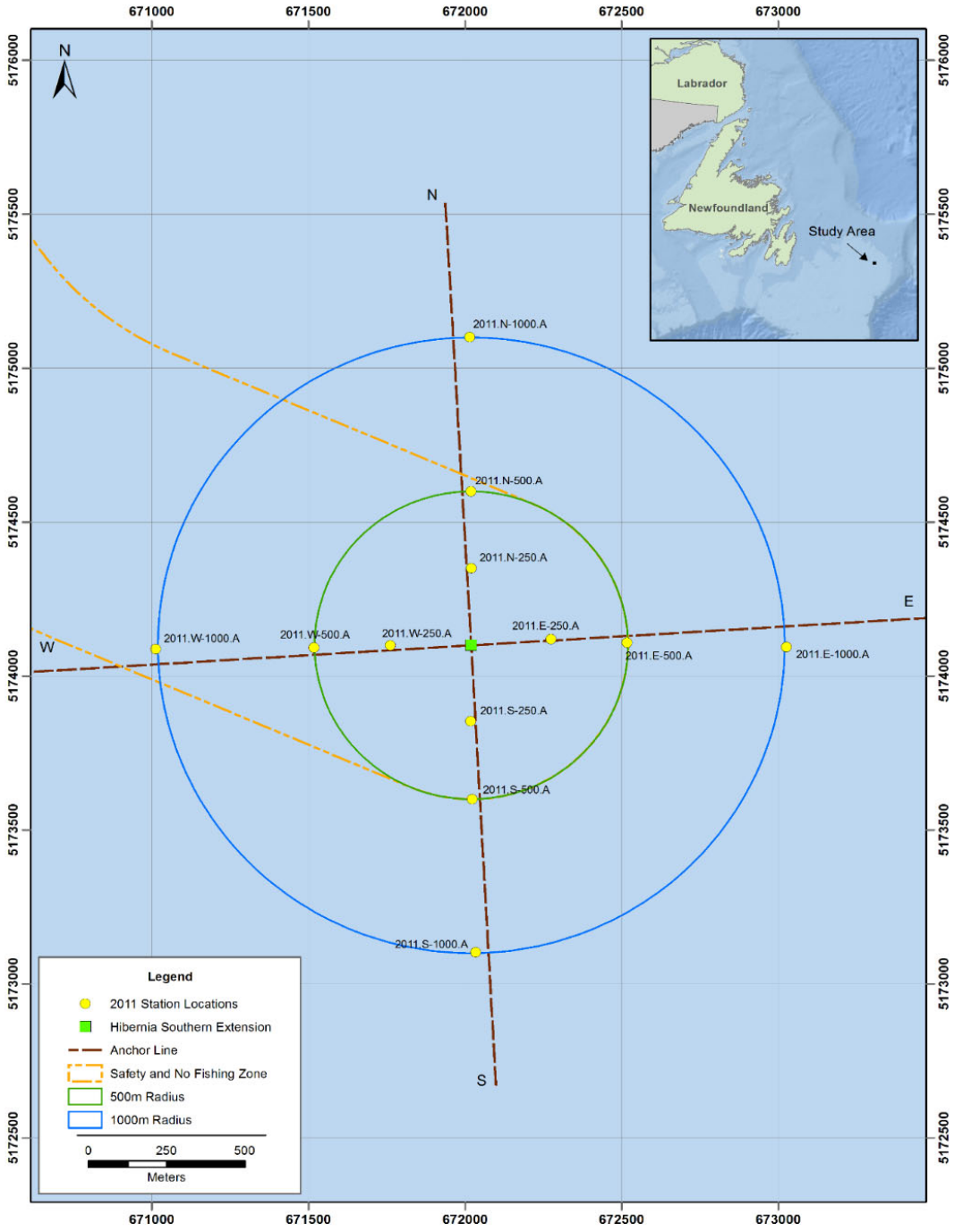


Figure 3.2 Near-field stations sampled at HSE for 2011 baseline survey

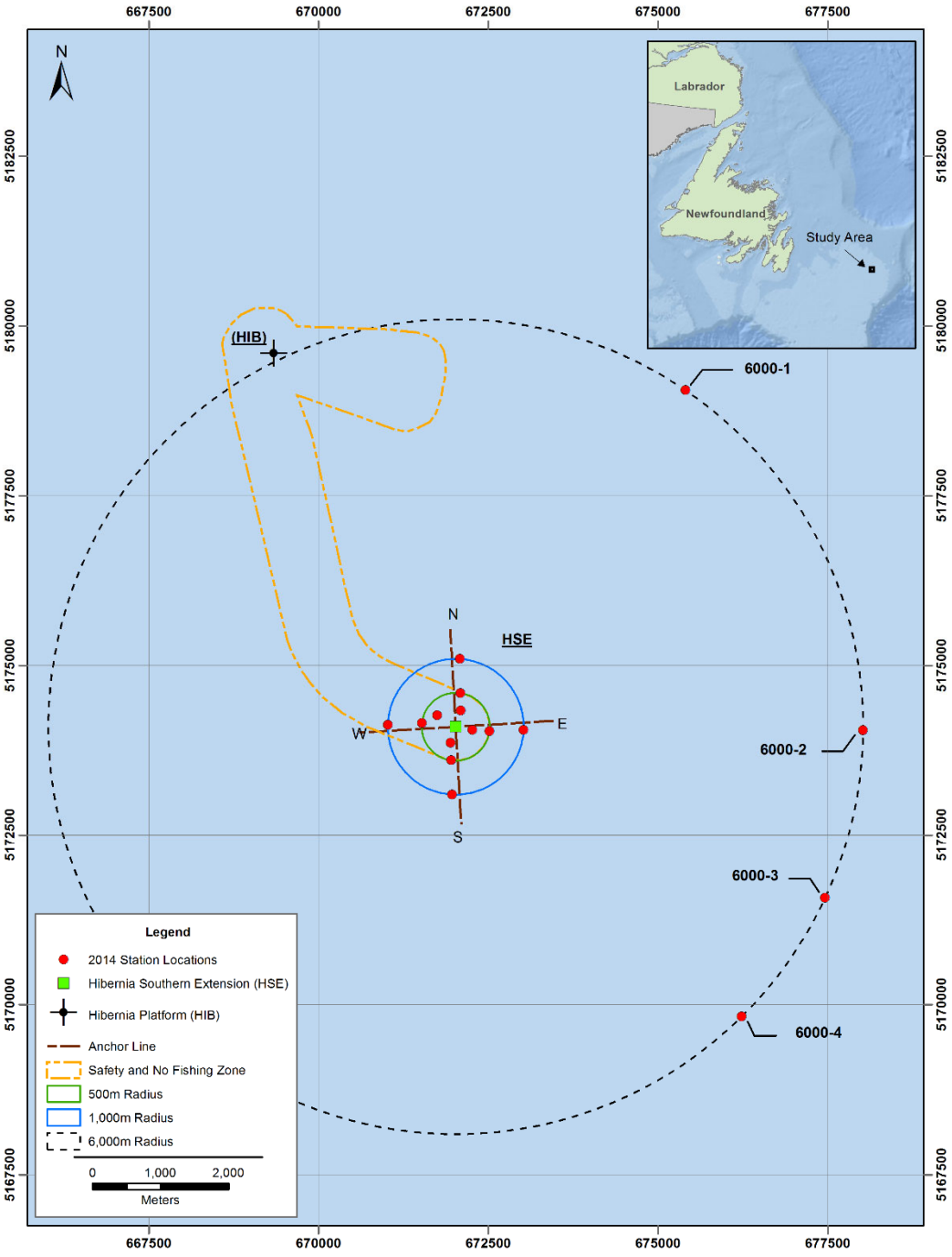


Figure 3.3 Near-field and 6,000 m stations (added after baseline) sampled for Year 1, 2014 EEM HSE survey.

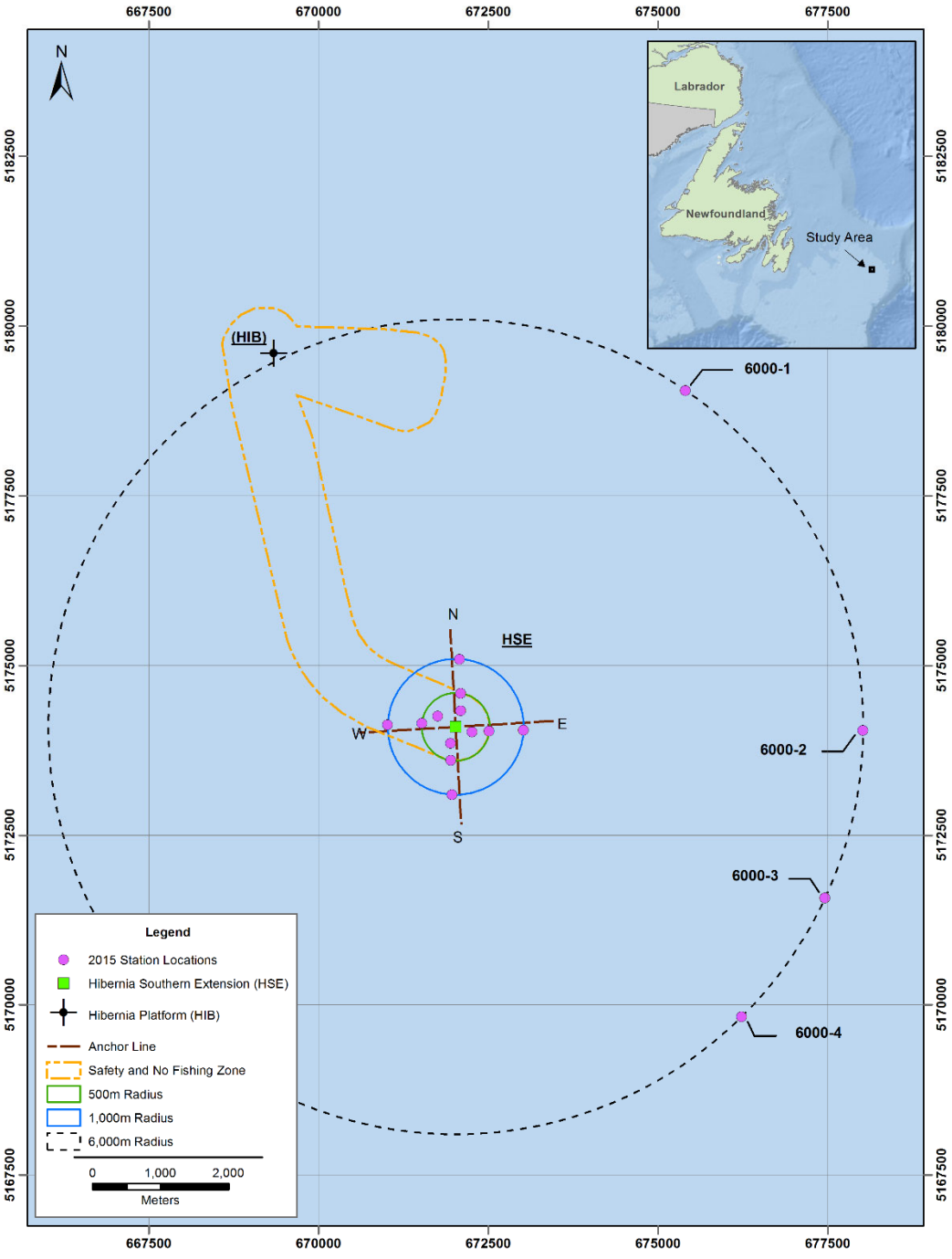


Figure 3.4 Near-field and 6,000 m stations (added after baseline) sampled for Year 2, 2015 EEM HSE survey

Table 3.4 Hibernia Southern Extension Field 2015 sediment sampling coordinates (UTM_NAD83)

Station	Proposed Position		Actual Position	
	Easting	Northing	Easting	Northing
N-1000	672081.00	5175098.00	672079.31	5175096.37
N-500	672091.00	5174595.00	672093.66	5174594.70
N-250	672096.00	5174338.00	672095.38	5174338.79
E-1000	673019.00	5174052.00	673020.71	5174051.75
E-500	672516.00	5174035.00	672515.14	5174038.14
E-250	672259.00	5174026.00	672260.21	5174026.02
S-1000	671967.00	5173101.00	671966.91	5173101.39
S-500	671952.00	5173605.00	671951.74	5173605.96
S-500 QA/QC	671952.00	5173605.00	671951.29	5173607.76
S-250	671945.00	5173861.00	671944.30	5173858.78
W-1000	671020.00	5174127.00	671018.34	5174130.50
W-500	671523.00	5174151.00	671521.24	5174151.03
W-250	671754.00	5174255.00	671754.40	5174256.97
6000-1	675405.00	5179054.00	675403.04	5179053.33
6000-2	678020.00	5174048.00	678019.27	5174047.82
6000-2 QA/QC	678020.00	5174048.00	678020.59	5174049.03
6000-3	677461.00	5171570.00	677462.32	5171571.39
6000-4	676232.00	5169827.00	676232.20	5169827.11
1-16000a	668966.40	5195808.00	668966.20	5195809.31
1-16000b	668966.40	5195808.00	668966.83	5195809.15
7-16000a	653425.40	5179364.00	653426.38	5179365.42
7-16000b	653425.40	5179364.00	653426.56	5179365.66

Table 3.5 Distances of HSE sediment stations sampled relative to baseline (2011) locations survey during EEM years 1 (2014) and 2 (2015).

Station ID	2011 Coordinates (NAD 83 UTM)		Distance (m) from baseline (2011 position)	
	Easting	Northing	2014	2015
N-250	672020.71	5174351.12	75.56	75.68
N-500	672019.35	5174600.37	75.53	74.53
N-1000	672016.27	5175101.13	61.60	63.22
E-250	672275.54	5174120.66	92.79	95.87
E-500	672518.15	5174108.84	77.92	70.76
E-1000	673026.94	5174094.18	48.59	42.88
S-250	672018.82	5173853.27	70.87	74.72
S-500	672023.93	5173600.03	71.43	72.43
S-1000	672034.67	5173102.53	73.57	67.77
W-250	671762.52	5174099.83	119.79	157.35
W-500	671519.02	5174092.43	69.57	58.64
W-1000	671013.66	5174087.59	43.37	43.16

3.3 Hibernia Southern Extension Monitoring Program Hypotheses

The design of the EEM program is consistent with that of the Hibernia Platform in that critical elements of the receiving marine environment are monitored to provide timely and beneficial information to detect deleterious effects to the marine environment (HMDC, 2013). The program has been strengthened based on recommendations from regulatory review as well as experience gained during previous Hibernia EEM programs. The body of data that is collected from the biological and sediment monitoring programs is evaluated in a scientifically-defensible manner (based on statistical analysis and interpretation with peer-reviewed research) for early indication of potential project-induced alterations to the surrounding environment for which a series of hypotheses have been developed (HMDC, 2013).

The monitoring hypotheses for the HSE EEM program are consistent with those of the Hibernia Platform EEM program and are stated in the *Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring Plan* (HMDC, 2013) as follows:

Hypothesis No.1:

- H_0 = Approved releases of solids and liquids from HSE's drilling operations will not result in significant adverse environmental effects on marine fish (as assessed by fish health indicators and integrative assessment).

- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in significant adverse environmental effects on marine fish (as assessed by fish health indicators and integrative assessment).

Hypothesis No.2:

- H_0 = Approved releases of solids and liquids from HSE's drilling operations will not result in significant adverse environmental effects on marine fish habitat (as evaluated by sediment toxicity assays and integrative assessment).
- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in significant adverse environmental effects on marine fish habitat (as evaluated by sediment toxicity assays and integrative assessment).

Hypothesis No.3:

- H_0 = Approved releases of solids and liquids from HSE's drilling operations will not result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.
- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.

To assess the environmental effects of the HSE project, an integrative weight of evidence approach is used whereby the physical, chemical, toxicity and biological data are considered collectively; thereby providing a more informed interpretation of the potential ecological impacts derived from chemical (pollutant) or other stressors (Chapman, 2007). Essentially, the results of the analyses from each component of the EEM program are reviewed collectively to provide an overall interpretation of the program hypotheses. For example, the null hypothesis for No. 2 would be rejected if the outcome of the EEM program were to demonstrate:

- Biological toxicity testing (including amphipod and/ or polychaete worm testing) indicate a toxic response at a sediment sampling station in the vicinity of the project;
- The toxic response is correlated to the elevated presence of an analyte known to be associated with drilling operations;
- There is a statistically significant difference in the concentration of that analyte compared to background or baseline conditions (HMDC, 2013).

Where a biological effect beyond the predictions of the Environmental Impact Statement is confirmed, the determination of biological significance of this effect according to the hypothesis statements of the program (listed above) is included in the annual environmental assessment update. These interpretations will include a qualitative and where possible, quantitative assessment using existing knowledge (referenced scientific studies), professional judgement and analytical tools (HMDC, 2015a).

Should a biological effect beyond the predictions of the environmental assessment be identified through the EEM program, the sampling associated with the program will be reviewed and, if needed, adapted to ensure resolution is adequate to determine the spatial scale of any observed biological effect. Any adaptations would be subject to the approval of the C-NLOPB. The

subsequent EEM program would proceed as per its regular schedule (unless a change is agreed to by the C-NLOPB) and include modifications to the sampling program design.

3.4 Data collection

3.4.1 Sediment Sampling Program

Consistent with previous EEM surveys and design plan (HMDC, 2013, 2015a), each sediment sample was collected within a 50 m radius of the established station coordinate and subjected to laboratory analyses for:

- particle size;
- total metals;
- barium (both total and weak-acid leachable);
- hydrocarbons (total petroleum hydrocarbons (TPHs), PAHs and alkyl PAHs);
- total inorganic carbon (TIC) and total organic carbon (TOC);
- sulphide and ammonia as nitrogen (-N).

3.4.2 Biological Sampling Program

For the biological sampling program, commercial fish were sampled on a separate cruise within the same season. Sample collection was completed onboard a commercial fishing vessel equipped with a Campelen trawl. The target commercial fish species was American plaice (*Hippoglossoides platessoides*) which were collected within a two km radius of the HSE EDC along with a reference site located 50 km northwest of the Hibernia Platform. As prescribed in the HMDC Design Plan (HMDC, 2013), a minimum of seven tows were conducted at each location and 50 American plaice 25 cm in length or greater collected. For every fish collected, the length and weight of the whole fish was recorded, condition of each fish assessed, and sexual maturity was indexed. Subsamples of organs and tissues were collected for analytical evaluation of chemical body burden in tissues, health parameters (described in detail in Chapter 8), and taste. Taste tests were conducted using a panel for qualitative assessment of fish fillets harvested from the study area (HSE) versus the reference area. By-catch data from trawls was also recorded.

4.0 HSE 2015 SEDIMENT PROGRAM

The following chapters present the results of the analysis of sediment samples collected during the 2015 HSE EEM program. Detailed descriptions of sampling methods and data reports are included in Volume II.

4.1 Data Collection

Sediment samples were collected using a box core device within a 50 m radius of predetermined sediment station locations. Sub-samples were collected from the sediment core and laboratory analysis was conducted to assay concentrations of the following analytes as specified in the Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring Plan (HMDC, 2013):

- Total metals;
- Petroleum hydrocarbons including total petroleum hydrocarbons, polycyclic aromatic; hydrocarbons (PAHs) and alkylated-PAHs (APAHs);
- Total organic carbon (TOC), and total inorganic carbon (TIC);
- Total barium and weak-acid extractable (leachable) barium;
- Ammonia;
- Sulphide;
- Particle size

These analytes are reported if their concentration is equal to or greater than the minimum concentration at which they can be detected in laboratory analysis. This threshold of detection is the reported detection limit (RDL). The RDL for each analyte is consistent with those specified according to regulatory testing standards (included in volume II).

The chemical data for analytes with detections above RDL during the 2015 HSE EEM program are summarized in Table 4.1. All sediment chemistry laboratory data are included in Volume II of this report. Consistent with the previous 2014 HSE EEM program, a total of 16 sediment stations were sampled for analysis (HMDC, 2015). The reported detection limit (RDL), number of samples analyzed, the number of stations with detected values (above RDL), as well as the average of the detected values (mean), standard deviation, median, minimum and maximum detected values are summarized in Table 4.1 for HSE and Table 4.2 for the Reference Area. As per previous Hibernia EEM programs, for samples with detection values below RDL, values equal to the RDL were used for calculating descriptive statistics to obtain a mean value no less than the RDL for that analyte. The descriptive statistics are used for visually screening which analytes are to be retained for further data analysis. The rationale for the use of other methods to address non-detection values (below RDL) is as described in the design plan (HMDC, 2013).

Table 4.1 Summary of Detectable Chemical Data for the 2015 HSE EEM Sediment Stations

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
WEAK ACID EXTRACTABLE METALS													
Barium	5	mg/kg	16	0	4	12	15	10	11	<RDL	35	-	-
TOTAL EXTRACTABLE METALS													
Aluminum	10	mg/kg	16	0	0	16	6406	2067	7100	2300	9600	-	-
Arsenic	2	mg/kg	16	0	16	0	2	0	2	<RDL	<RDL	7.24	41.6
Barium	50	mg/kg	16	0	0	16	715	999	185	93	2900	-	-
Cadmium	0.05	mg/kg	16	0	13	3	0.05	0.01	0.05	<RDL	0.09	-	-
Chromium	2	mg/kg	16	0	0	16	5	1	4	3	7	52.3	160
Cobalt	1	mg/kg	16	1	14	1	1	0	1	<RDL	1	-	-
Copper	2	mg/kg	16	1	13	2	2	0	2	<RDL	2	-	-
Iron	50	mg/kg	16	0	0	16	1837	784	1750	890	3500	-	-
Lead	0.50	mg/kg	16	0	0	16	2.77	1.16	2.45	1.20	5.40	30.2	112
Lithium	2	mg/kg	16	0	13	3	2	0	2	<RDL	3	-	-
Manganese	2	mg/kg	16	0	0	16	38	16	36	19	78	-	-
Mercury	0.01	mg/kg	16	0	15	1	0.01	0.01	0.01	<RDL	0.03	-	-
Nickel	2	mg/kg	16	0	12	4	2	0	2	<RDL	3	-	-
Strontium	50	mg/kg	16	0	0	16	434	338	490	28	1100	-	-
Thallium	0.1	mg/kg	16	1	15	0	0.1	0.0	0.1	<RDL	0.1	-	-
Uranium	0.1	mg/kg	16	0	0	16	0.3	0.2	0.3	0.1	1.0	-	-
Vanadium	2	mg/kg	16	0	0	16	7	3	7	4	13	-	-
Zinc	5	mg/kg	16	0	11	5	6	2	5	<RDL	9	124	271
PARTICLE SIZE ANALYSIS													
Gravel	0.1	%	16	1	0	16	16.8	14.4	12.0	0.1	47.0	-	-
Sand	0.1	%	16	0	0	16	80.5	15.3	85.0	50.0	99.0	-	-
Silt	0.1	%	16	0	3	13	0.6	0.6	0.3	<RDL	2.1	-	-
Clay	0.1	%	16	0	0	16	2.2	1.2	1.9	0.6	4.9	-	-
TIC/TOC													
Total Inorganic Carbon	0.2	g/kg	16	0	1	15	9.1	7.6	10.2	<RDL	23.0	-	-

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
Organic Carbon	0.2	g/kg	16	0	0	16	2.5	2.3	1.9	0.2	8.5	-	-
HYDROCARBONS													
Toluene	0.025	mg/kg	16	0	16	0	0.025	0.0	0.025	<RDL	<RDL	-	-
>C_{10}-C_{21} Hydrocarbons	0.25	mg/kg	16	0	4	12	97.57	169.68	14.35	<RDL	510.00	-	-
>C_{21}-C_{32} Hydrocarbons	0.25	mg/kg	16	0	8	8	0.82	0.82	0.29	<RDL	2.60	-	-
OTHER													
Sulphide	0.5	ug/g	16	0	5	11	0.9	0.5	0.7	<RDL	2.1	-	-
Moisture	0.3	%	16	0	0	16	15.7	2.9	16.5	8.5	20.0	-	-
Ammonia-N	1.7	mg/kg	16	0	0	16	8.1	5.0	7.3	1.4	17.0	-	-

[1]ISQG – Interim Sediment Quality Guidelines and PEL – Probable Effect Levels as specified in the *Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment* (1999, updated 2001). Analytes detected at or above RDL are reported here.

Table 4.2 Summary of Detectable Chemical Data for the 2015 Hibernia Reference Sediment Stations

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
WEAK ACID EXTRACTABLE METALS													
Barium	5	mg/kg	4	0	4	0	5	0	5	<RDL	<RDL	-	-
TOTAL EXTRACTABLE METALS													
Aluminum	10	mg/kg	4	0	0	4	4350	1907	4300	2700	6100	-	-
Arsenic	2	mg/kg	4	0	4	0	2	0	2	<RDL	<RDL	7.24	41.6
Barium	50	mg/kg	4	0	0	4	90	29	88	64	120	-	-
Cadmium	0.05	mg/kg	4	0	4	0	0.05	0.00	0.05	<RDL	<RDL	-	-
Chromium	2	mg/kg	4	0	0	4	4	1	5	4	5	52.3	160
Cobalt	1	mg/kg	4	0	4	0	1	0	1	<RDL	<RDL	-	-
Copper	2	mg/kg	4	0	4	0	2	0	2	<RDL	<RDL	-	-
Iron	50	mg/kg	4	0	0	4	1625	479	1600	1100	2200	-	-
Lead	0.5	mg/kg	4	0	0	4	1.9	0.3	1.9	1.5	2.2	30.2	112
Lithium	2	mg/kg	4	0	0	4	2	0	2	2	2	-	-
Manganese	2	mg/kg	4	0	0	4	35	33	27	8	80	-	-
Mercury	0.01	mg/kg	4	0	4	0	0.01	0.00	0.01	<RDL	<RDL	-	-
Nickel	2	mg/kg	4	0	4	0	2	0	2	<RDL	<RDL	-	-
Strontium	50	mg/kg	4	0	0	4	22	12	22	12	34	-	-
Thallium	0.1	mg/kg	4	0	4	0	0.1	0.0	0.1	<RDL	<RDL	-	-
Uranium	0.1	mg/kg	4	0	0	4	0.2	0.0	0.2	0.1	0.2	-	-
Vanadium	2	mg/kg	4	0	0	4	5	1	5	4	7	-	-
Zinc	5	mg/kg	4	0	4	0	5	0	5	<RDL	<RDL	124	271
PARTICLE SIZE ANALYSIS													
Gravel	0.1	%	4	0	2	2	2.4	1.7	0.6	<RDL	3.7	-	-
Sand	0.1	%	4	0	0	4	97.8	1.9	98.5	95.0	99.0	-	-
Silt	0.1	%	4	0	3	1	0.1	0.0	0.1	<RDL	0.1	-	-
Clay	0.1	%	4	0	0	4	1.0	0.2	1.0	0.8	1.3	-	-
TIC/TOC													
Total Inorganic Carbon	0.2	g/kg	4	0	2	2	0.3	0.2	0.2	<RDL	0.6	-	-

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
Organic Carbon	0.2	g/kg	4	0	2	2	0.3	0.2	0.3	<RDL	0.5	-	-
HYDROCARBONS													
Toluene	0.025	mg/kg	4	0	4	0	0.025	0.00	0.025	<RDL	<RDL	-	-
>C_{10}-C_{21} Hydrocarbons	0.25	mg/kg	4	0	4	0	0.29	0.00	0.29	<RDL	<RDL	-	-
>C_{21}-C_{32} Hydrocarbons	0.25	mg/kg	4	0	4	0	0.29	0.00	0.29	<RDL	<RDL	-	-
OTHER													
Sulphide	0.5	ug/g	4	0	1	3	0.6	0.1	0.6	<RDL	0.6	-	-
Moisture	0.3	%	4	0	0	4	11.9	7.3	11.0	5.5	20.0	-	-
Ammonia-N	1.7	mg/kg	4	1	0	4	2.7	1.8	2.9	0.7	4.5	-	-

[1]ISQG – Interim Sediment Quality Guidelines and PEL – Probable Effect Levels as specified in the *Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment* (1999, updated 2001). Analytes detected at or above RDL are reported here.

4.2 Data Screening

Additional analysis was conducted on chemical analytes from 2015 that conformed to the following considerations during an initial data screening process (from HMDC, 2013, 2015a):

- more than fifty percent of data values above RDL;
- analytes are likely to be observed in association with drilling operations;
- less than fifty percent of data above the RDL however, the distribution and quantities of the analyte could plausibly have originated from HSE; and/or
- the absence of an analyte previously detected in prior EEM sediment chemistry programs at HSE (i.e., indicating potential recovery from a previously observed effect).

Based on the above criteria, a suite of chemical parameters have been screened for further analysis. A summary of the parameters that have been subjected to additional analyses for all HSE programs to date are listed as follows:

Hydrocarbons
TPH (C_6-C_{32})
TEH (>C_{10}-C_{21}) Fuel range
TEH (>C_{21}-C_{32}) Lube range

Carbon
TIC
TOC

Total Metals
Aluminum
Barium
Chromium
Iron
Lead
Manganese
Strontium
Uranium
Vanadium
Zinc

Weak-acid leachable Metal
Barium

Other
Ammonia (as N)
Sulphide
Sediment Particle size (PSA)

4.3 Sediment Sampling QA/QC

Replicate benthic grabs were sampled in 2015 at two QA/QC stations; along the southern radial 500 m from the EDC (station S-500) and around the 6 km radius (station 6000-2). Replicate station sediment samples were subjected to the same sub-sampling strategy with the exception of toxicity and Microtox samples which are not required for QA/QC stations (HMDC, 2013). The difference between the values of chemical analytes that are likely to be released from operations at HSE are compared between the primary sample (used for reporting and further analysis) and the values obtained from the secondary QA/QC sample and the differences are reported as percentages (Table 4.3). Overall, variation was minimal at the Far-field station (6000-2) compared to the Near-field one (S-250) and the largest difference observed was for barium at the latter station (140% difference). Weak-acid extractable barium and fuel and lube range hydrocarbons varied the least (0%) at the Far-field station. The concentration of barium in sediment is frequently used as a tracer for monitoring offshore oil and gas discharges (Hartley, 1996; Phillips et al., 1998; Holdaway, 2002; Whiteway et al., 2014) and elevated values are expected in proximity to drill cuttings disposal associated with drilling operations (DeBlois, Paine, et al., 2014; Whiteway et al., 2014). However, barium concentrations in marine sediment can be similar to those considered background levels (reference sites) within 250 m from a discharge point (Jerez Vegueria, Godoy, & Miekeley, 2002). Meanwhile, the difference in barium concentrations between primary and

QA/QC samples may be owing to unequal sedimentation of a small fraction of barite (a component of drilling mud) between the two samples (Jerez Vegueria et al., 2002).

Table 4.3 Differences between sample and QA/QC replicate sample chemical analyses for 2015 HSE EEM sediment data

Analyte	S-500	S-500-QA	% difference	6000-2	6000-2-QA	% difference
Barium (mg/kg)	100	240	**140.0**	140	120	**-14.3**
Weak Acid Extractable Barium (mg/kg)	13	11	**-15.4**	5*	5*	**0.0**
Fuel Range Hydrocarbon (>C_{10}-C_{21}) (mg/kg)	9.3	7	**-24.7**	0.25*	0.25*	**0.0**
Lube Range Hydrocarbon (>C_{21}-C_{32}) (mg/kg)	0.25*	0.46	**84.0**	0.25*	0.25*	**0.0**
* Denotes RDL values used for calculations when value of analyte was below detection limit.						

4.4 Exploratory Sediment Data Analysis

Initial data screening was completed using two-dimensional (2-D) plots. The objective of 2-D plots is initial data screening according to the conditions listed in section 4.2 and not statistical evaluation, which is described in Chapter 5. The R software environment for statistical computing and graphics was used to generate 2-D plots (R Core Team, 2016). The spatial and temporal trends of sediment chemistry are presented in 2-D surface bubble plots with the X and Y axes representing the east-west and north south distances respectively (in meters). The X and Y axes scales have been set to 1,000 m from the HSE EDC for greater resolution of the Near-field; however, the 6,000 m stations are evaluated in the subsequent statistical exploration of the data (see Chapter 5). Analyte values below RDL (<RDL) were expressed as half (0.5) RDL in the 2-D plots (HMDC, 2013). For the 2-D plots, analyte values are represented as range with the upper limit stated in the legend. The lower limit of the range is the previous upper limit or zero in the case of the first range bin. The EDC is located in the centre of the plot and the color and size of each sediment sampling station denote the concentration of analyte for that area. This format of 2-D plot presents the data with greater accuracy and precision for observing spatial and temporal patterns compared to the inverse weighted interpolation plots used previously (Figure 4.1). These plots are presented for qualitative exploratory purposes only and no statistical inferences are made. They are to illustrate patterns of changing analyte concentrations over successive survey programs that could indicate potential environmental trends in sediment from the HSE program.

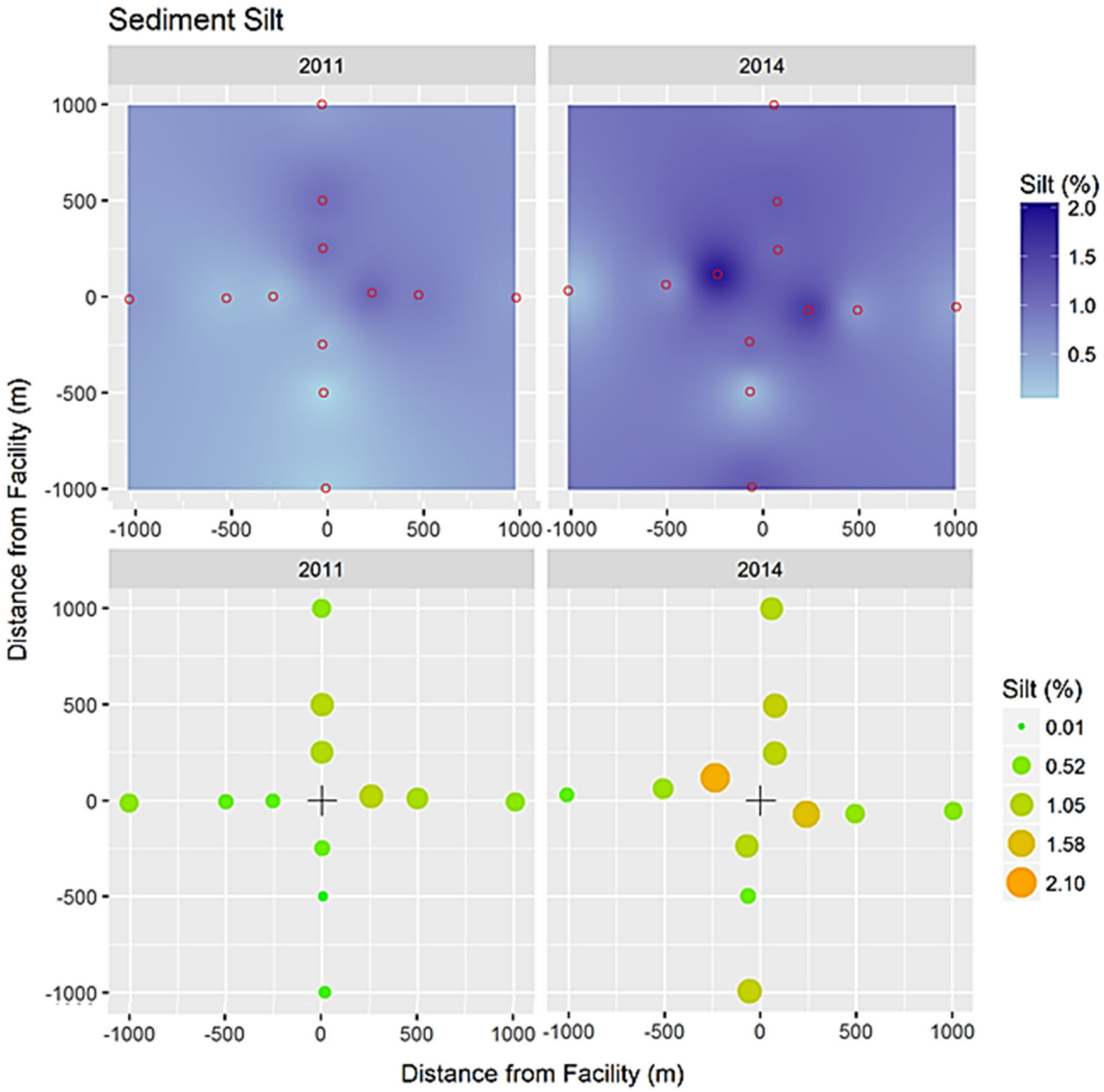


Figure 4.1 Comparison of inverse weighted interpolation plot (upper panels) and bubble 2 dimensional plots (lower panels).

4.5 Particle Size Analyses (PSA)

Particle size can strongly influence its associated chemical profile depending on the compositional characteristics of the sediment as well as the surface area of sediment type (Herut & Sandler, 2006; Horowitz, 1985). Smaller fractions in particular, such as those of silt and clay, have higher concentrations of phyllosilicates and organic matter which have affinity for organic pollutants and trace elements (Herut & Sandler, 2006). In the Hibernia region, sedimentary features (bedforms) typically consist of large sand fields (~400 m wide), ribbons (~100 m wide) and ripples (< 5m wide), interspersed by patches of gravel, and reworking of these sedimentary features is evident

after seasonal storms (Barrie et al., 1984; reviewed by Schneider, Gagnon, & Gilkinson, 1987). The following descriptions of sediments surrounding HSE are based on physical and chemical analysis of benthic samples (as opposed to analysis of the minerology) (HMDC, 2015a).

For the duration of the HSE program, a longstanding and widely used index for the classification of sediment grain size (the Wentworth Scale) has been used to describe Particle Size Analysis (PSA). The particle size ranges for this index are defined as follows: gravel (2-250 mm), sand (0.0625-2 mm), silt (0.0039-0.0625 mm) and clay (0.0005-0.0039 mm) (Wentworth, 1922). Overall, the mean percentages of sediment composition of all HSE stations (250, 500, 1,000 and 6,000 m) sampled in the 2015 survey were: 16.8 (gravel), 80.5 (sand), 0.6 (silt), and 2.2 (clay) (Table 4.1 sediment summary data), compared to 2.4 (gravel), 97.8 (sand), 0.1 (silt), and 1.0 (clay) in the Reference Areas (Table 4.2 reference area summary data). Consistent with the 2014 EEM survey, sand was the predominant sediment type in the HSE study area followed by gravel, clay and silt respectively. However, since the 2011 survey, the proportion of sand in sediment samples appears to be greater overall in the Near-field (≤ 1,000 m) in each successive survey program (Figure 4.2). Likewise, a similar overall increase has been observed for clay since the 2011 survey (Figure 4.3). In contrast, the proportion of gravel has decreased each year since the 2011 program (Figure 4.4), as has the proportion of silt for all stations sampled within 6,000 m (Figure 4.5). Most notable, is an apparent increase in the fine sediment fraction (silt and clay) at the N-250 and E-250 stations in 2015 compared to previous survey years. The patterns of sediment types at varying distances from the EDC are evaluated statistically in Chapter 5.

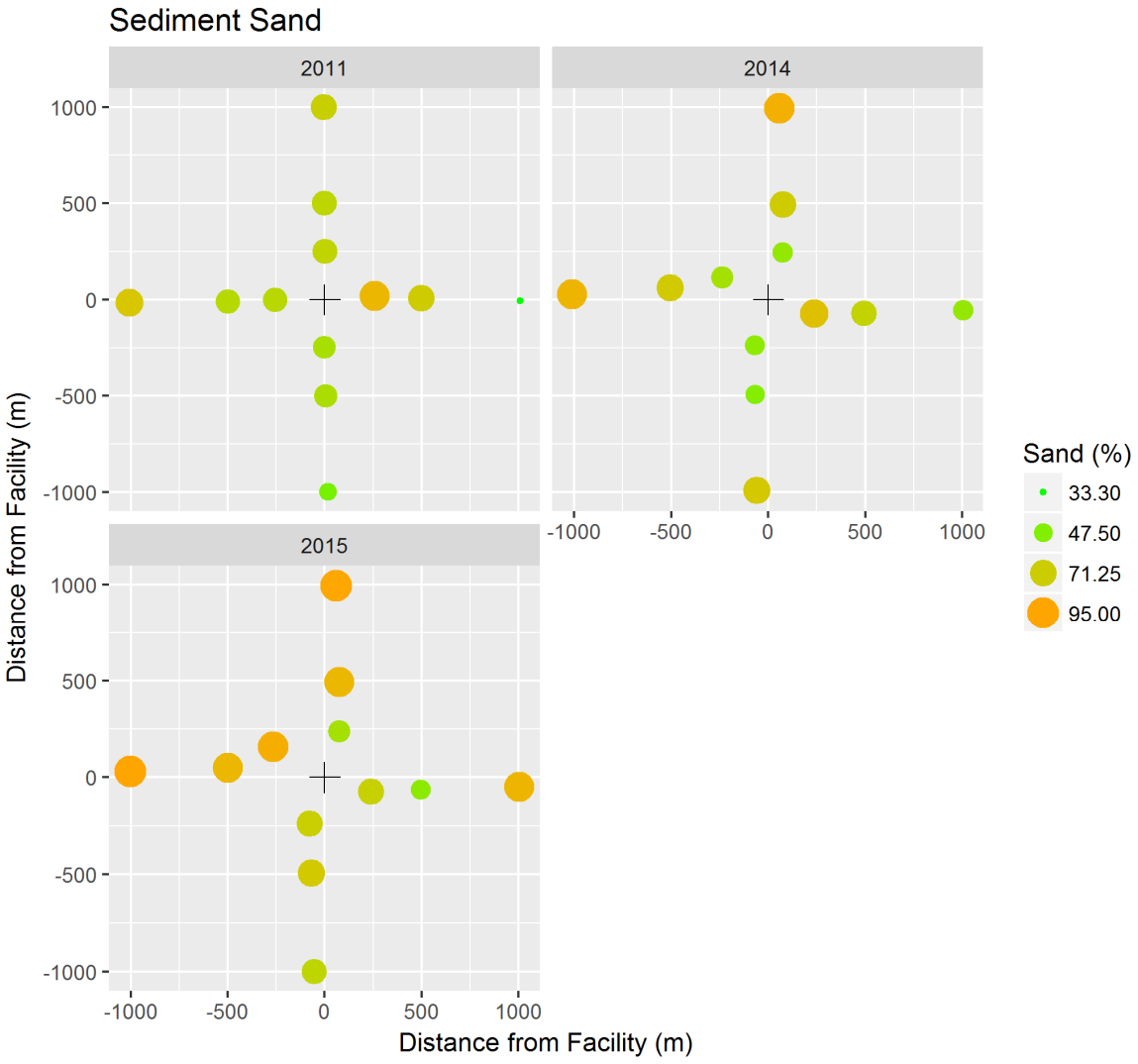


Figure 4.2 Spatial and temporal pattern of sand content (%) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

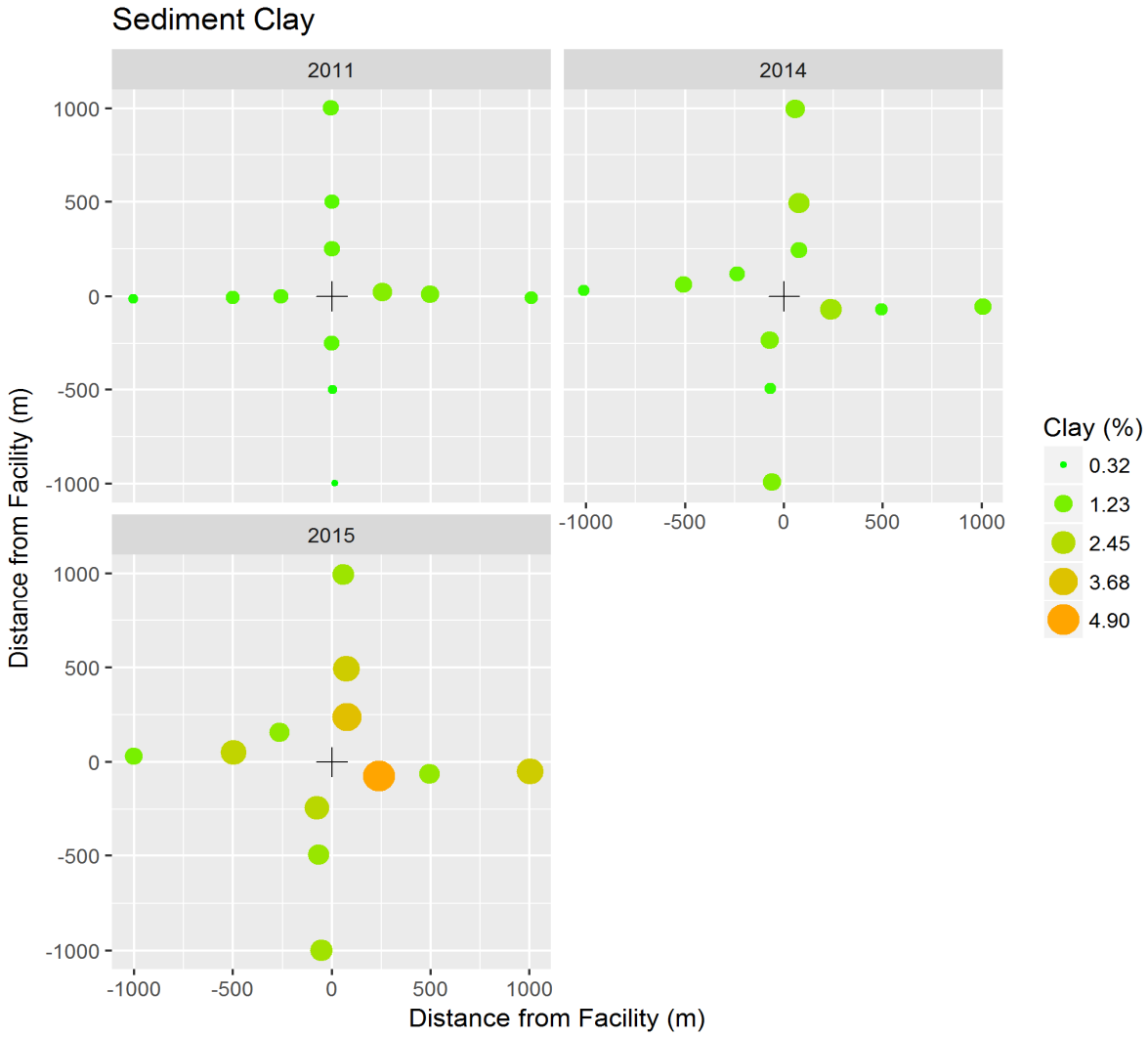


Figure 4.3 Spatial and temporal pattern of clay content (%) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

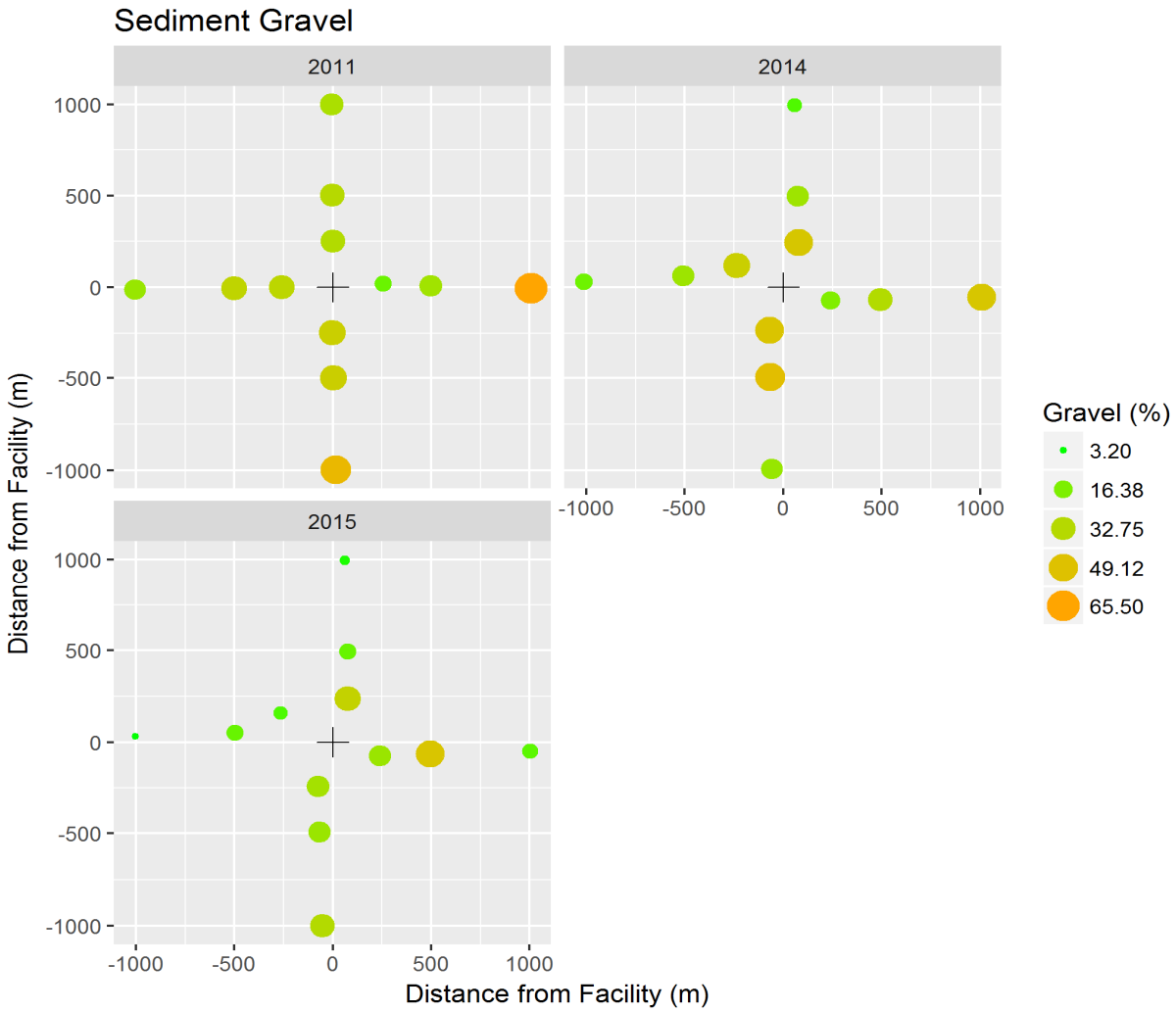


Figure 4.4 Spatial and temporal pattern of gravel content (%) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015)

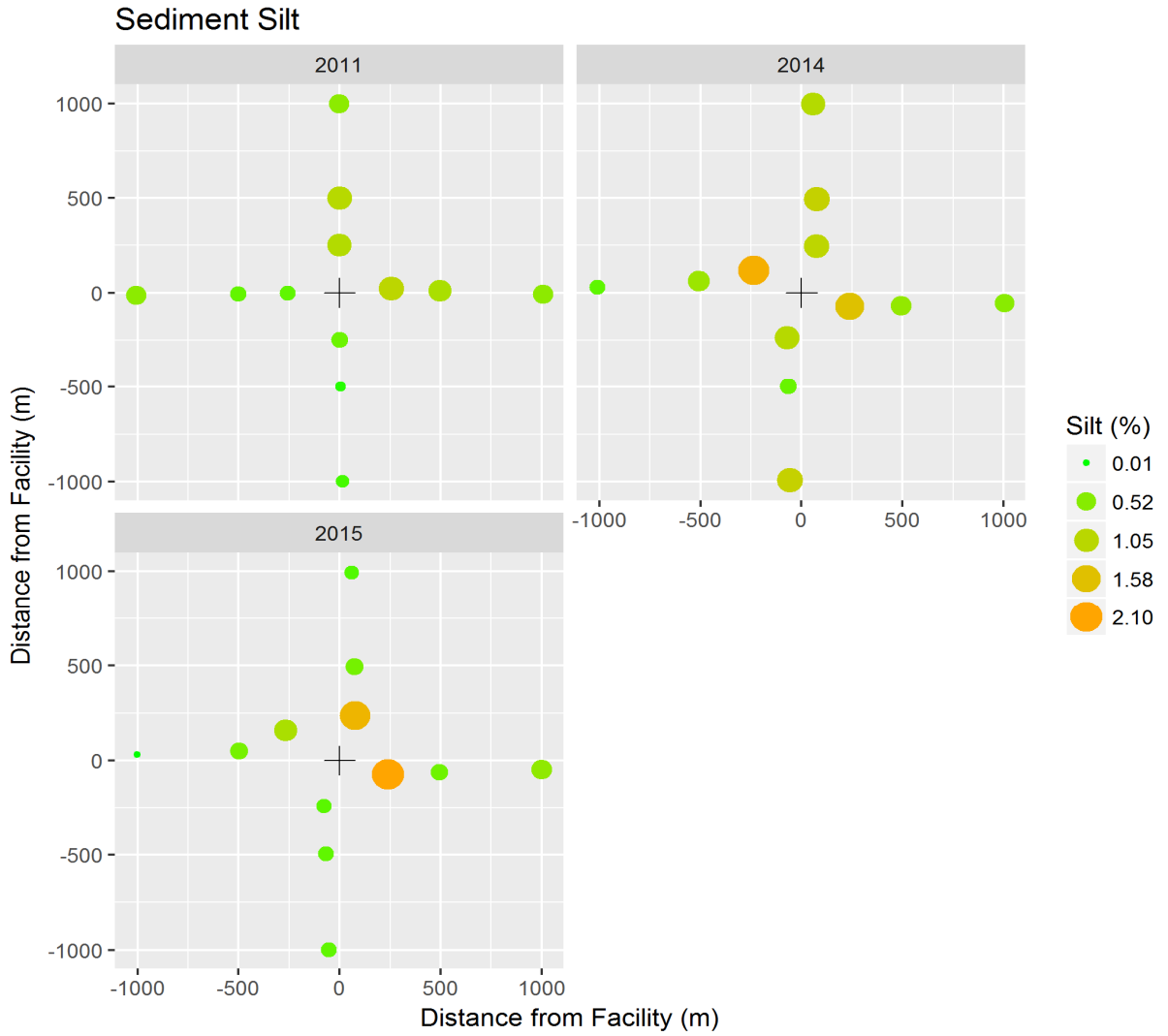


Figure 4.5 Spatial and temporal pattern of silt content (%) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015)

4.6 Total Metals

Quantification of metals in sediment provides an indicator of overall sediment quality (Larner, Palmer, Seen, & Townsend, 2008). In the 2015 HSE EEM there was a decrease in overall mean concentration of several metal analytes compared to 2014, including aluminum (6406.3 vs. 6618.8 mg/kg), iron (1,836.9 vs. 1,884.4 mg/kg), and manganese (38.1 vs. 42.3 mg/kg). Regardless of an overall decrease in mean concentration of aluminum, the sampling stations with the highest detected values in 2015 were proximal to those that had the highest concentrations detected in 2014 (Figure 4.6). In 2015, these were stations E-250 (9,600 mg/kg), W-250 (9,000 mg/kg) and 6000-1 (8,100 mg/kg compared to N-250 (12,000 mg/kg), W-250 (11,000 mg/kg) and 6000-3 (11,000 mg/kg) in 2014.

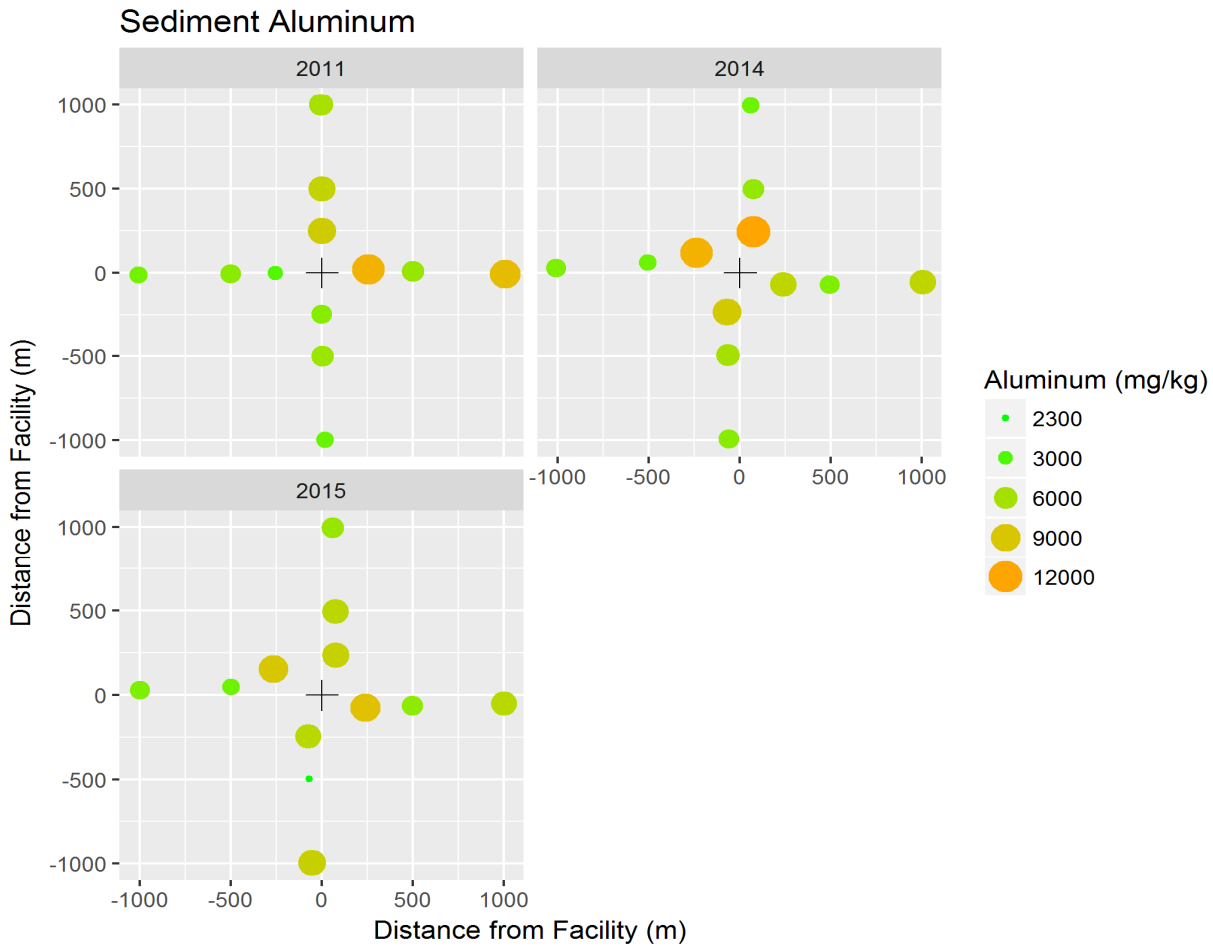


Figure 4.6 Spatial and temporal pattern of total aluminum content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

Similar to aluminum, the concentrations of iron and manganese were greatest at stations W-250, N-250 and E-250 around the EDC (Figures 4.7 and 4.8). In 2015, the highest concentrations observed for iron were 3,500 mg/kg at station W-250, and 3,100 mg/kg at both stations E-250 and N-250. Likewise for manganese, the highest concentrations measured were also at station W-250 (78 mg/kg), and 61 and 59 mg/kg at stations N-250 and E-250 respectively. Stations E-250 and N-250 also had among the highest detected values of both these analytes in the 2011 baseline survey. Whereas, in 2014 the highest concentrations for each of these analytes was at stations N-250, W-250 and S-250, with concentrations of 4,300, 4,100 and 93,300 mg/kg respectively for iron, and 83, 74 and 78 mg/kg respectively for manganese. Overall, there appears to have been a slight north-easterly shift in the location of greatest accumulation for these analytes since the 2014 EEM at stations closest to the EDC.

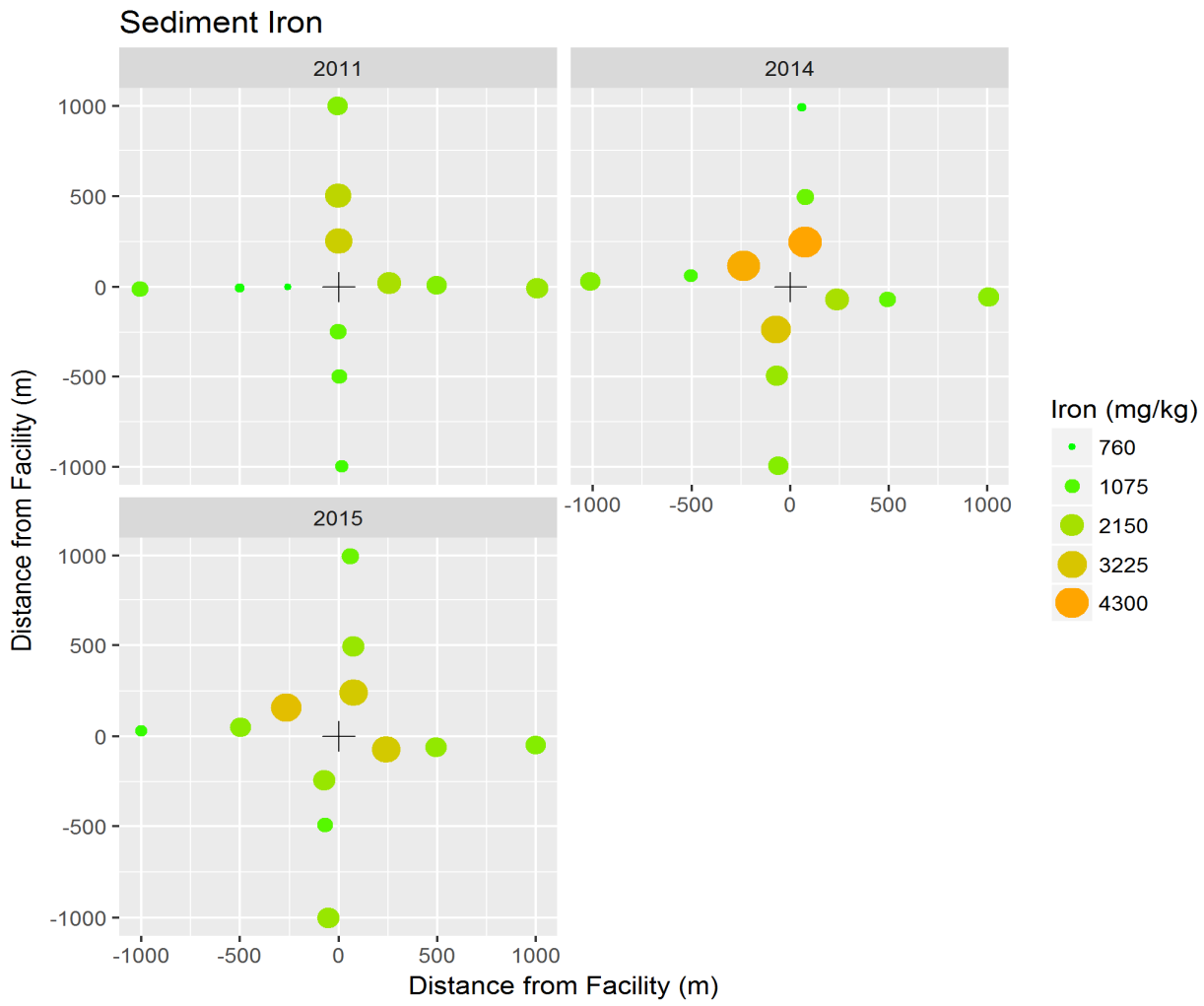


Figure 4.7 Spatial and temporal pattern of total iron content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

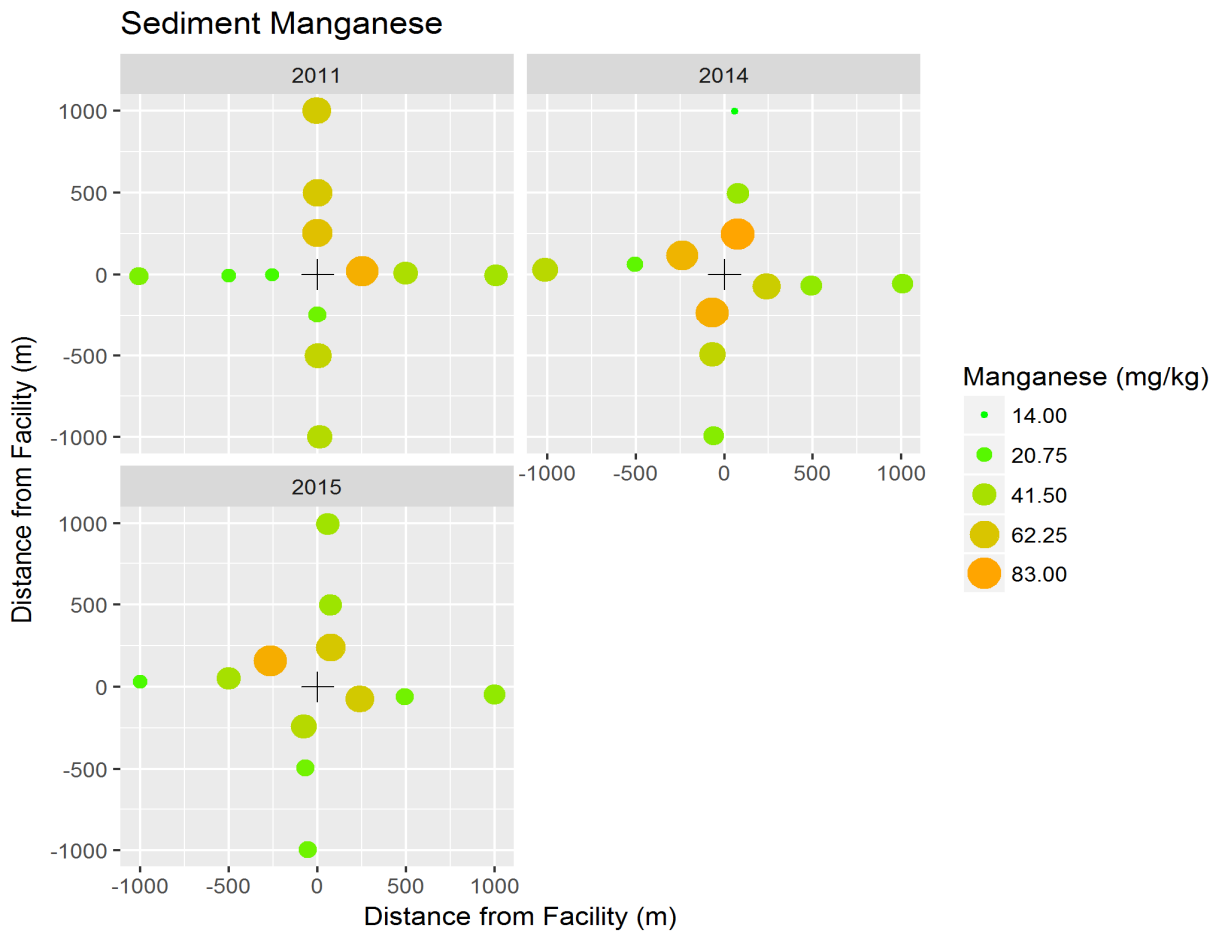


Figure 4.8 Spatial and temporal pattern of total manganese content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

Metal analytes with higher overall mean concentrations in 2015 compared to 2014 EEM values included: chromium (4.54 vs 4.01 mg/kg), lead (2.7 vs 2.33 mg/kg), strontium (427.5 vs 300.1 mg/kg), uranium (0.34 vs 0.24 mg/kg) and vanadium (7.09 vs 6.87 mg/kg). Most notable were increases in mean barium concentrations in 2015 (714.6 mg/kg) compared to 2014 (176.6 mg/kg) and likewise for weak-acid extractable barium (14.9 mg/kg vs 5.3 mg/kg). Spatially, the highest concentrations for all of these analytes were co-localized at stations W-250, N-250 and E-250 with the exceptions of strontium and uranium (described further below).

The concentrations of chromium in 2015 were 7.2, 7.0 and 6.3 mg/kg at stations W-250, E-250 and N-250 respectively, and were below Canadian Council for Ministers of the Environment (CCME) guideline standards (Table 4.1). In 2014 the highest concentrations were 8.4, 7.2 and

7.1 mg/kg at stations N-250, S-250 and W-250 respectively. Spatially, the patterns of greater chromium concentration (Figure 4.9), appear similar to those of the finer sediment fractions described above (silt and clay) and clay in particular (Figure 4.3 and 4.5).

The distribution of lead appears to have increased over successive survey years since baseline in particular among stations closest to the EDC (Figure 4.10). The highest concentrations of lead detected in the 2015 EEM were 5.4, 4.9 and 4.2 mg/kg at stations W-250, E-250 and N-250 respectively, and were below CCME guideline standards (Table 4.1). The highest concentrations in the Near-field in 2014 were 4.0, 3.7, and 3.1 mg/kg at stations N-250, W-250 and S-250 respectively.

The highest concentrations of strontium were 1,100, 860 and 770 mg/kg at stations S-500, E-1000 and E-500 respectively (Figure 4.11). These same stations had the highest levels of strontium in 2014 with values of 870, 640 and 630 mg/kg at stations S-500-M, E-500-M and E-1000-M, respectively. However, unlike the previous metal analytes described, the pattern of strontium abundance appear to resemble that of higher gravel abundance (Figure 4.6).

The concentration of uranium appears to have increased at certain stations along the west and southern radials, in particular at stations W-500, S-500 as well as station N-250 (Figure 4.12). The concentrations of uranium detected in sediment at each of these stations were 1.0, 0.73 and 0.42 mg/kg respectively. The largely decentralized spatial pattern of uranium distribution from the EDC is generally consistent with observations of the 2014 EEM, when highest concentrations observed were 0.43, 0.41 and 0.36 mg/kg at stations S-500, W-250 and 6000-2 respectively (Figure 4.12).

In contrast, the spatial distribution of vanadium (Figure 4.13) appears similar to that of chromium and lead (Figures 4.9 and 4.10), where the highest concentrations observed were 13 mg/kg at station W-250 and 12 mg/kg at stations E-250 and N-250. In 2014 the highest concentrations observed were greater: 16, 14 and 12 mg/kg at stations N-250, W-250 and S-250 respectively. Likewise, the pattern of greater vanadium concentration appears to overlap with those of finer sediment fractions (Figures 4.3 and 4.5).

Although mean concentrations of zinc at HSE increased from 5.13 to 5.92 mg/kg between 2014 and 2015, it is lower than the mean concentration for 2011 baseline (8.33 mg/kg). Likewise, the most elevated levels detected to date at HSE were along the north radial in 2011 (Figure 4.14). However, in 2014 and 2015 the most elevated levels of zinc were in proximity to the EDC. Specifically, the highest concentrations of zinc in 2015 were at the 250 m stations and were 8.8 mg/kg at E-250, 8.6 mg/kg at S-250 and E-250, and 8.2 mg/kg at N-250. All values were below CCME guideline standards (Table 4.1). In 2014 the highest concentration was 7.1 mg/kg at station N-250 and all other stations were below detectable limits (<5.0 mg/kg).

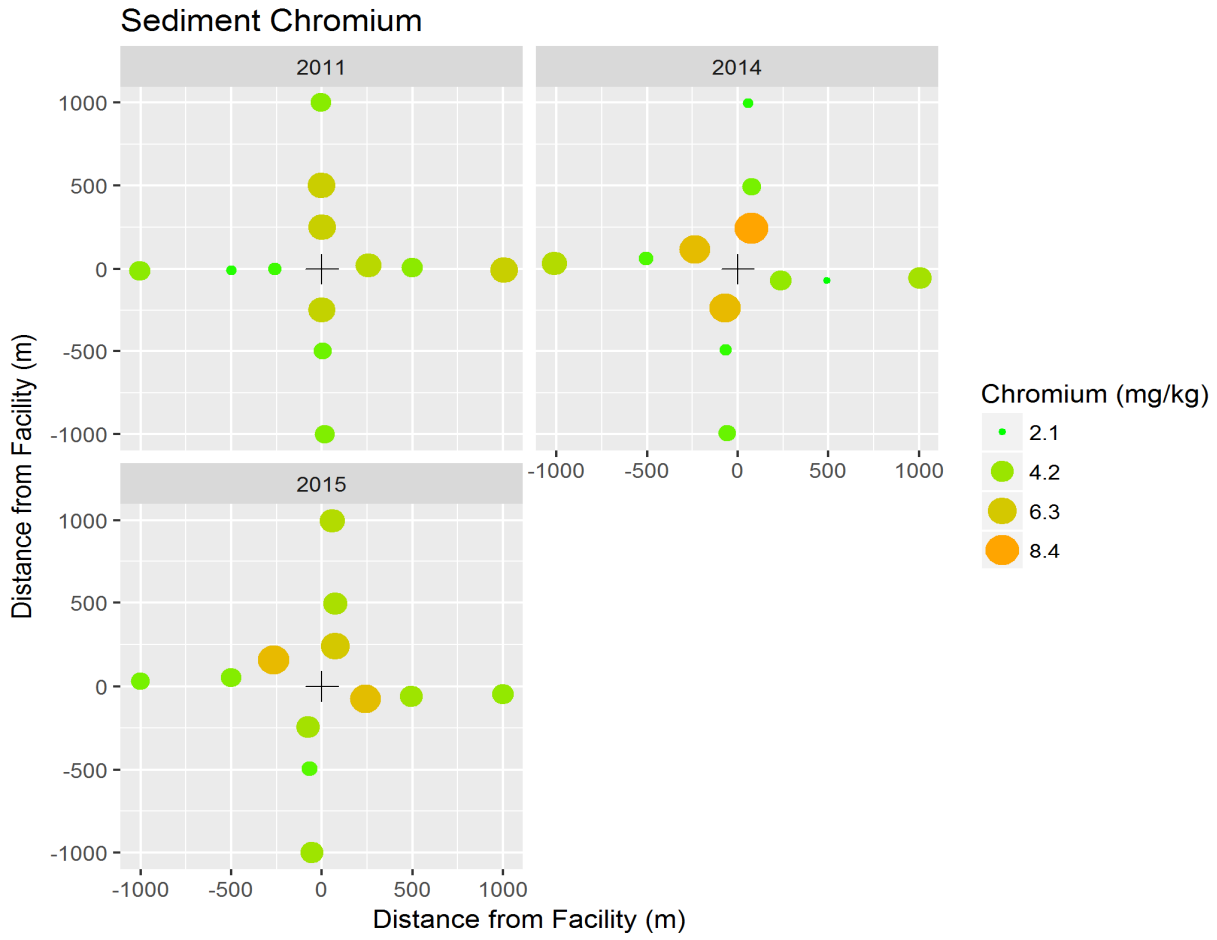


Figure 4.9 Spatial and temporal pattern of total chromium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

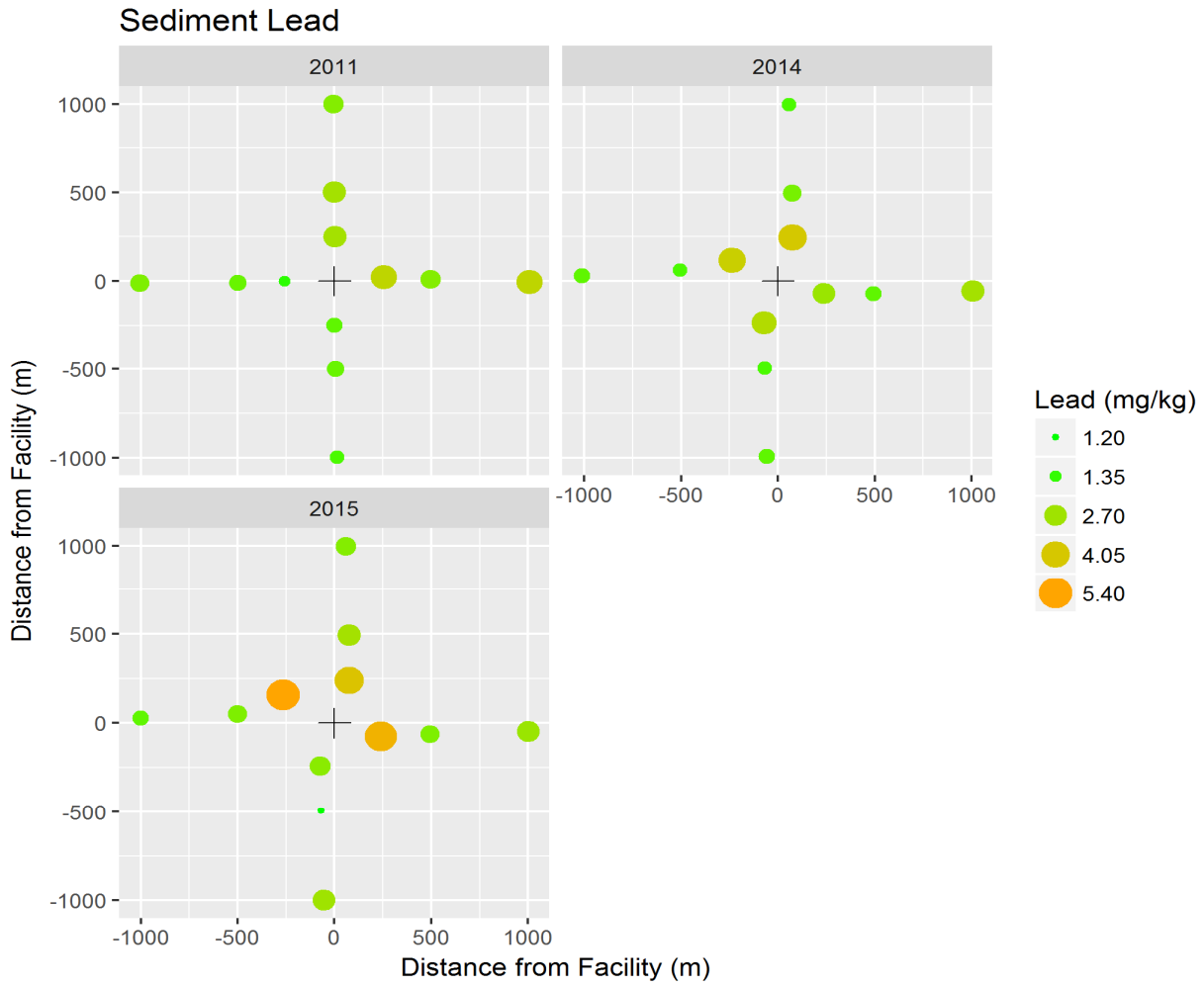


Figure 4.10 Spatial and temporal pattern of total lead content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

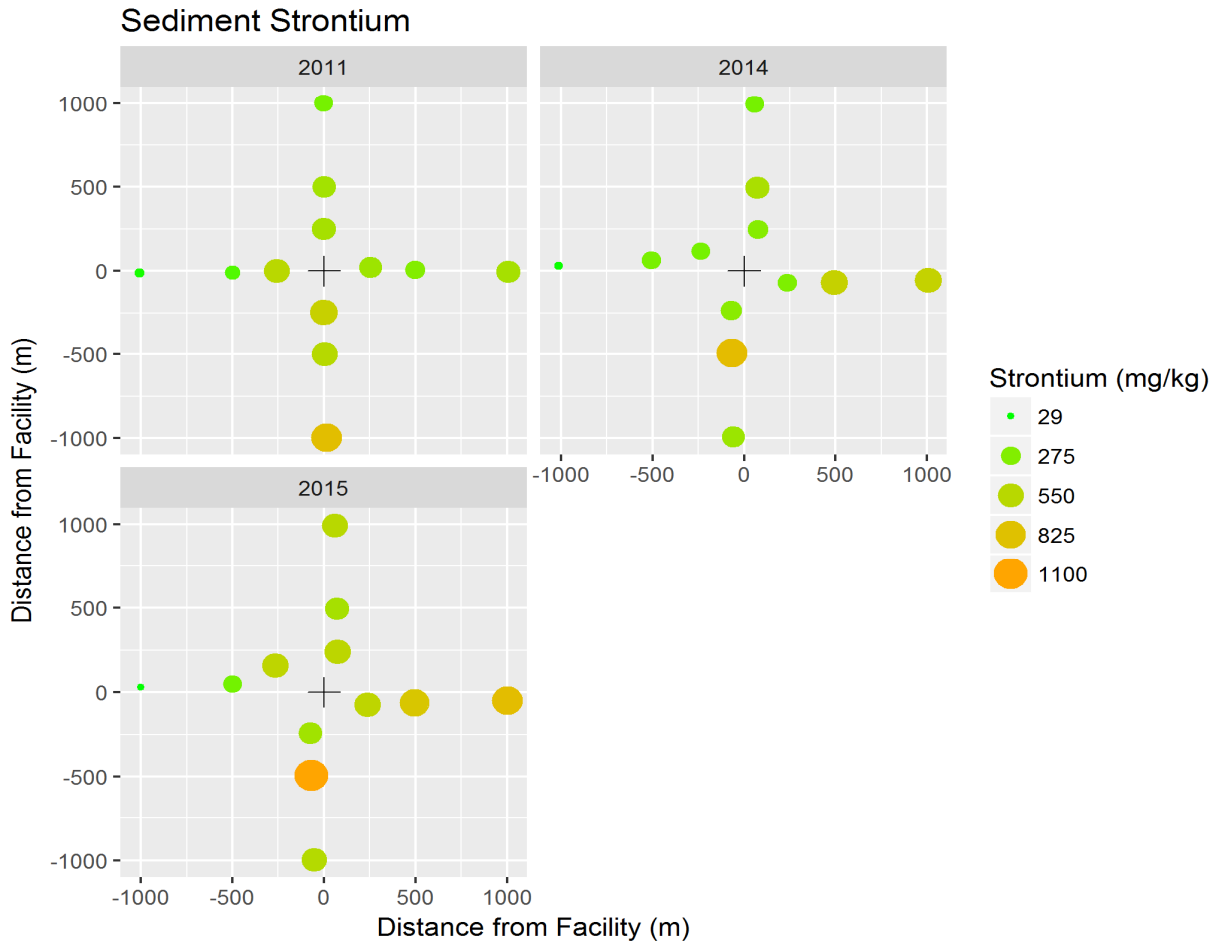


Figure 4.11 Spatial and temporal pattern of total strontium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

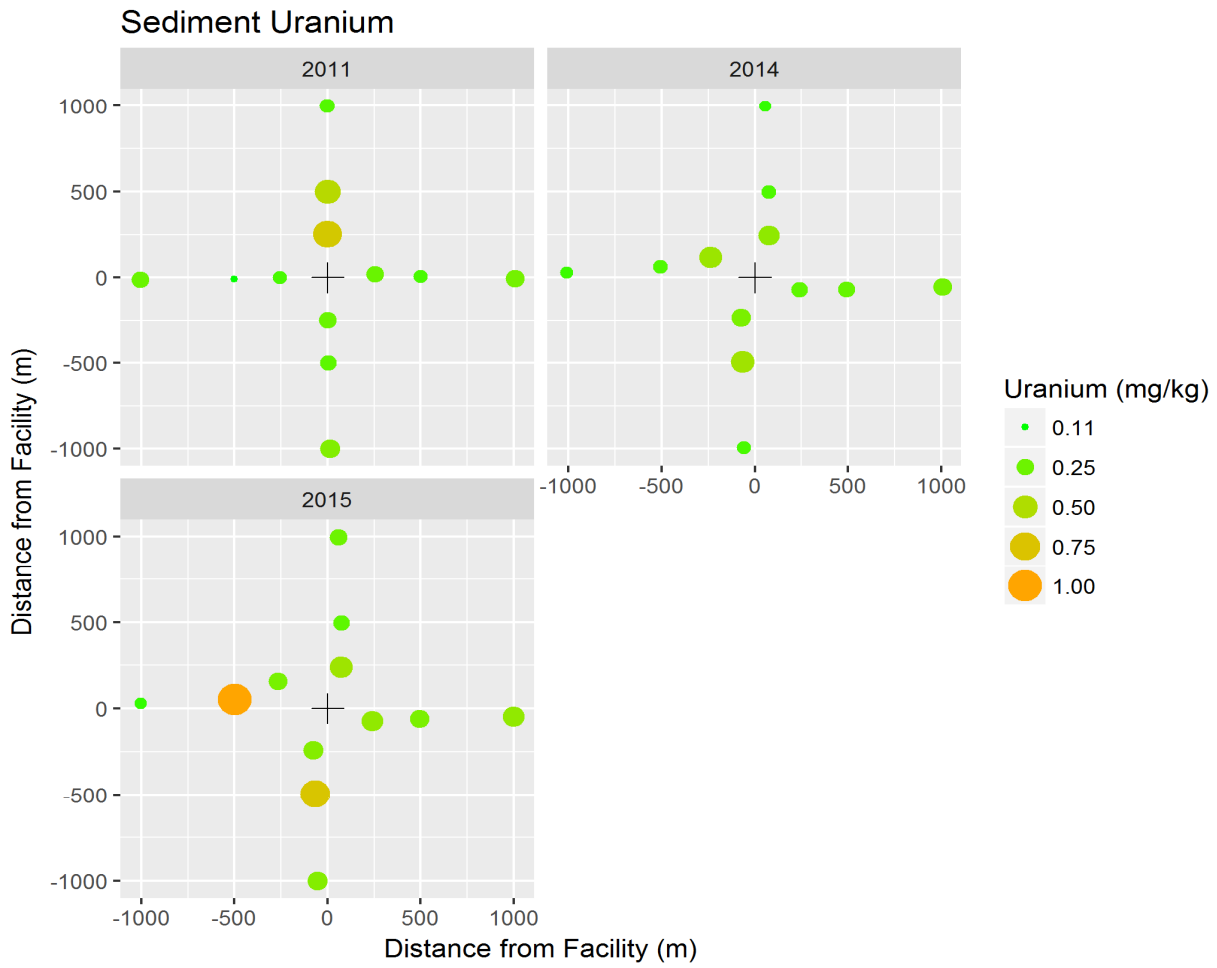


Figure 4.12 Spatial and temporal pattern of total uranium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

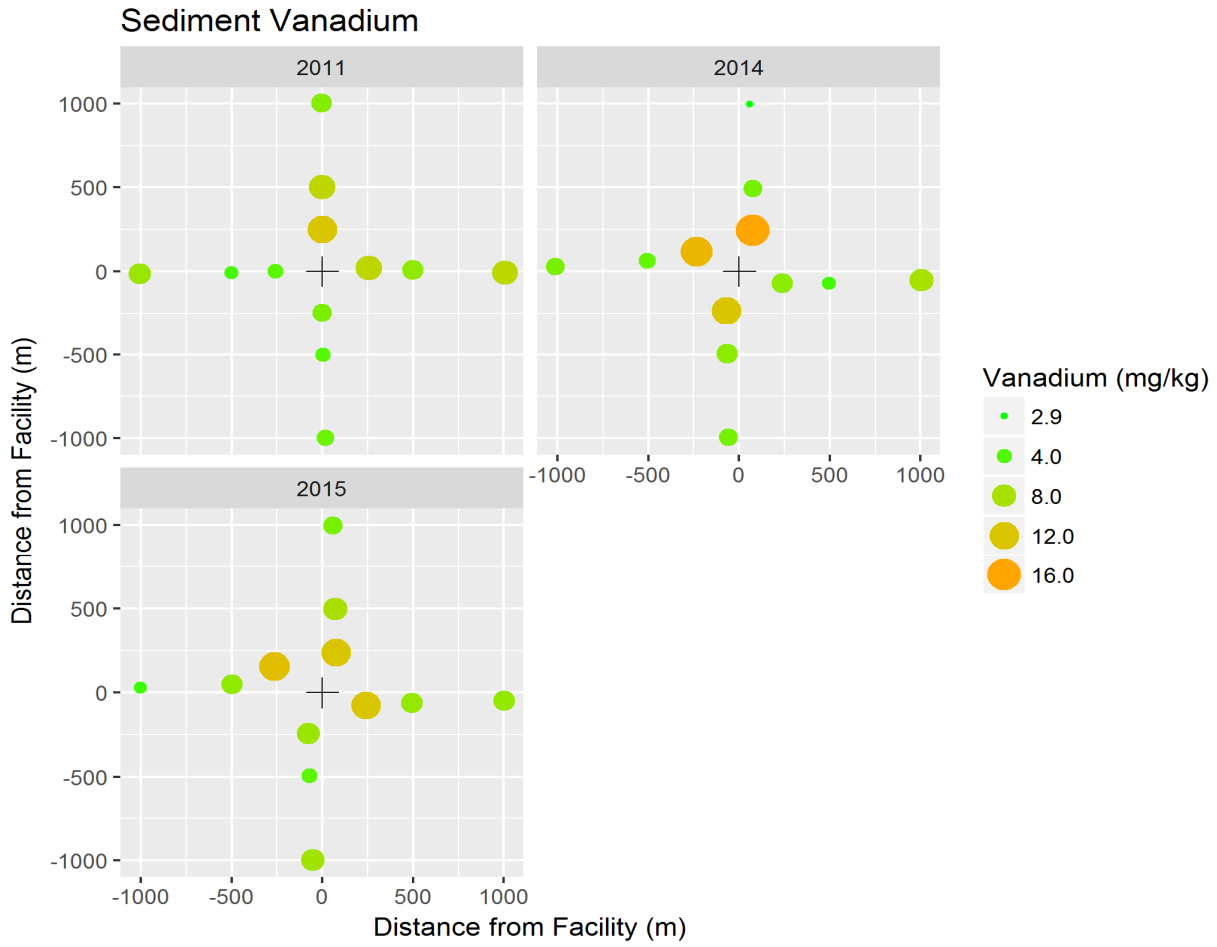


Figure 4.13 Spatial and temporal pattern of total vanadium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

Figure 4.14 Spatial and temporal pattern of total zinc content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

4.7 Barium

Barium sulphate (a.k.a. barite, $BaSO_4$) is one of the main, least toxic components of drilling muds; it has extremely low solubility and is used as a marker for drilling mud in sediment by quantifying barium (Bakhtyar & Gagnon, 2012; DeBlois, Tracy, et al., 2014; Neff, 2008; Trefry et al., 2013). The concentration of barium appears to have increased around the HSE EDC since the 2011 baseline survey (Figure 4.15). In particular, during the 2015 EEM survey stations N-250, E-250 and W-250 had the highest concentrations of barium (2,900, 2,600 and 2,500 mg/kg respectively). Compared to values measured in 2014, when the highest concentrations measured were 460, 440 and 250 mg/kg at stations N-250, W-250 and S-250 respectively. This increase appears to be centralized around the HSE EDC at the 250 m stations in particular, based on visual comparison of spatial distribution between all years. Consistent with this, the spatial distribution

of weak-acid extractable barium has also increased around the EDC since baseline. This increase appears to be the most pronounced change among all the analytes and the increased concentration is evident at least to the 500 m stations (Figure 4.16). The highest concentrations of weak-acid extractable barium were 35, 31 and 30 mg/kg at stations E-250, W-250 and N-250 respectively, compared to 8.6, 6.0 and 5.2 mg/kg at stations W-250, S-250 and N-250 in 2014.

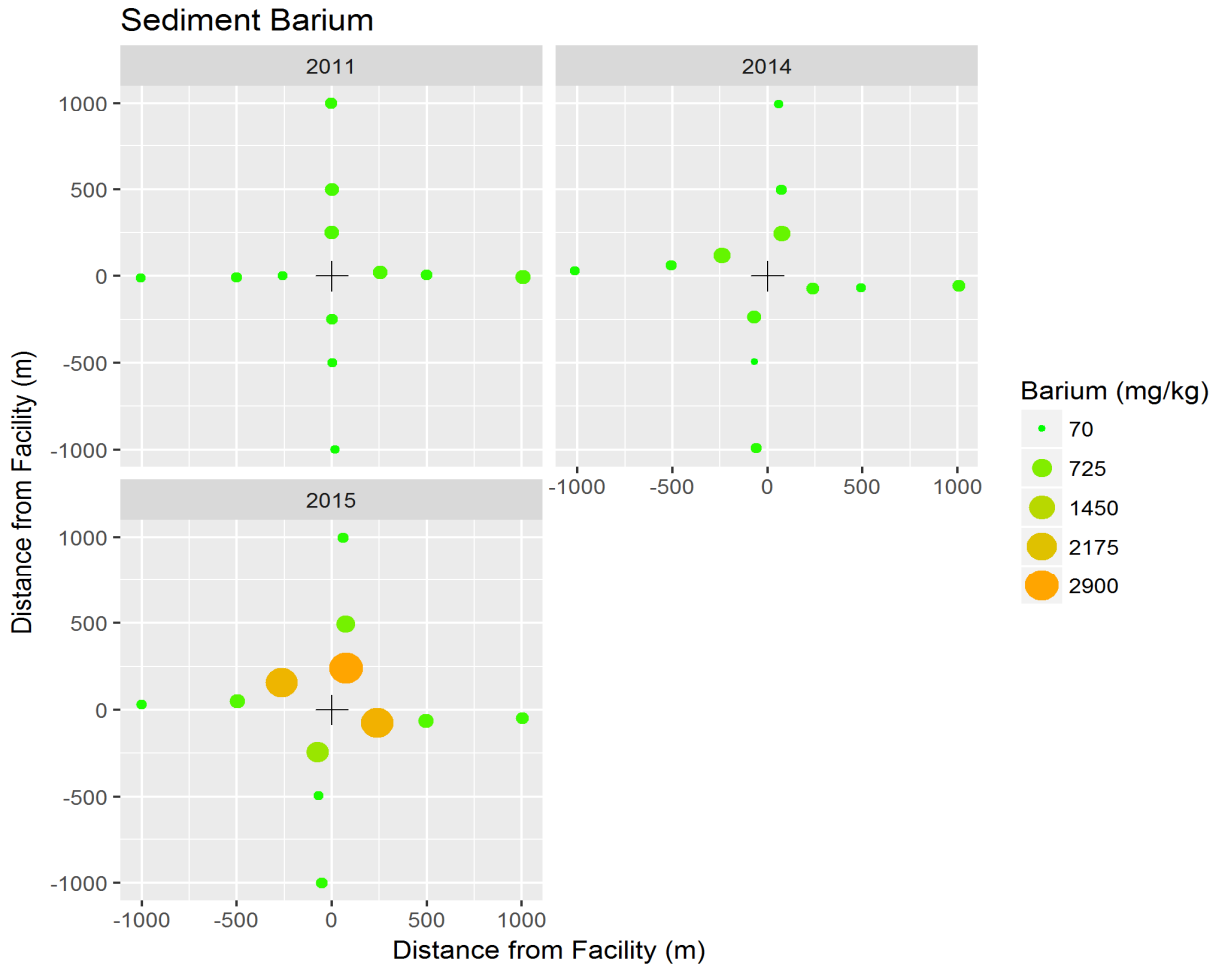


Figure 4.15 Spatial and temporal pattern of total barium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

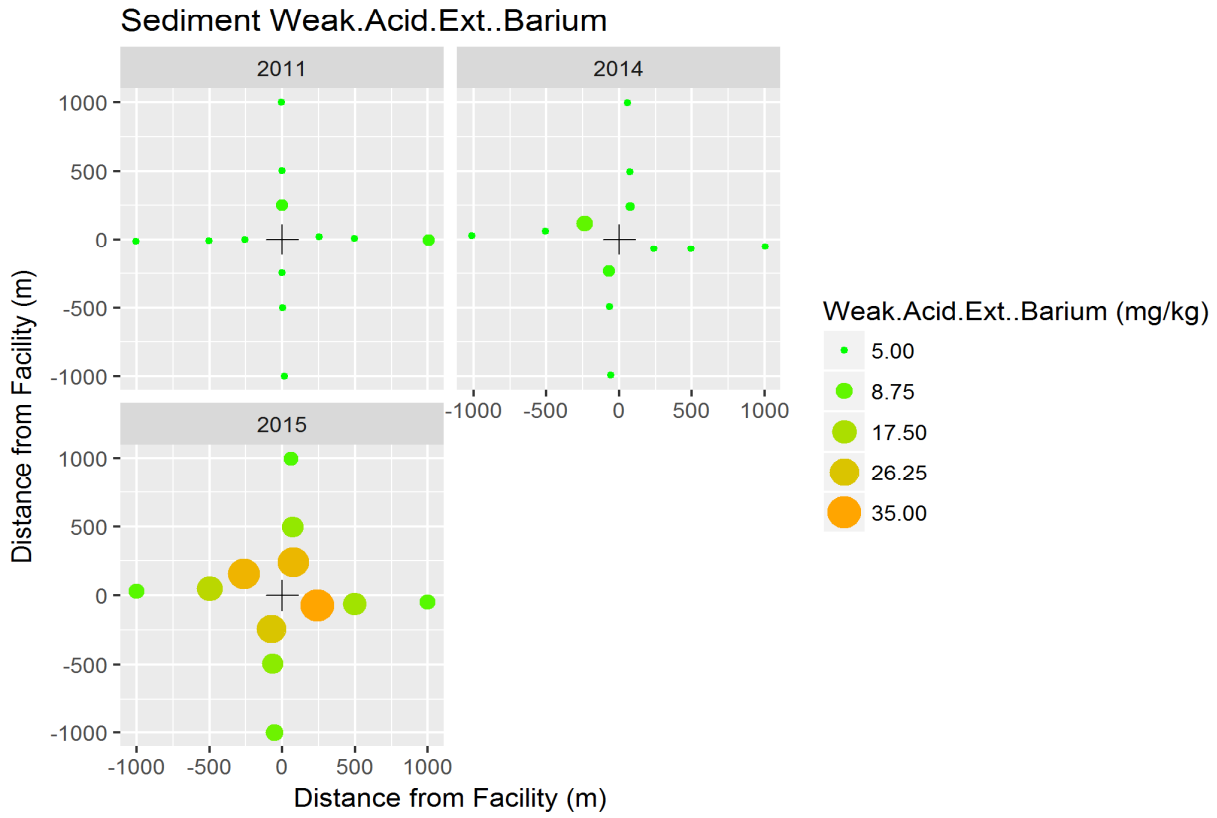


Figure 4.16 Spatial and temporal pattern of weak-acid extractable barium content in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

4.7.1 Organics

Similar to other drilling-associated analytes such as barium described above, the spatial abundance of fuel range hydrocarbons (>C_{10}-C_{21}), appears to have increased most notably around the EDC since the 2011 baseline survey (Figure 4.17). Mean concentrations of fuel range hydrocarbons have increased progressively from 1.18 mg/kg in 2011, to 5.37 mg/kg in 2014 and 34.07 mg/kg in 2015. Likewise, the highest concentrations detected in 2015 for >C_{10}-C_{21} were 510, 430, and 350 mg/kg at stations E-250, N-250 and W-250 respectively. In contrast the highest concentrations observed at HSE in 2014 were 35, 18 and 11 mg/kg at stations W-250, N-250 and S-250. Overall, the concentration of this analyte appears to dissipate at Near-field stations that are farthest from the EDC.

The 2015 spatial distribution of lube range hydrocarbons (>C_{21}-C_{32}) appeared to be largely similar to that of fuel range hydrocarbons with the exception of one slightly elevated Near-field station (E-1000) (Figure 4.18). However, this station appears to have been slightly elevated since the baseline survey; with highest concentrations detected (1.2 mg/kg), followed by 1.1 and 1.0 mg/kg at stations N-250 and S-250. Whereas in 2015 the stations proximal to the EDC had the highest concentrations of lube range hydrocarbons including E-250, N-250 and W-250 (2.6, 2.3 and 2.1 mg/kg respectively). Overall the pattern of increasing concentration around the EDC appears to be generally similar to that of fuel range hydrocarbons although to a lesser extent; the mean concentration of lube range hydrocarbons has increased since baseline (0.73 mg/kg in 2011 vs 0.80 mg/kg in 2015). Meanwhile the N-500 station which had an elevated concentration of lube range hydrocarbons detected in 2011 appears to have diminished.

Physiochemical parameters such as organic carbon, sulphide and nitrogen (among others) can be associated with the breakdown of hydrocarbons in marine sediment (Steichen, Holbrook, & Osenberg, 1996). Spatially, the distribution of organic carbon around the HSE EDC appears to have varied since baseline with few stations appearing to have overlapping elevated concentrations among surveyed years (Figure 4.19). The stations with the highest concentrations in 2015 were E-500, E-1000 and S-1000 at 8.5, 5.9 and 4.3 g/kg respectively. In 2014 the highest concentrations were at stations N-500, N-250 and S-250 at 2.9, 2.3 and 2.1 g/kg. Overall, the mean concentration of organic carbon was 2.5 g/kg for HSE compared to 0.3 g/kg for 16 km Reference Areas stations.

Likewise, ammonia-N and sulphide have shown no pattern of consistent stations having an elevated detection level among years (Figures 4.20 and 4.21 respectively). The mean concentrations of ammonia-N were 8.1 mg/kg at HSE and 2.7 at the Reference Area (Table 4.1 and 4.2 respectively). The highest concentrations of ammonia-N were at stations W-250, S-250 and 6000-1 at levels of 17, 16 and 15 mg/kg respectively (Figure 4.20). The mean concentration of sulphide was 0.9 µg/g at HSE and 0.6 µg/g for the Reference Area stations. The highest concentrations were at stations E-500, E-250 and N-250 at levels of 2.10, 1.35 and 1.17 µg/g. The highest sulphide values around HSE were 4.0 and 3.9 µg/g at stations N-500 and E-1000 respectively during the 2011 baseline survey. In 2014 the highest levels were 2.30 and 1.33 µg/g at stations N-250 and S-500. Overall the spatial distribution of sulphide appears to be centralizing in proximity to the EDC, but the highest levels detected are decreasing (statistical evaluation of this analyte is presented in Chapter 5).

4.7.2 Summary

Overall in the 2015 HSE EEM stations W-250, N-250 and E-250 were most commonly associated with higher detected levels of key monitoring analytes such as barium and fuel-range hydrocarbons in sediment samples. These observations are based on visual assessment of spatial distribution around the HSE EDC. The significance of the concentrations of analytes that were detected, and their distribution is examined statistically in the proceeding section (Chapter 5).

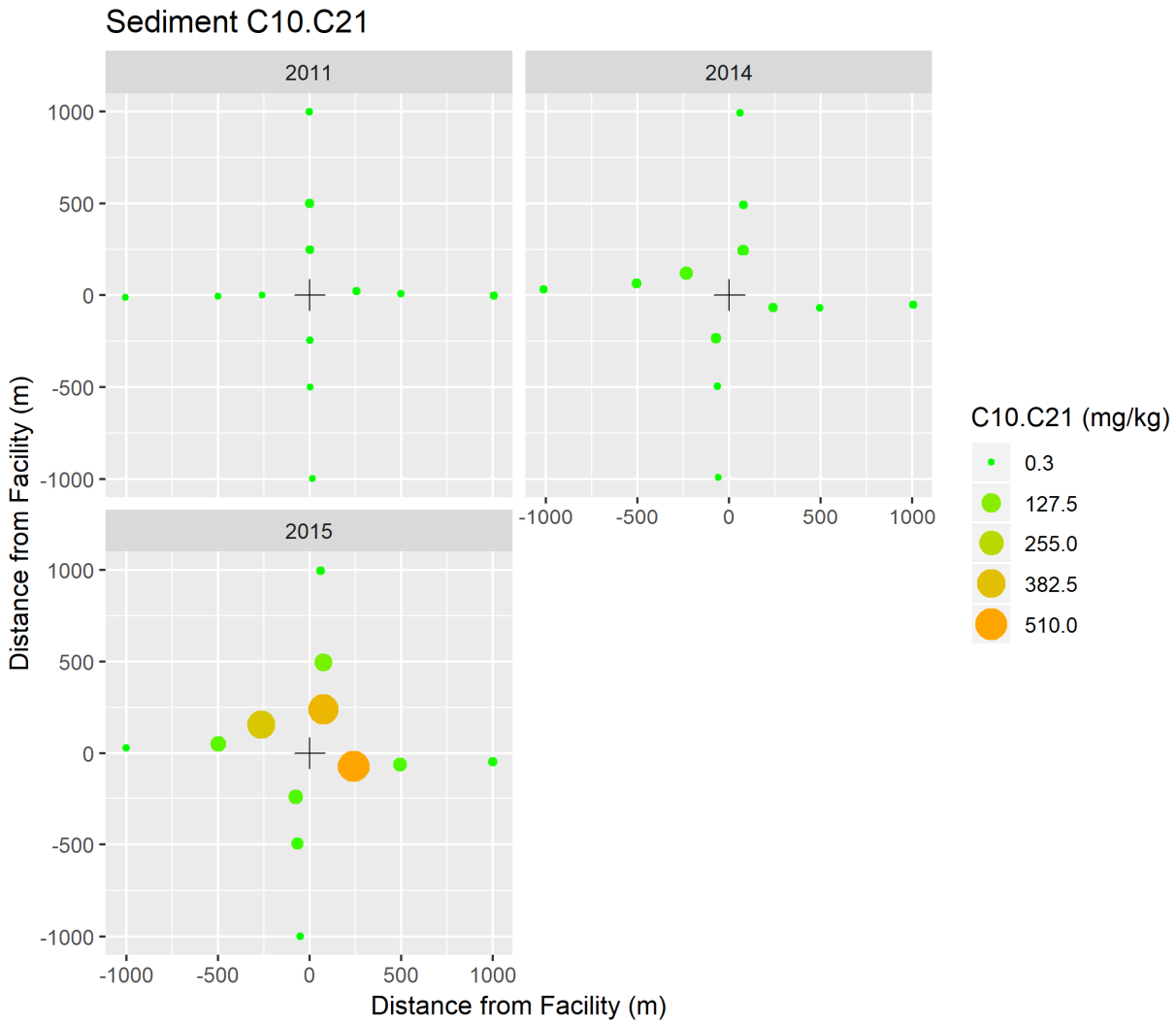


Figure 4.17 Spatial and temporal pattern of fuel range hydrocarbons (>C_{10}-C_{21}) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

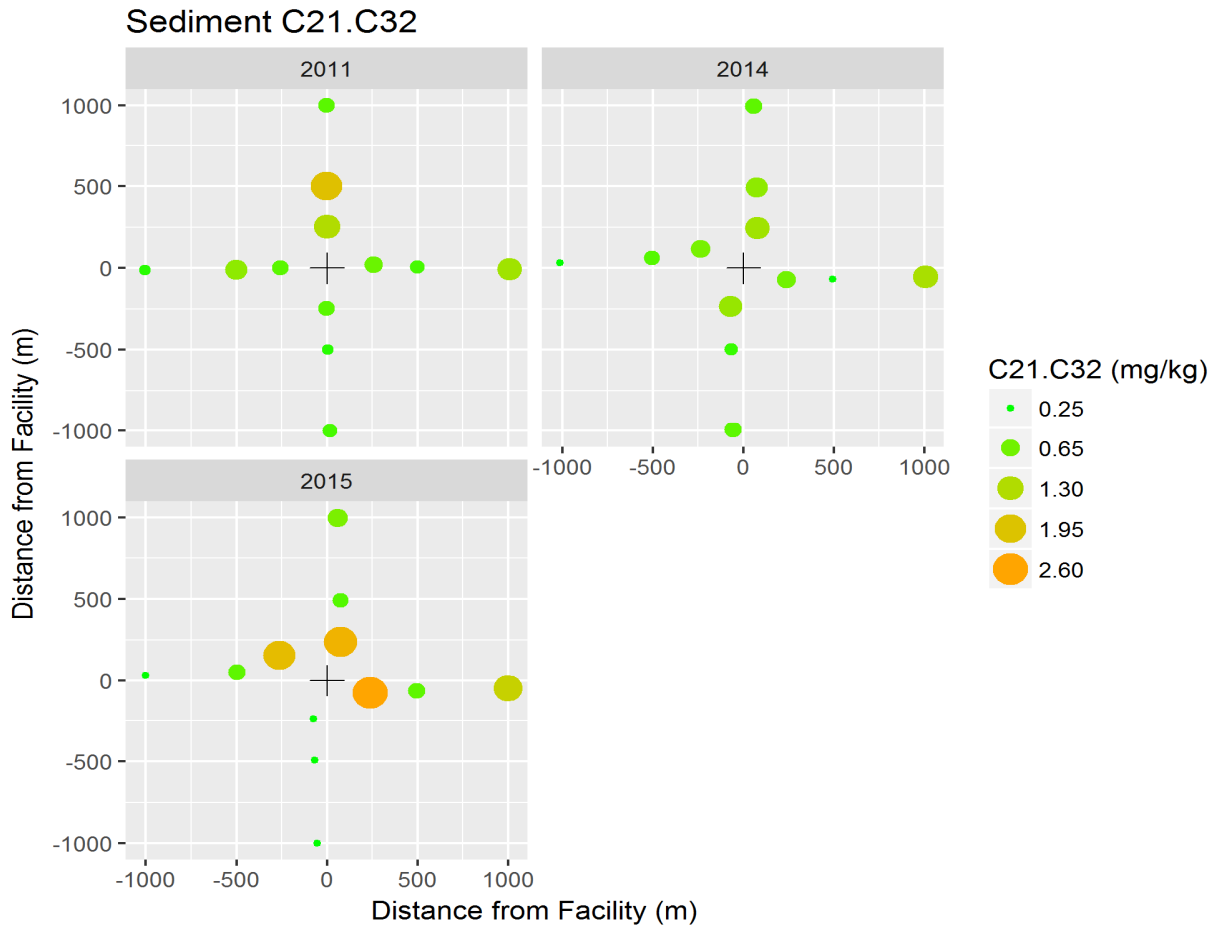


Figure 4.18 Spatial and temporal pattern of lube range hydrocarbons (>C_{21}-C_{32}) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

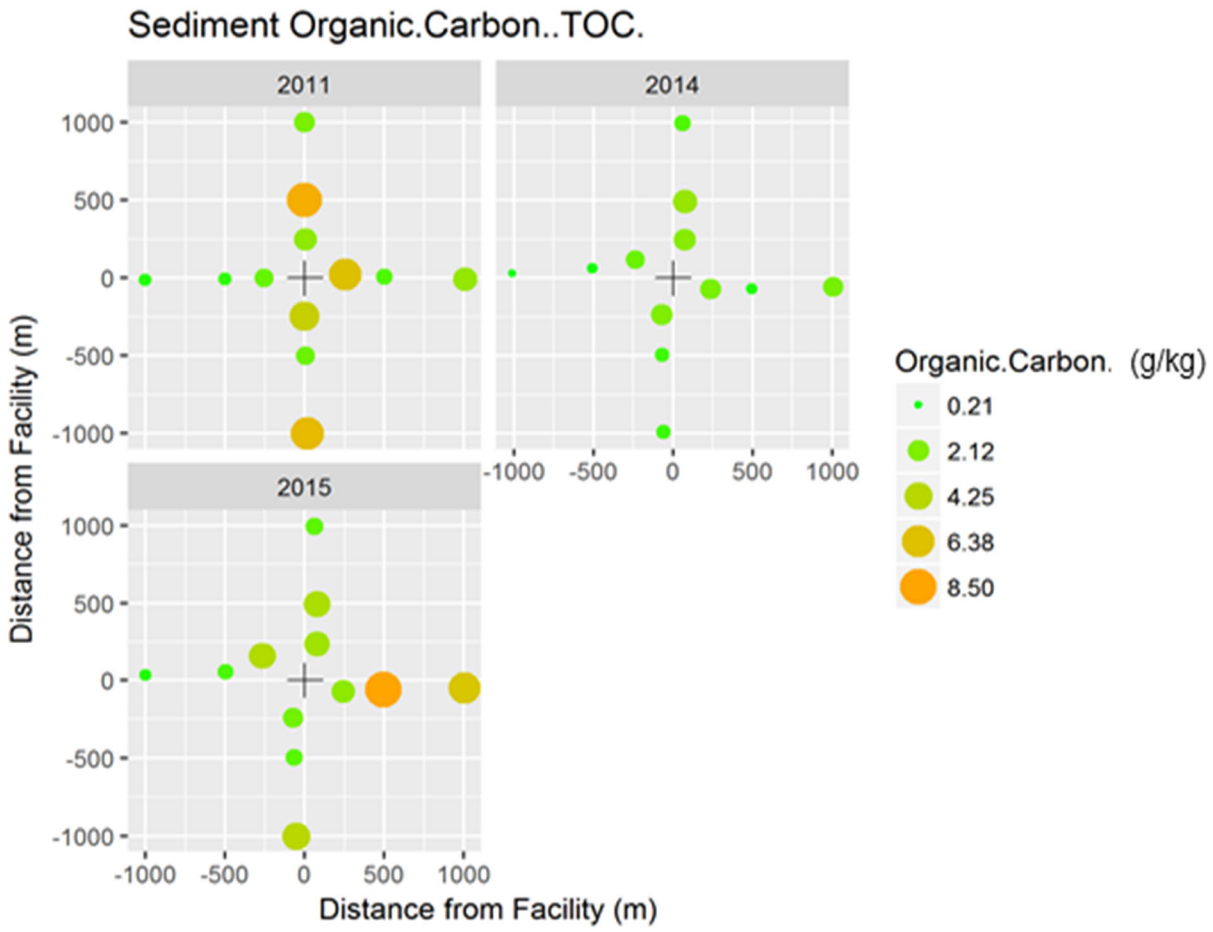


Figure 4.19 Spatial and temporal pattern of organic carbon (TOC) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

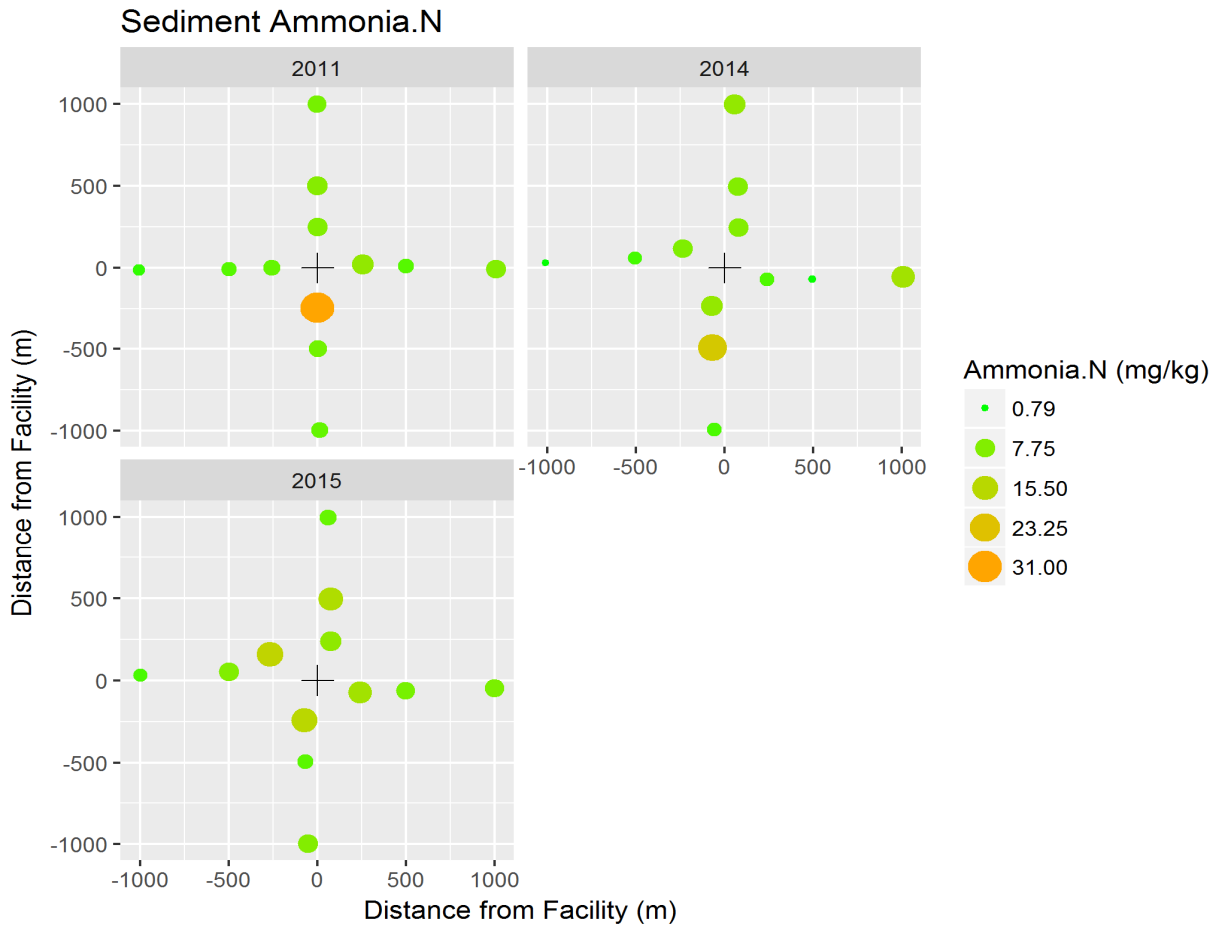


Figure 4.20 Spatial and temporal pattern of ammonia-N in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

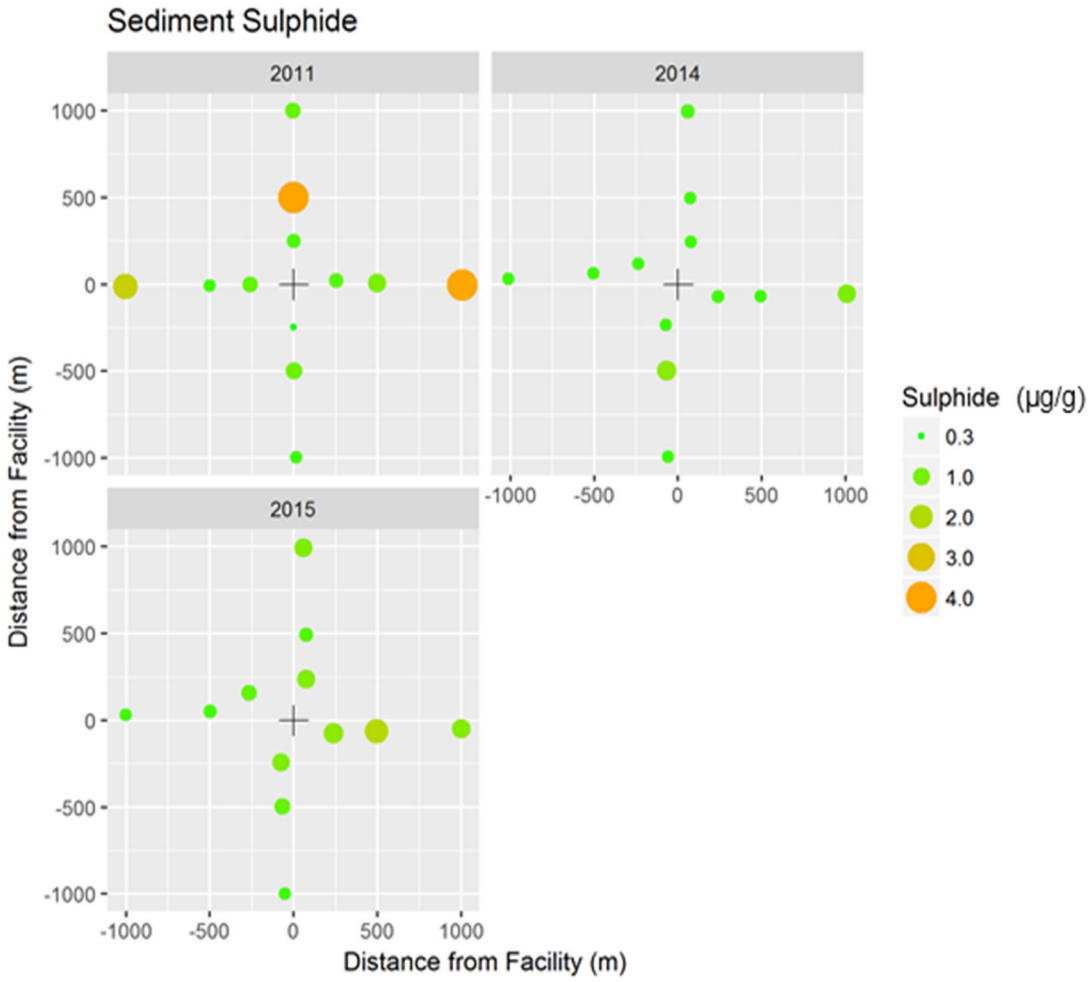


Figure 4.21 Spatial and temporal pattern of sulphide in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

5.0 HSE 2015 SEDIMENT CHEMISTRY STATISTICAL ANALYSIS

In survey years that are synchronized between HSE and the Hibernia Platform, a Whole-field analysis is conducted across the two fields in addition to the field-specific analyses (HMDC, 2015a). However, the 2015 EEM program was restricted to the HSE and therefore the statistical approach is comparisons of HSE to baseline (2011) and previous sampling years including the 16 km Reference Areas. As described in Chapter 3, in 2011 baseline Near-field stations (≤ 1,000 m from the EDC) were collected at 250 m intervals along the cardinal radials. From 2014 onwards, four additional stations have been sampled around a radius 6,000 m to the east of the EDC, as well as the two Reference Area stations located 16 km to the north and west of the Hibernia Platform (see Figure 3.2).

As described within the exploratory examination of analytes in sediment provided in Chapter 4, analytes were excluded from statistical analyses according to the following: if the majority (>50%) did not have a detectable concentration above RDL (>RDL); and for analytes whose maximum detected values in the 2015 EEM survey were less than Marine Interim Sediment Quality Guidelines (CCME 2001) thresholds, such as chromium, lead, and zinc (HMDC, 2013, 2015a).

The framework for statistical analysis of sediment analytes is illustrated in Figure 5.1 and is described below. To test for correlation between sediment grain size and analyte concentration, Pearson correlations of the arcsine square root-transformed sediment fraction and the coefficient of log 10-transformed analyte concentrations were calculated (correlation between sediment grain sizes was also tested). Subsequently, for analytes that did not have a large positive correlation with any sediment fraction (r<0.5), a 2x2 ANOVA was used for analysis (HMDC, 2013, 2015a) to determine if the interaction term between Distance from the EDC and Year was significant; a significant interaction term would indicate a Project-related effect. For any analyte with a large positive correlation (r>0.5) with an identified sediment type, the potential effect of this correlation was taken into account within the analysis by conducting an analysis of covariance (ANCOVA) to assess if the assumption of equality of slopes was met. Accordingly, if the interaction between distance and the covariate was significant (P<0.05), the ANCOVA analysis was considered inappropriate and the 2x2 Analysis of Variance (ANOVA) was interpreted instead (HMDC, 2013, 2015a). The Categorical factors and associated interactions examined via ANOVA for HSE statistical analyses are summarized in Table 5.1. For analytes having a positive correlation (r>0.5) with more than one sediment type, the sediment type with the greatest correlation coefficient was selected for ANCOVA analysis (HMDC, 2015a). Analyses were done for Whole-field (all distances including 16,000 m Reference Areas) for 2014 and 2015 (there were no 6,000 m stations for 2011 baseline), and for Near-field (≤1,000 m stations) for 2011, 2014 and 2015 (Table 5.1).

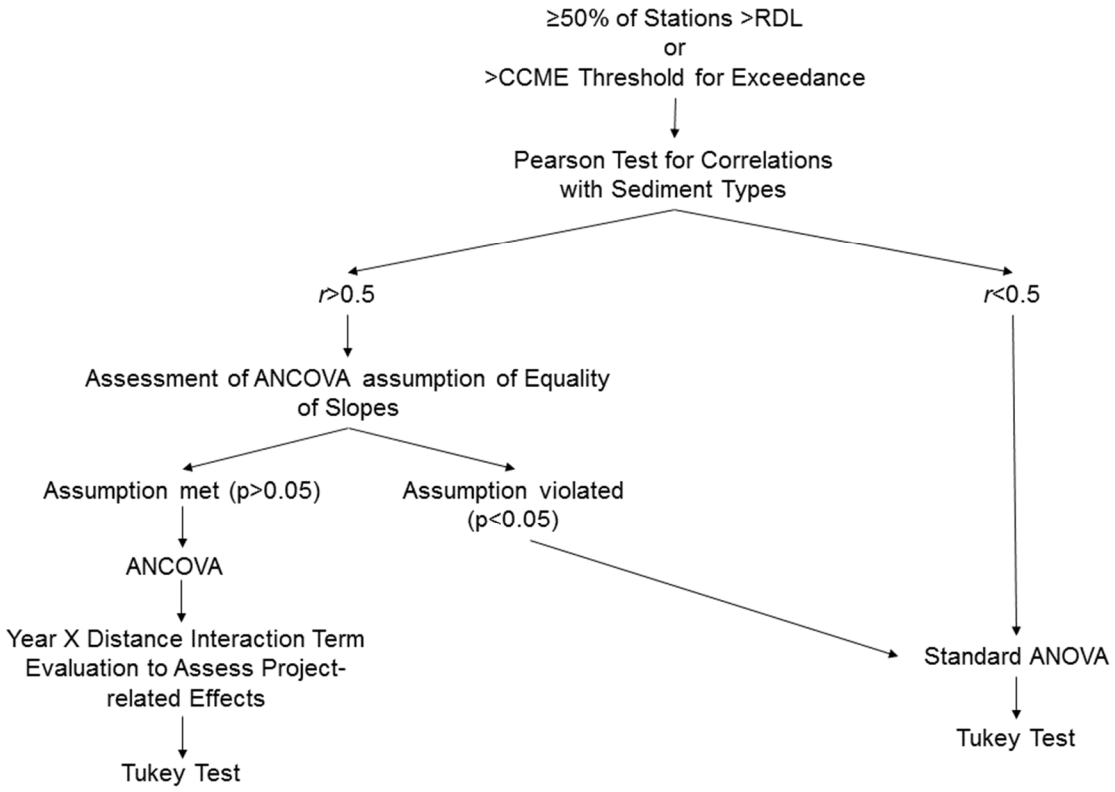


Figure 5.1 Sediment statistical analysis framework.

Table 5.1 Categorical factors and associated interactions examined via ANOVA for HSE statistical analyses.

Factor	Levels	df
Distance (D)	250, 500, 1,000, 6,000, 16,000 m	4
Year (Y)	2011, 2014, 2015	2
D x Y	--	5
Note: For Distance Factor the 6,000 stations have been sampled since 2014.		

5.1 Analyses of HSE Sediment Fractions

5.1.1 Sand

Sand was not positively correlated with silt, clay or gravel (r = -0.309, -0.039 and -0.955 respectively) and ANOVA was selected for analysis. In the Whole-field analysis, the interaction between distance and year was not significant (P=0.456; Table 5.2) and therefore did not provide evidence of a Project-related effect as would be expected within a Before-After Control-Impact (BACI) study design. Sand did vary significantly by Field (P<0.001), but not by Year (P=0.098). In the Near-field, the interaction between distance and year was not significant (P=0.262; Table 5.2). Significant differences were also not detected across distance categories (P=0.460; Table 5.2) but were detected across years (P=0.047; Table 5.2). Tukey Honest Significant Difference (HSD) post hoc tests indicated the significant differences (increases) occurred between 2011 and 2015

(Tukey multiple comparisons of means 95% family-wise confidence level P=0.045). However, there were no significant Year differences between 2011 and 2014, or 2014 and 2015 (Tukey HSD P>0.05) (Figure 5.2).

Table 5.2 Two-factor ANOVA Table for sand percentage (square-root arc-sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.075	0.075	2.93	0.098
Field	1	0.644	0.644	25.2	<0.001*
Year X Field	1	0.015	0.015	0.571	0.456
Residuals	28	0.715	0.026		
Near-field (2011-2015)					
Year	2	0.177	0.088	3.44	0.047*
Distance	2	0.041	0.021	0.799	0.460
Year X Distance	4	0.143	0.036	1.397	0.262
Residuals	27	0.693	0.257		
*Denotes significant result (P<0.05)					

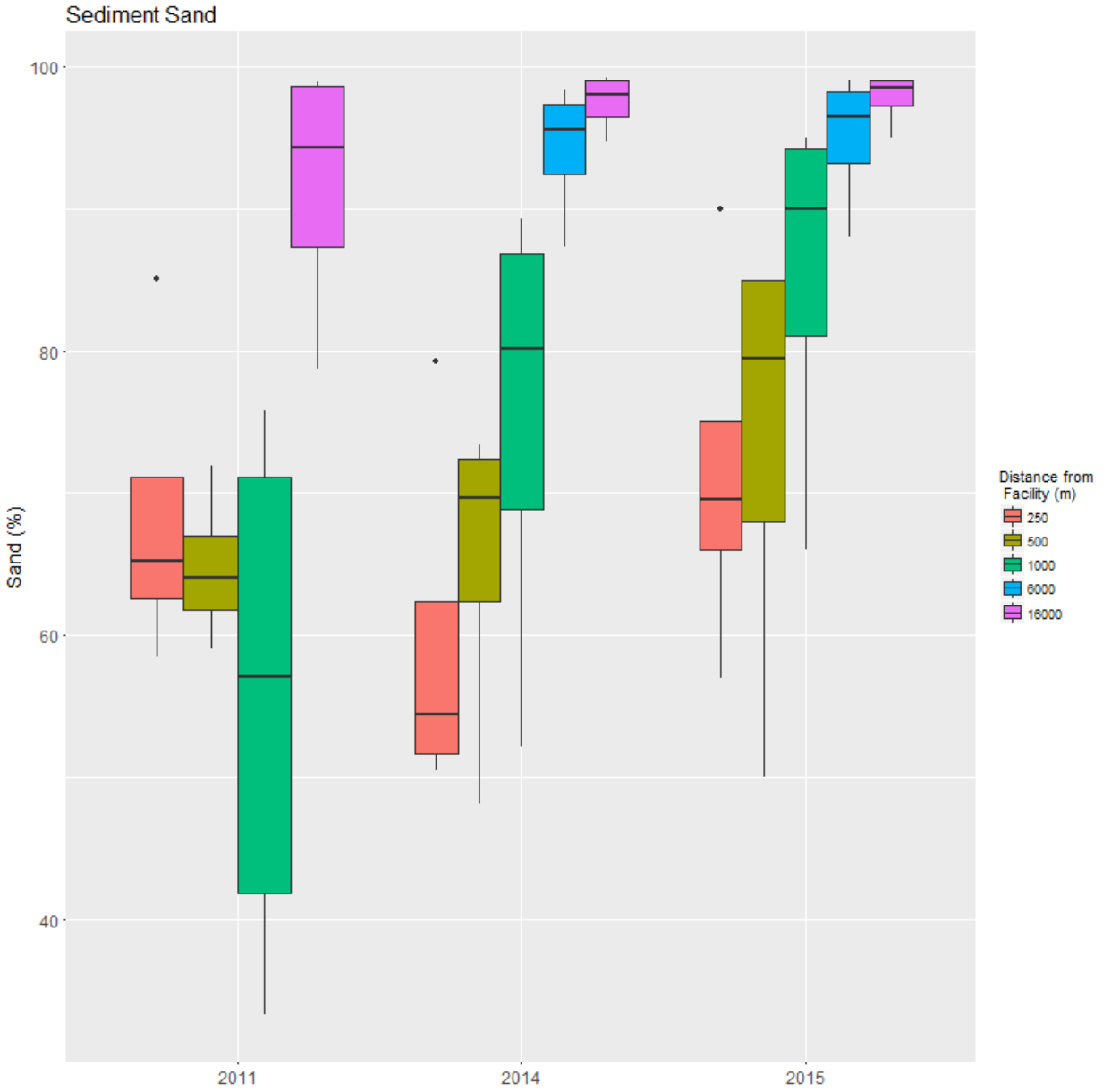


Figure 5.2 Boxplots of sand (%) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.2 Clay

There was no significant correlation between clay and other sediment types, r=0.340 (silt), -0.121 (sand), and 0.078 (gravel). In the Whole-field analysis, the interaction between distance and year was not significant (P=0.196; Table 5.3) and therefore did not provide evidence of a Project-related effect. Clay did vary significantly by Field (P=0.002) or by Year (P<0.001). In the Near-field, ANOVA analyses for clay at HSE reveal the interaction between distance and year was not significant (P=0.897; Table 5.3) and did not provide evidence of a Project-related effect.

Significant differences were detected across years (P<0.001; Table 5.3) but not for distance (P=0.080; Table 5.3). Tukey post hoc tests indicate the percentage of clay in the Near-field at HSE was significantly different in 2015 compared to 2011 baseline and the 2014 samples (Tukey HSD; P<0.001 for both). The median percentage of clay concentrations at stations 250 m from the EDC has increased over 3-fold since the 2011 baseline (Figures 4.3 and 5.3) and was significantly different at 250 m stations in 2015 compared to those in 2011 and 2014 (Tukey HSD; P=0.006 and 0.032 respectively). The concentration of clay at 500 m and 1,000 m stations in 2015 was significantly elevated compared to 2011 baseline values (Tukey HSD; P=0.022 and 0.018), however not compared to the corresponding values from the 2014 EEM (Tukey HSD; P>0.05).

Table 5.3 Two-factor ANOVA Table for clay percentage (square-root arc sine transformed) in HSE sediment

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.018	0.018	22.3	<0.001*
Field	1	0.009	0.009	11.8	0.002*
Year X Field	1	0.001	0.001	1.75	0.196
Residuals	28	0.022	0.001		
Near-field (2011-2015)					
Year	2	0.034	0.017	25.3	<0.001*
Distance	2	0.004	0.002	2.77	0.080
Year X Distance	4	0.001	0.0002	0.267	0.897
Residuals	27	0.018	0.001		
*Denotes significant result (P<0.05)					

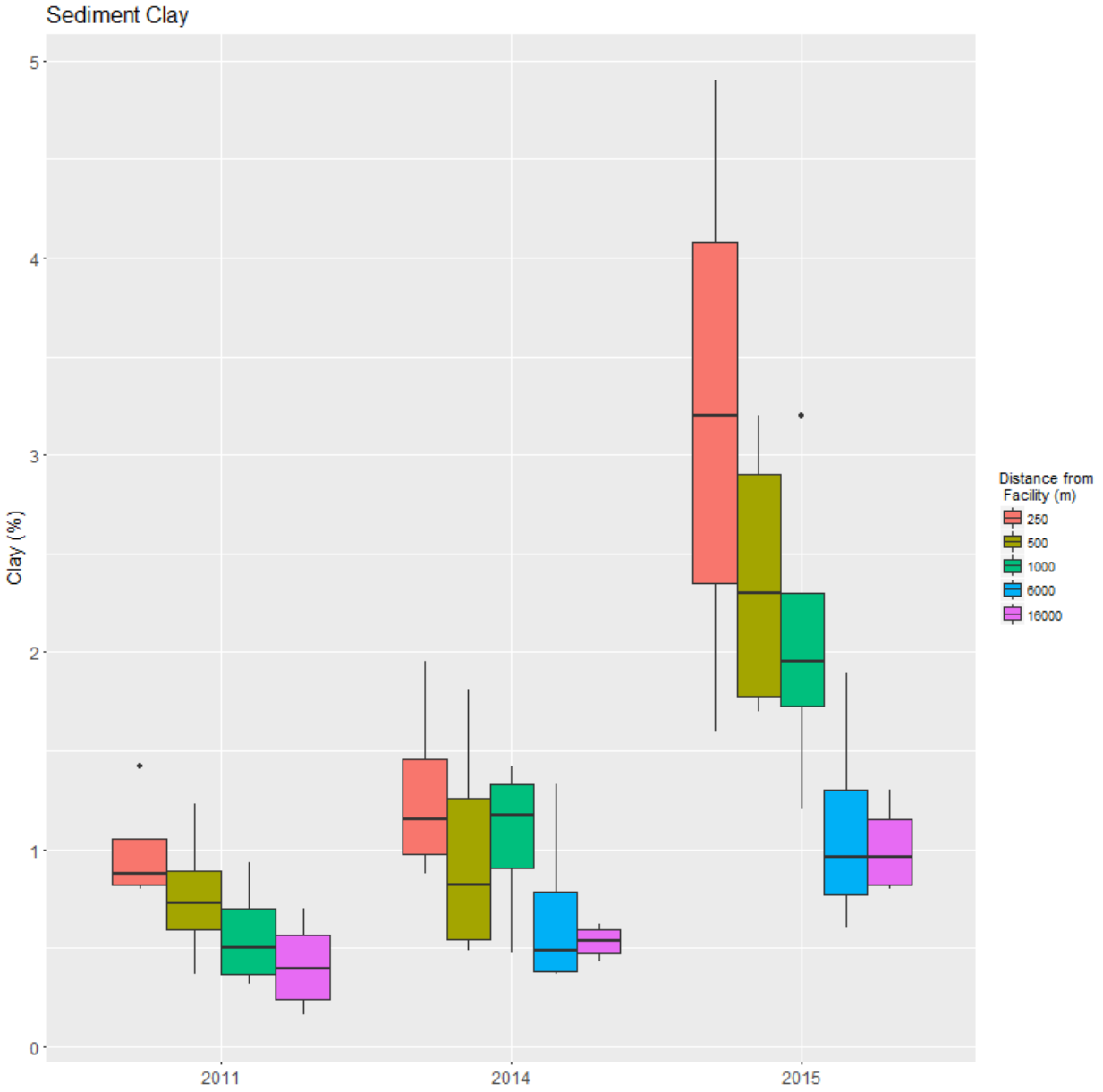


Figure 5.3 Boxplots of clay (%) in Sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.3 Gravel

Gravel was not correlated with silt, clay or sand (r = 0.399, 0.185 and -0.893) and ANOVA was selected for analyses. In the Whole-field analysis, the interaction between distance and year was not significant (P=0.419; Table 5.4) and therefore did not provide evidence of a Project-related effect. Gravel did vary significantly by Field (P<0.001) but not by Year (P=0.063). In the Near-field, the interaction between field and year was not significant (P=0.279; Table 5.4) and did not provide evidence of a Project-related effect. Significant differences were also not detected across

distance categories (P=0.505; Table 5.4) but were detected across years (P=0.023; Table 5.4). Tukey post hoc tests indicate there was no significant difference in the Near-field between 2011 baseline and the 2014 EEM program, nor between the 2014 and 2015 EEM programs for all Distance categories (Tukey HSD P>0.05) (Figure 5. 4). These results combined with the lack of gravel occurring Near the EDC (Figure 4. 4), suggests changes to gravel is not an effect associated with drilling activities at HSE.

Table 5.4 Two-factor ANOVA Table for gravel percentage (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.102	0.102	3.74	0.063
Field	1	0.662	0.662	24.3	<0.001*
Year X Field	1	0.018	0.018	0.674	0.419
Residuals	28	0.764	0.027		
Near-field (2011-2015)					
Year	2	0.241	0.12040	4.36	0.023*
Distance	2	0.039	0.01936	0.700	0.505
Year X Distance	4	0.149	0.03718	1.35	0.279
Residuals	27	0.746	0.02764		
*Denotes significant result (P<0.05)					

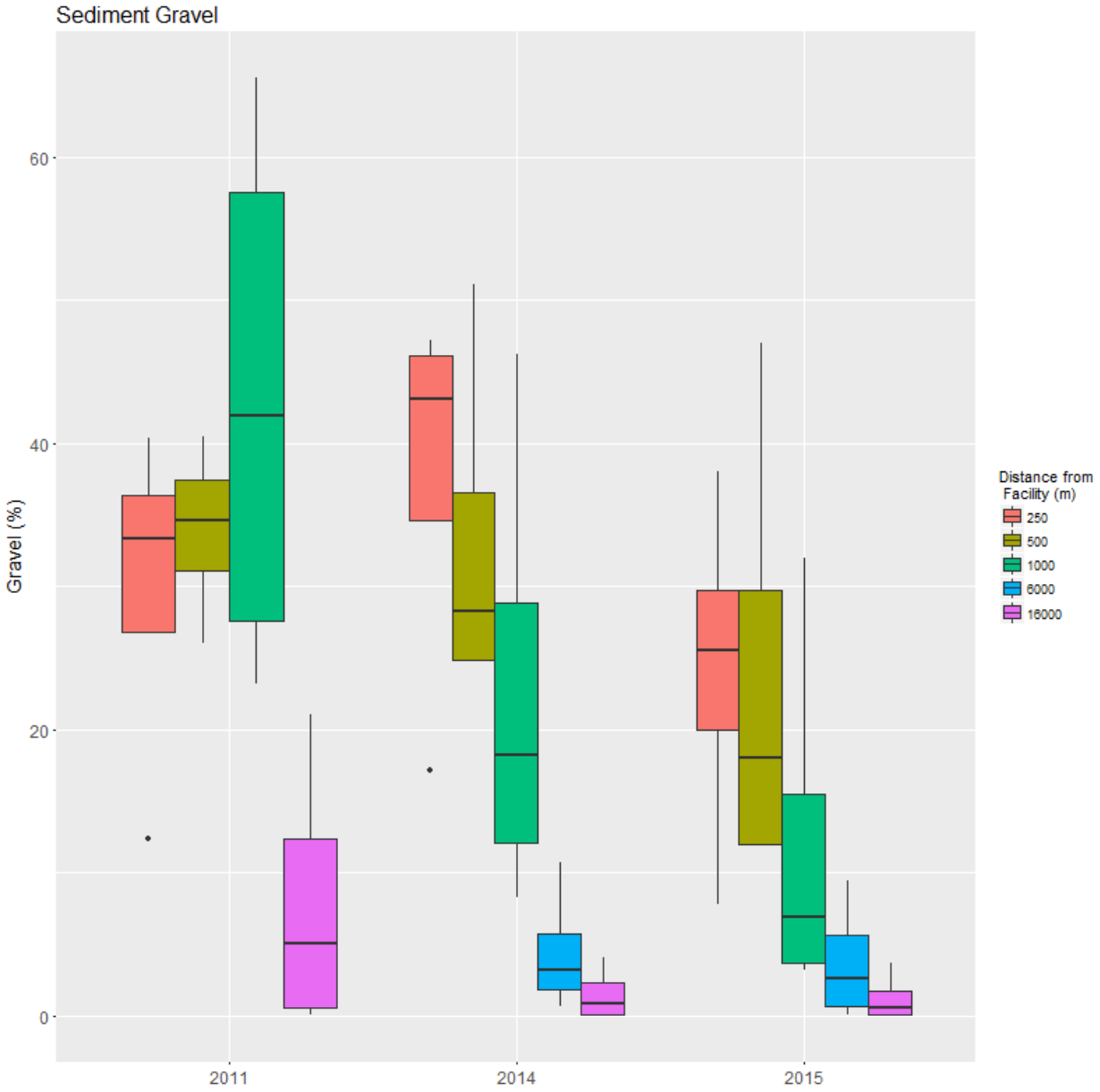


Figure 5.4 Boxplots of gravel (%) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.4 Silt

Silt did not significantly correlate with clay, sand or gravel (*r*= 0.283, -0.427 and 0.405 respectively). In the Whole-field analysis, the interaction between distance and year was not significant (P=0.334; Table 5.5) and therefore did not provide evidence of a Project-related effect. Silt did vary significantly by Field (P=0.029) or by Year (P=0.011). In the Near-field, the interaction between year and distance was not significant (P=0.499; Table 5.5 and Figure 5.5) and therefore did not provide evidence of a Project-related effect. Significant differences were not detected

across years (P=0.062; Table 5.5); however, they were detected across distance categories (P=0.008; Table 5.5). Most notably, 250 m stations were significantly elevated compared to 500 m and 1,000 m stations (Tukey HSD; P=0.029 and 0.011 respectively) (Figure 4.5). However, 500 m and 1,000 m stations are not significantly different (P=0.912). Overall, the percentage of silt concentration at stations 250 m from the EDC has increased significantly since 2011 baseline.

Table 5.5 Two-factor ANOVA Table for silt percentage (square-root arc sine transformed) in HSE sediment

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	P
Whole-field (2014-2015)					
Year	1	0.008	0.008	7.37	0.011*
Field	1	0.005	0.005	5.34	0.029*
Year X Field	1	0.001	0.001	0.968	0.334
Residuals	28	0.029	0.001		
Near-field (2011-2015)					
Year	2	0.005	0.002	3.09	0.062
Distance	2	0.009	0.004	5.80	0.008*
Year X Distance	4	0.003	0.001	0.862	0.499
Residuals	27	0.020	0.001		
*Denotes significant result (P<0.05)					

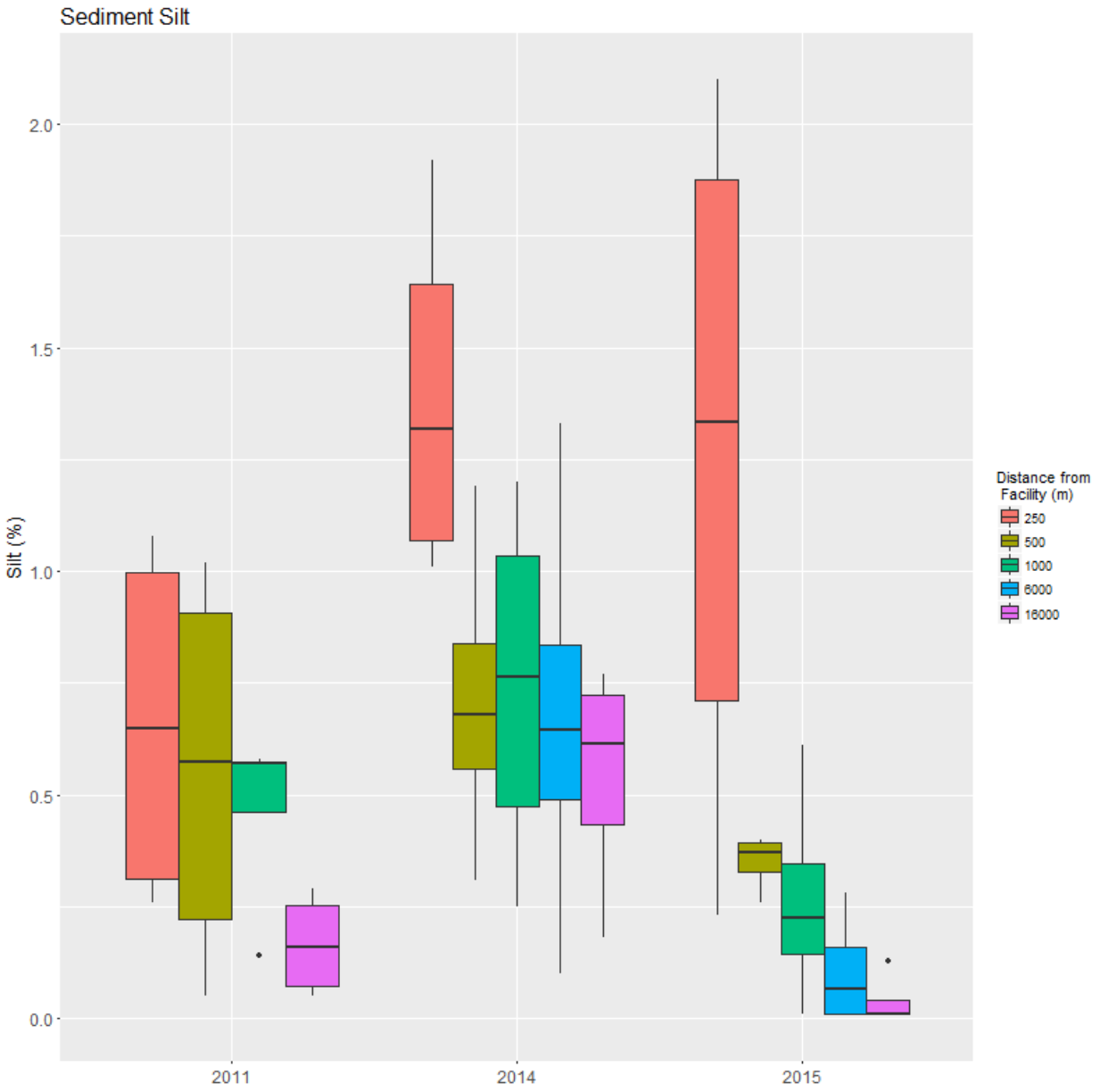


Figure 5.5 Boxplots of Silt (%) in Sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.5 Statistical Exploration of Analytes in Sediment

With the above analysis of potential correlation between sediment types with Year and Distance completed, the correlation between analyte concentration and sediment type (across all distances and study area levels) was tested. The sediment grain sizes considered as potential covariates (r>0.5) are summarized in Table 5.6. The interpretation for each analyte is discussed separately below according to the analysis framework summarized in Figure 5.1.

Table 5.6 Summary of analytes with HSE sediment covariate types. All positive correlations >0.5 are in bold.

Analyte	Covariate Sediment Type (r > 0.5)[1]			
	Silt	Clay	Sand	Gravel
Aluminium	0.492	0.335	-0.273	0.244
Iron	**0.562***	0.333	-0.296	0.273
Manganese	0.462	0.272	-0.336	0.312
Strontium	0.460	0.497	-0.767	**0.747***
Uranium	0.397	0.430	-0.495	0.477
Vanadium	**0.585***	0.348	-0.459	0.440
Barium	**0.535**	**0.680***	-0.334	0.299
Weak Acid extractable barium	0.261	**0.736***	-0.202	0.171
>C_{10}-C_{21} (Fuel range hydrocarbons)	**0.529**	**0.730***	-0.414	0.382
>C_{21}-C_{32} (Lube range hydrocarbons)	**0.666***	0.467	-0.472	0.443
Organic Carbon (TOC)	0.416	**0.521****	-0.646	**0.620**
Ammonia-N	0.302	0.478	-0.540	**0.523***
Sulphide	0.214	0.227	-0.327	0.311

[1]HMDC (2013)
* Indicates sediment type with highest correlation. Unless otherwise noted, this was used as a covariate within ANCOVA analyses.
** Covariate selected for ANCOVA as it is associated with sediment type increasing around the HSE EDC (Figure 5.3).

5.6 Analyses of Extractable Metals in Sediment

5.7 Aluminum

There was no significant correlation (r>0.5) between aluminum concentration and sediment particle sizes (Table 5.6). The ANOVA analyses for aluminum at HSE revealed no significant Year x Distance interaction within the Near-field (P=0.233; Table 5.7). In the Whole-field analysis, the Year x Field interaction was not significant (P=0.952; Table 5.7) and therefore did not provide evidence of a Project-related effect. Aluminum also did not vary significantly by Field (P=0.801) or by Year (P=0.898). In the Near-field, there was no significant year effect (P=0.922; Table 5.7) but distance effects were detected (P=0.006; Table 5.7) with 250 m stations being significantly different than 500 m (Tukey HSD; P=0.006) and 1,000 m stations (Tukey HSD; P=0.041). The differences are clear as the median concentration of aluminum at the 250 m stations, were nearly double that of the 500 m stations (Figure 5.6 and Figure 4.6). Overall, even though there are no statistically significant Project-related effects, significant differences have occurred in the Near-field and graphical examination suggests that concentrations appear to be increasing in proximity to the EDC (Figure 5.6 and Figure 4.6).

Table 5.7 Two-factor ANOVA Table for aluminum (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.001	0.001	0.017	0.898
Field	1	0.002	0.002	0.065	0.801
Year X Field	1	0.0001	0.0001	0.004	0.952
Residuals	28	0.839	0.030		
Near-field (2011-2015)					
Year	2	0.004	0.002	0.082	0.922
Distance	2	0.280	0.140	6.26	0.006*
Year X Distance	4	0.133	0.033	1.49	0.233
Residuals	27	0.604	0.022		
*Denotes significant result (P<0.05)					

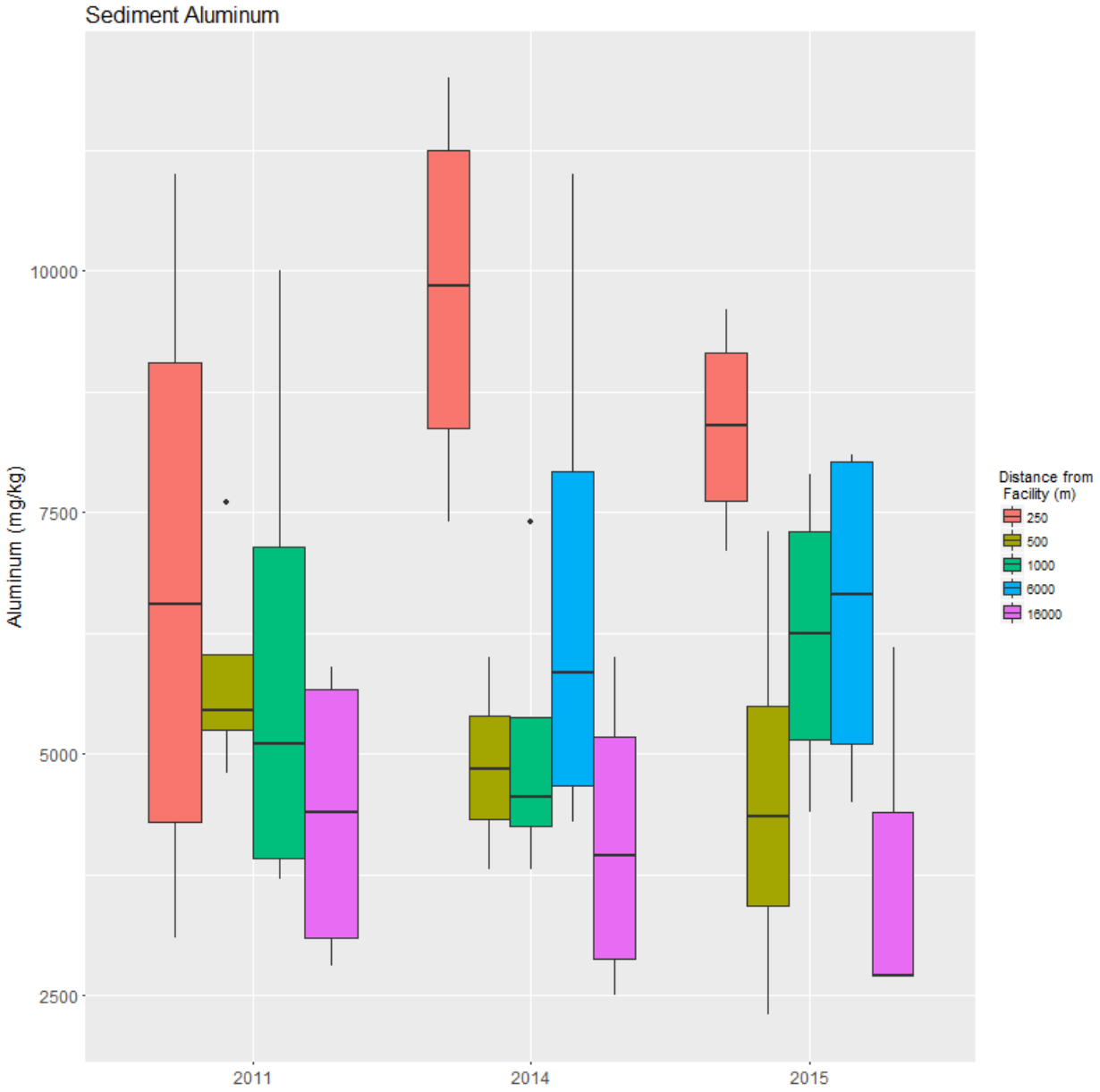


Figure 5.6 Boxplot of aluminum (mg/kg) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.8 Iron

Iron was significantly correlated with silt concentration (Table 5.6), and therefore the inclusion of silt as a covariate with iron in a two-factor ANCOVA was evaluated. The non-significant interaction term Field x silt suggested the ANCOVA model was suitable for both Whole-field and Near-field analyses. In the Whole-field analysis, the interaction between Year x Field was not significant (P=0.414; Table 5.8) and therefore did not provide evidence of a Project-related effect. Iron did vary significantly by Field (P=0.026) but not by Year (P=0.798). In the Near-field, the Year x

Distance interaction term was not significant (P=0.354; Table 5.8) and therefore also did not provide evidence for Project related effects. The Year term was also not significant (P=0.165; Table 5.8); however, the Distance term was significant (P<0.001; Table 5.8; Figures 5.7, 5.8). The median concentration of iron at the 250 m stations was nearly double that of stations from 500 m and beyond in 2015 (Figure 5.8). These significant Near-field distance differences were not evident in 2011 baseline data (Tukey post hoc test, 250 m > 500 m; P=0.972; 250 m > 1,000 m; P=0.956), however were significantly different in 2014 (Tukey post hoc test; 250 m > 500 m; P=0.027; 250 m > 1,000 m; P=0.029). Overall, even though there are no statistically significant Project-related effects, graphical examination suggests that concentrations appear to be increasing in proximity to the EDC (Figures 4.7, 5.7 and 5.8).

Table 5.8 Two-factor ANCOVA Table for iron concentration (mg/kg) and silt (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.002	0.002	0.067	0.798
Field	1	0.152	0.152	5.59	0.026*
Year X Field	1	0.019	0.019	0.690	0.414
Field X Silt	1	0.007	0.007	0.248	0.622
Residuals	26	0.706	0.027		
Near-field (2011-2015)					
Year	2	0.090	0.045	1.94	0.165
Distance	2	0.486	0.243	10.5	<0.001*
Year X Distance	4	0.107	0.027	1.16	0.354
Distance X Silt	2	0.011	0.006	0.239	0.789
Residuals	24	0.555	0.023		
*Denotes significant result (P<0.05)					

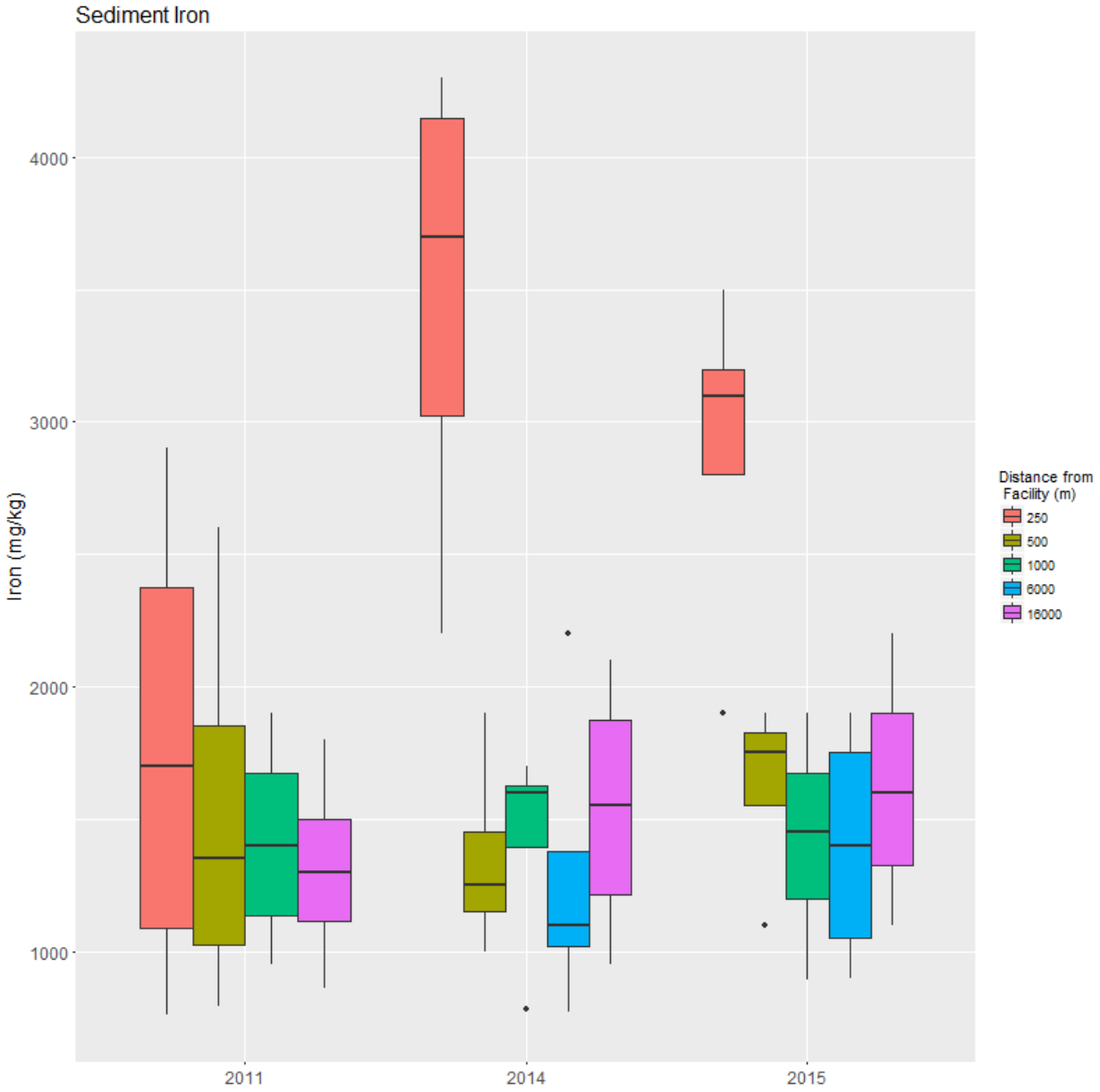


Figure 5.7 Boxplots of iron (mg/kg) in Sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

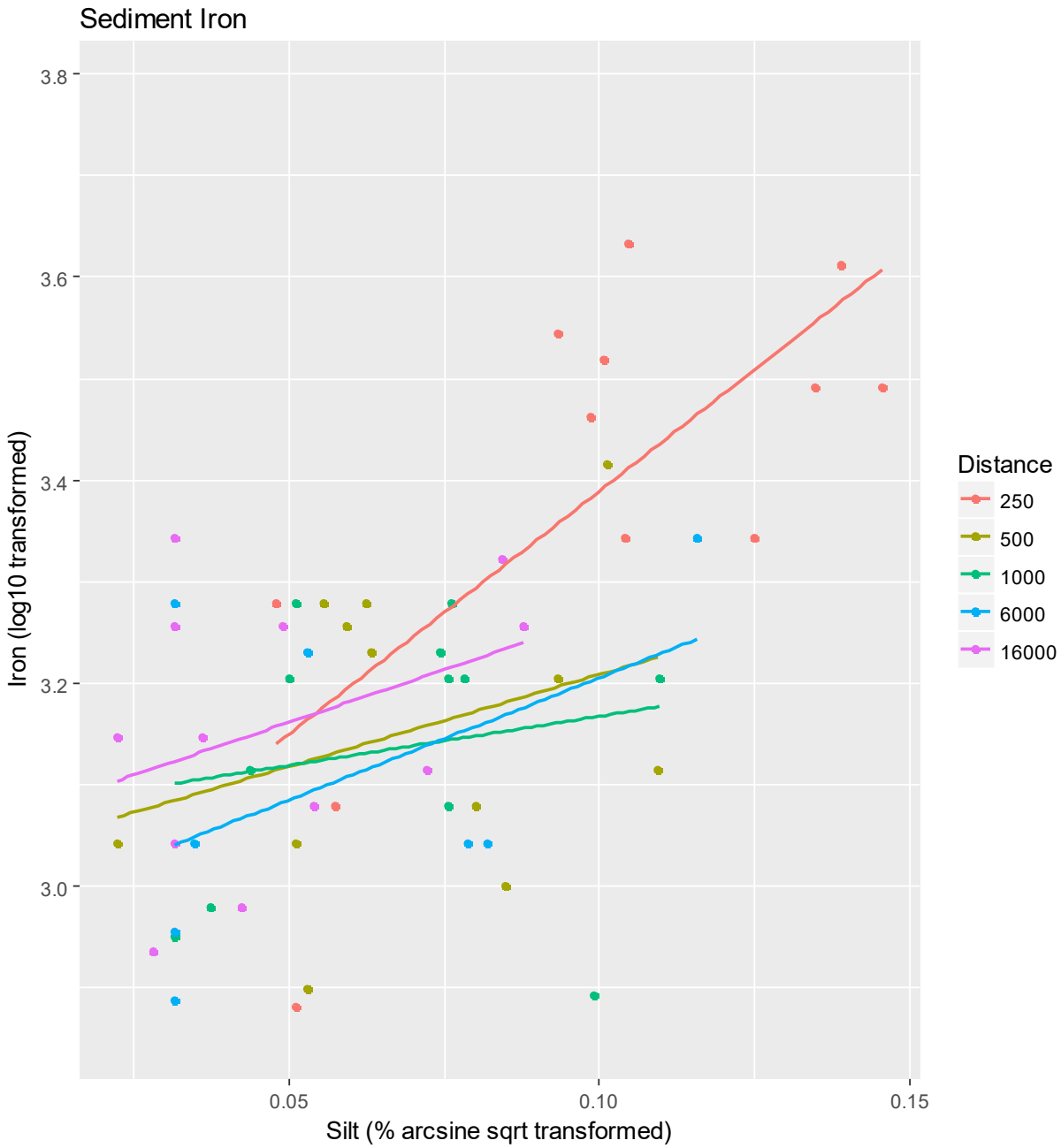


Figure 5.8 Covariate regression of iron concentration (log_{10}-transformed) against silt percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas in 2015.

5.9 Manganese

Concentrations of manganese were not significantly correlated (r>0.5) to a sediment particle size (Table 5.6), therefore ANOVA was selected for analyses. In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.889; Table 5.9) and therefore does not provide evidence of a Project-related effect. The concentration of manganese did not vary significantly by Field (P=0.081) or by Year (P=0.645). In the Near-field, the Year x Distance interaction term was also not significant (P=0.140; Table 5.9) and therefore does not provide evidence of a Project-related effect. Differences across Year categories were also not significant (P=0.870; Table 5.9); however, significant differences were detected across Distances (P=0.007; Table 5.9). The effect of distance was significant between 250 m and 500 m as well as 250 m and 1,000 m (Tukey HSD; P=0.032 and 0.009 respectively). Stations 500 m and beyond were statistically indistinguishable (P>0.05) (Figure 5.9). Overall, even though there are no statistically significant Project-related effects, significant differences have occurred in the Near-field and graphical examination suggests that concentrations appear to be increasing in proximity to the EDC since 2011 baseline (Figures 4.8 and 5.9).

Table 5.9 Two-factor ANOVA Table for manganese (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.008	0.008	0.218	0.645
Field	1	0.122	0.122	3.28	0.081
Year X Field	1	0.001	0.001	0.020	0.889
Residuals	28	1.041	0.037		
Near-field (2011-2015)					
Year	2	0.009	0.004	0.140	0.870
Distance	2	0.376	0.188	5.98	0.007*
Year X Distance	4	0.238	0.060	1.90	0.140
Residuals	27	0.848	0.031		
*Denotes significant result (P<0.05)					

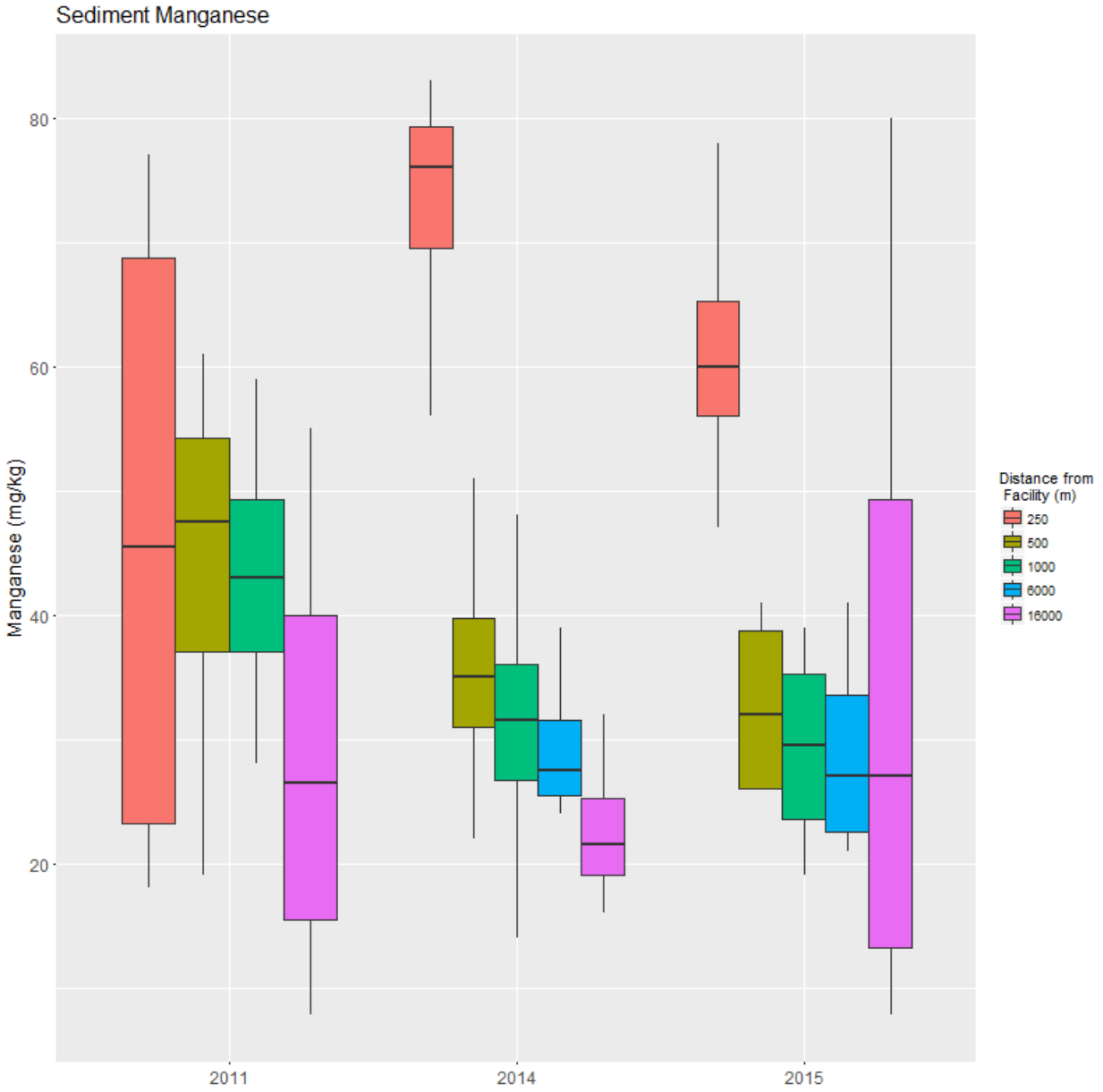


Figure 5.9 Boxplots of manganese (mg/kg) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.10 Strontium

The concentration of strontium in sediment was significantly correlated with the percentage of gravel sediment composition (Table 5.6), therefore ANCOVA was selected for analyses. The non-significant Field x Gravel interaction term suggested the ANCOVA model was appropriate (P=0.557; Table 5.10). In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.186; Table 5.10) and the concentration of strontium varied significantly by Field (P<0.001) but not by Year (P=0.343). In the Near-field, the Year x Distance interaction term was

also not significant (P=0.359; Table 5.10) and supports the evidence of no Project-related effect. The separate Year and Distance terms were also not significant (P=0.463 and 0.133, respectively; Table 5.10). Although there is a significant difference between Near-field and Far-field stations for 2014 and 2015 EEM surveys, changes in concentrations of strontium in the Near-field since the 2011 baseline survey have not been significant (Tukey post hoc test; P>0.05) (Figure 5.11).

Table 5.10 Two-factor ANCOVA Table for strontium and gravel (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.091	0.091	0.932	0.343
Field	1	5.74	5.74	58.8	<0.001
Year X Field	1	0.180	0.180	1.848	0.186
Field X Gravel	1	0.035	0.035	0.354	0.557
Residuals	26	2.54	0.098		
Near-field (2011-2015)					
Year	2	0.170	0.085	0.796	0.463
Distance	2	0.4685	0.2343	2.198	0.133
Year X Distance	4	0.488	0.122	1.15	0.359
Distance X Gravel	2	0.399	0.199	1.87	0.176
Residuals	24	2.56	0.107		
*Denotes significant result (P<0.05)					

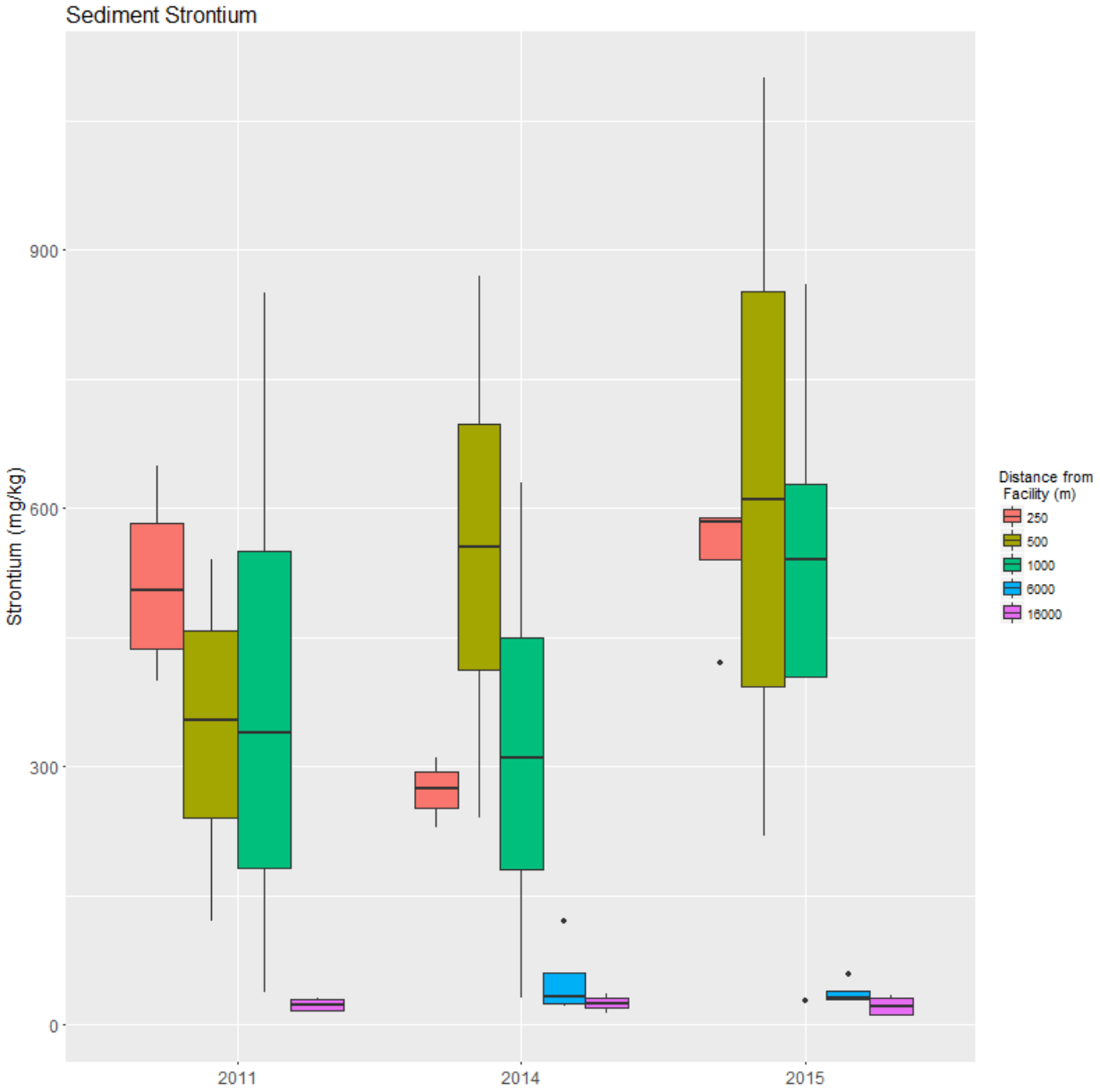


Figure 5.10 Boxplots of strontium (mg/kg) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.11 Uranium

There was no significant correlation (r>0.5) between uranium concentrations and sediment particle size (Table 5. 6), therefore ANOVA was selected for analysis. In the Whole-field analysis, the Year x Field interaction term was not found to be significant (P=0.241; Table 5.11) and therefore does not provide evidence of a Project-related effect. The concentration of uranium did vary significantly by Field (P=0.023) but not by Year (P=0.111). In the Near-field, the Year x Distance interaction term was also not significant (P=0.490; Table 5.11) and does not provide

evidence of a Project related effect. No significant differences were detected for either the Year or Distance terms (P=0.124 and 0.209; Table 5.11). Overall there have been no significant changes in the concentrations of uranium since baseline (Figures 4.12 and 5.11).

Table 5.11 Two-factor ANOVA Table for uranium concentration (mg/kg) (square-root arc sine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.106	0.106	2.71	0.111
Field	1	0.227	0.227	5.76	0.023*
Year X Field	1	0.056	0.056	1.44	0.241
Residuals	28	1.10	0.039		
Near-field (2011-2015)					
Year	2	0.187	0.093	2.26	0.124
Distance	2	0.138	0.069	1.66	0.209
Year X Distance	4	0.145	0.036	0.878	0.490
Residuals	27	1.12	0.041		
*Denotes significant result (P<0.05)					

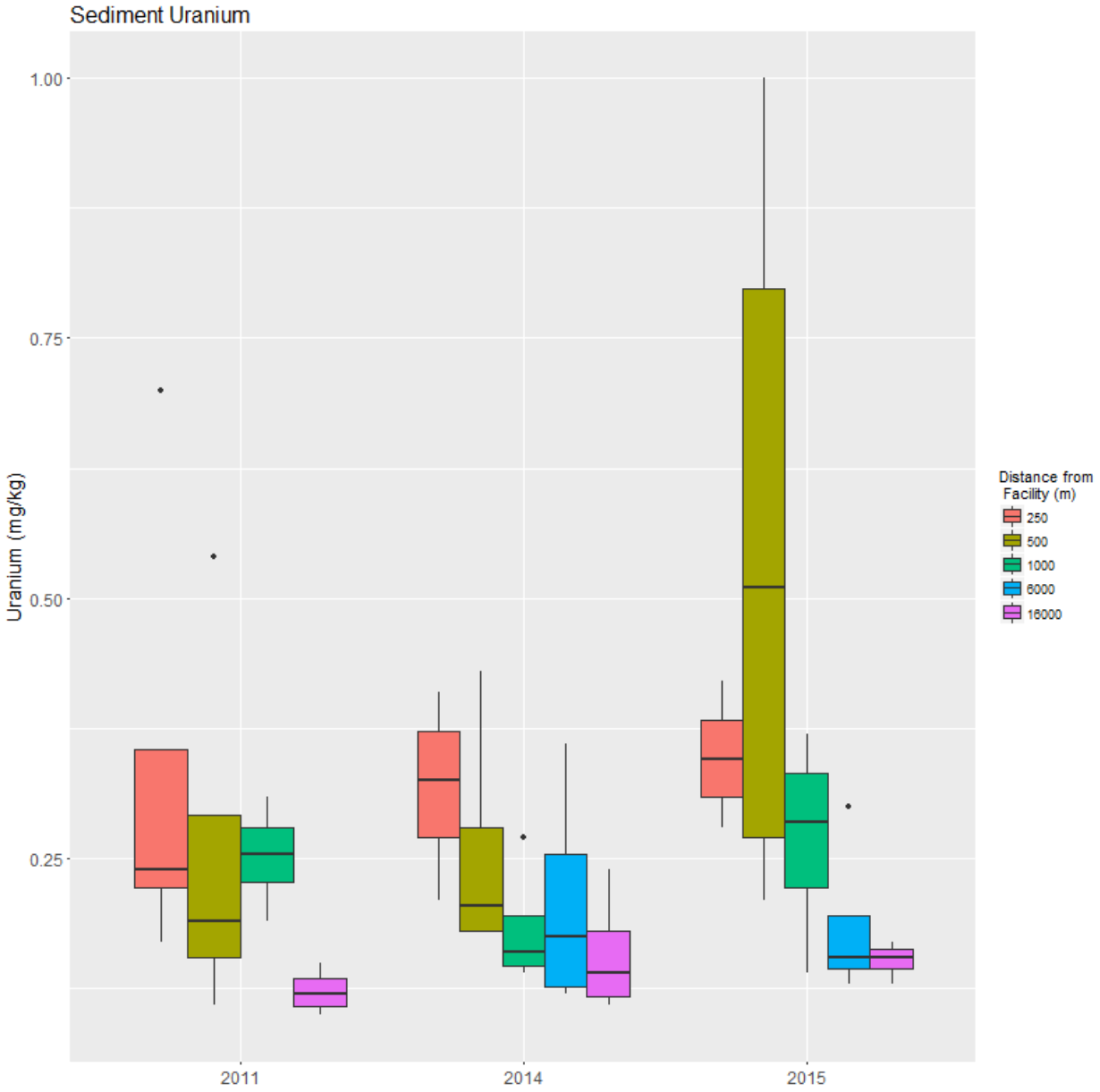


Figure 5.11 Boxplots of uranium (mg/kg) in sediment by Distance and Year at HSE sample. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.12 Vanadium

Vanadium was significantly correlated with silt particle size (Table 5.6), therefore ANCOVA was selected for further analyses. The non-significant Field x Silt interaction term indicated the ANCOVA was a suitable model (P=0.496; Table 5.12). In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.754; Table 5.12). The concentration of vanadium did vary significantly by Field (P=0.015) but not by Year (P=0.509). In the Near-field, the Year x Distance interaction term was also not significant (P=0.754; Table 5.12) and therefore provided

further evidence of no Project-related effect. The Year term was also not significant (P=0.657; Table 5.12); however, the Distance term was significant (P<0.001; Table 5.12, Figures 5.12, 5.13).

There were significant differences between 250 m and 500 m stations (Tukey post hoc test; P=0.002), as well as between 250 m and 1,000 m stations (Tukey post hoc test; P=0.003). However, vanadium levels between 500 m and 1,000 m stations are not distinguishable (P=0.971), and there is no significant difference within distances between years (e.g.; 250 m 2011 vs. 250 m 2015) (Tukey post hoc test; P>0.05; Figures 4.13, 5.12, 5.13) and these differences are therefore not considered project-related.

Table 5.12 Two-factor ANCOVA Table for vanadium concentration and silt (mg/kg) (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.012	0.012	0.448	0.509
Field	1	0.175	0.175	6.81	0.015*
Year X Field	1	0.003	0.003	0.101	0.754
Field X Silt	1	0.012	0.012	0.477	0.496
Residuals	26	0.669	0.026		
Near-field (2011-2015)					
Year	2	0.018	0.009	0.427	0.657
Distance	2	0.431	0.215	10.0	<0.001*
Year X Distance	4	0.079	0.020	0.917	0.470
Distance X Silt	2	0.011	0.005	0.246	0.784
Residuals	24	0.517	0.022		
*Denotes significant result (P<0.05)					

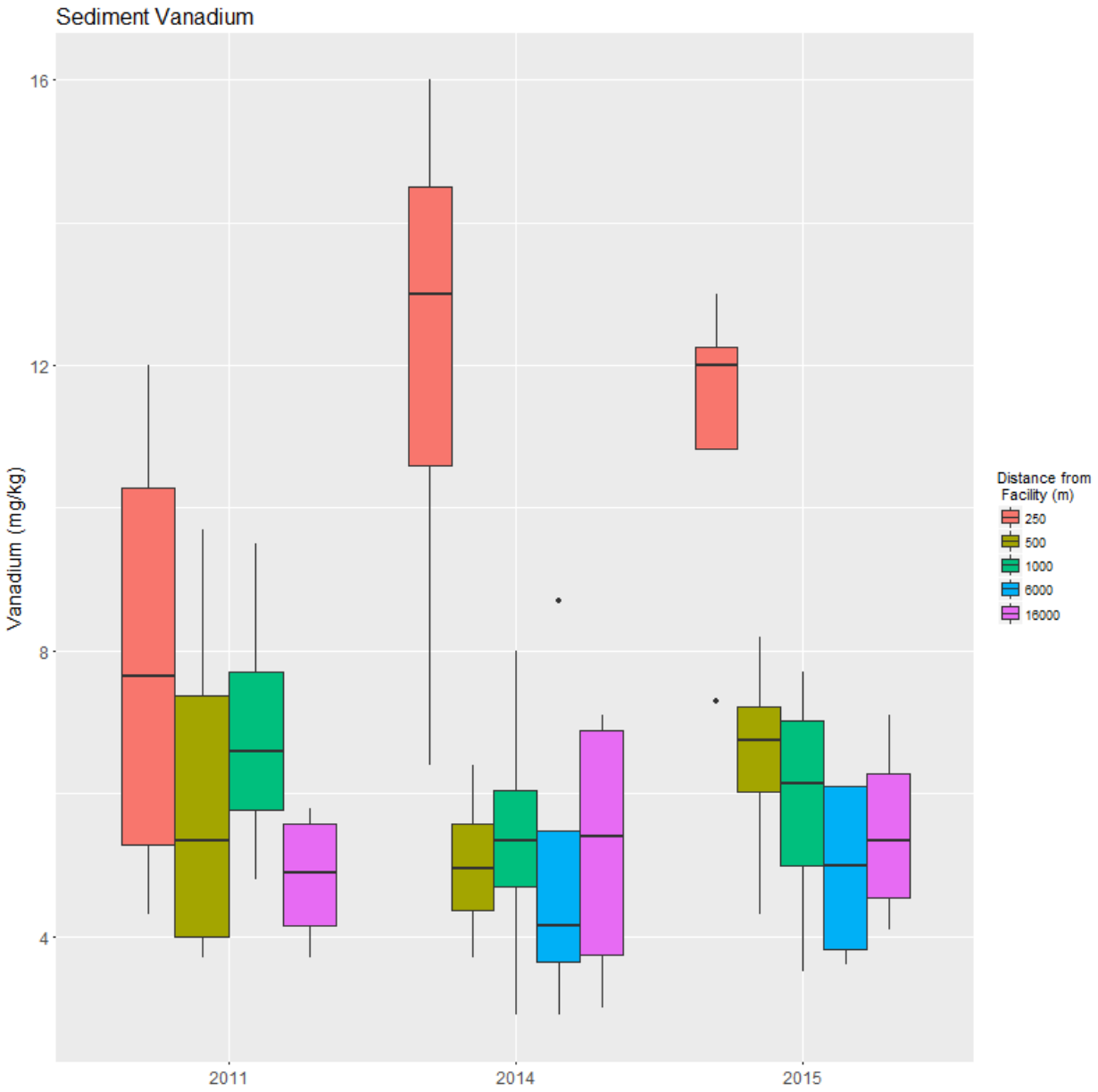


Figure 5.12 Boxplots of vanadium (mg/kg) in Sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

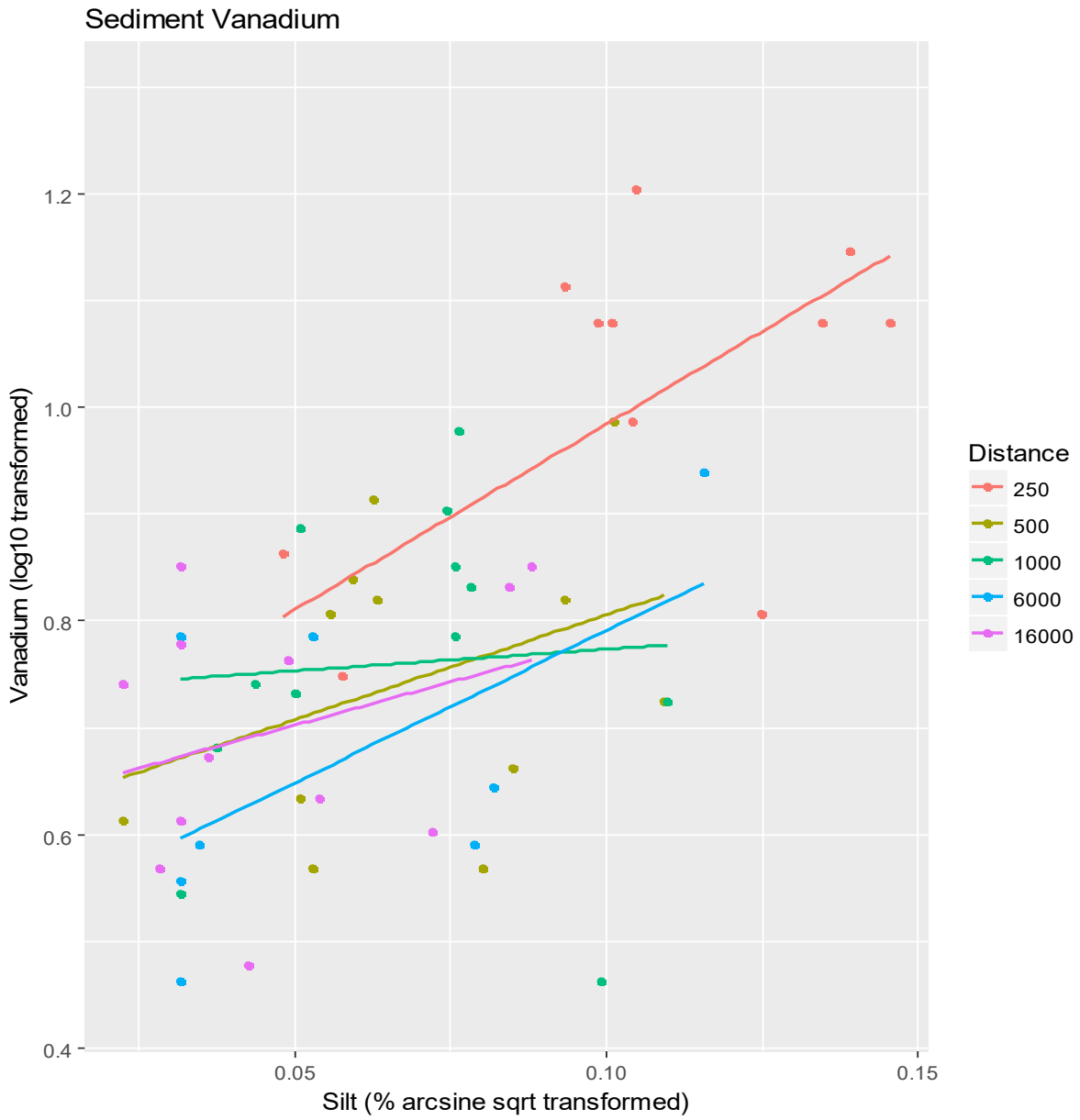


Figure 5.13 Covariate regression of vanadium concentration (log_{10}-transformed) against silt percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas.

5.13 Barium

The concentration of barium was positively correlated to silt and clay, and ANCOVA was selected for analyses with clay as a covariate as it was most strongly correlated with barium concentration (Table 5.6). The non-significant Field x Clay interaction term in both the Whole-field and Near-field analyses indicated that the ANCOVA model was suitable (P=0.407; Table 5.13). In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.348; Table 5.13) and therefore did not provide evidence of a Project-related effect. The concentration of barium did vary significantly by Field (P=0.045) and by Year (P=0.015).

In the Near-field, the Year x Distance interaction term was significant (P<0.001; Table 5.13), indicating the observed increases in Barium are likely a Project-related effect (Figures 4.15, 5.14, 5.15). Overall, there has been an eleven-fold increase in the concentration of barium in sediments around the 250 m stations that is also positively correlated (*r*>0.5) to co-localized increases in fine sediment fractions since the 2011 baseline survey (Figure 4.15). However, this increase is limited to the 250 m stations as there were no significant differences (Tukey post hoc; P>0.05) between any distances 500 m and beyond in the Near-field for all years.

Table 5.13 Two-factor ANCOVA Table for barium and clay (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.841	0.841	6.78	0.015*
Field	1	0.552	0.552	4.45	0.045*
Year X Field	1	0.113	0.113	0.912	0.348
Field X Clay	1	0.088	0.088	0.711	0.407
Residuals	26	3.22	0.124		
Near-field (2011-2015)					
Year	2	1.59	0.794	21.2	<0.001*
Distance	2	2.22	1.11	29.6	<0.001*
Year X Distance	4	1.17	0.292	7.80	<0.001*
Distance X Clay	2	0.076	0.038	1.02	0.377
Residuals	24	0.898	0.037		
*Denotes significant result (P<0.05)					

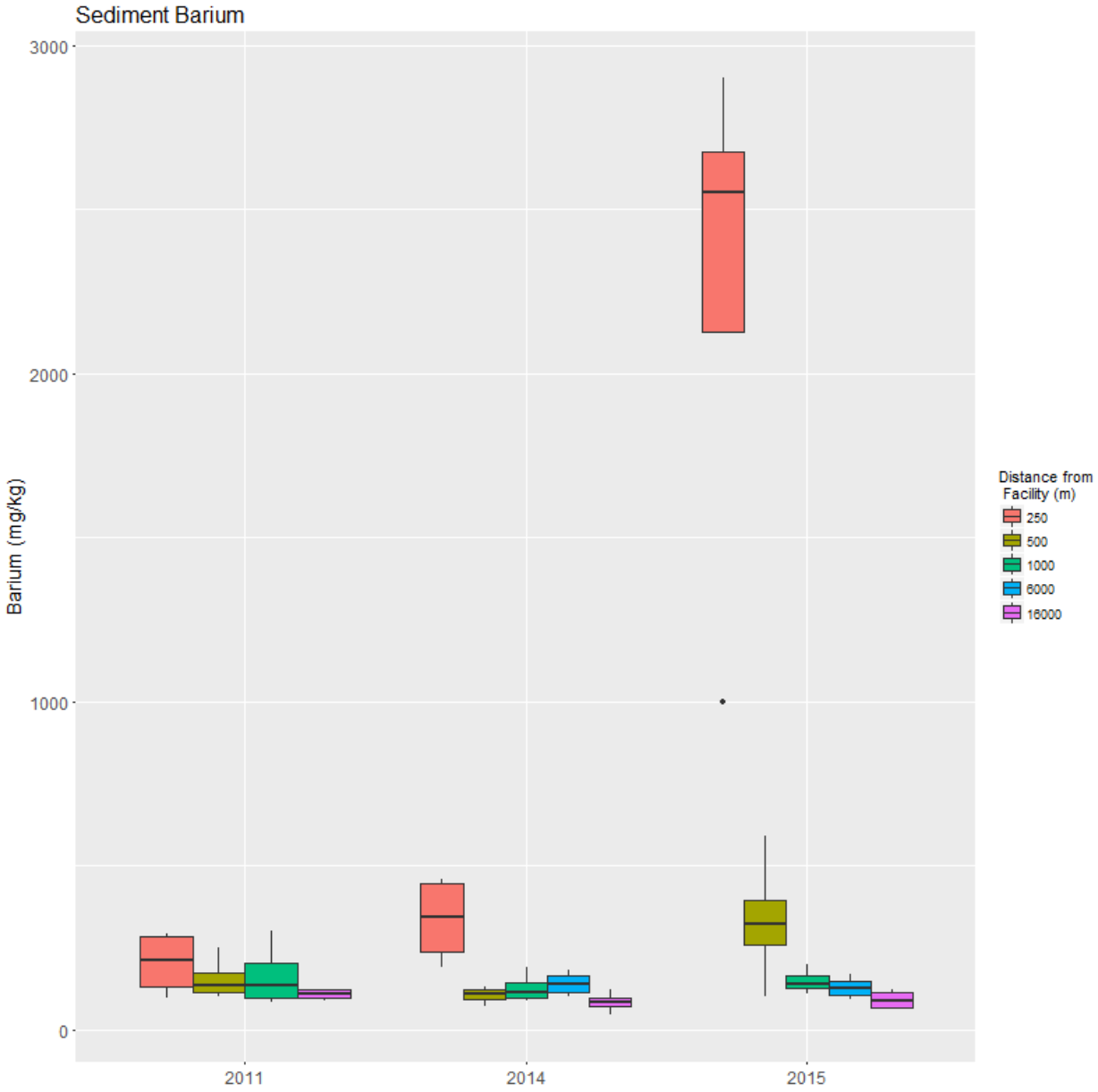


Figure 5.14 Boxplots of barium (mg/kg) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

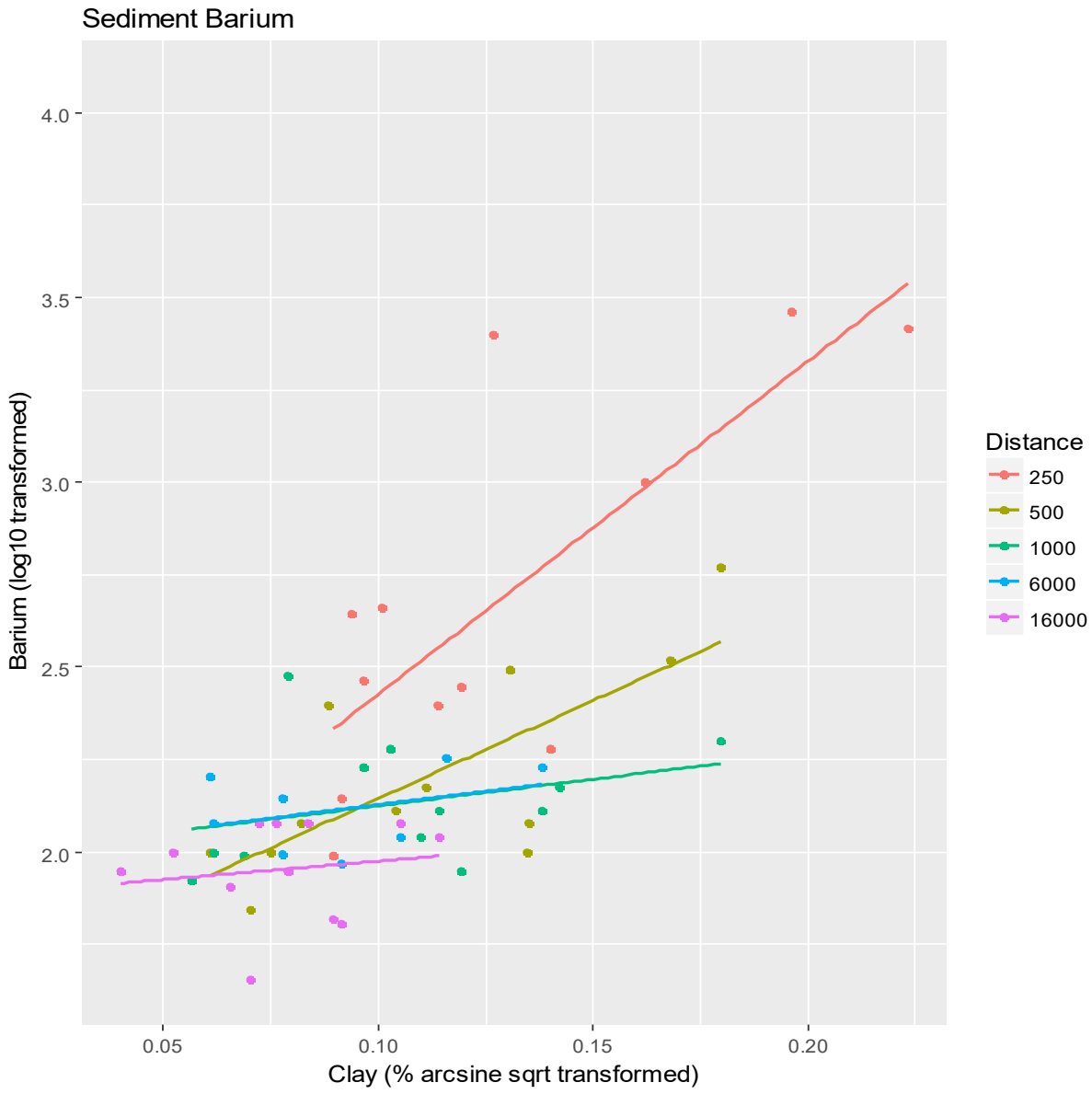


Figure 5.15 Covariate regression of barium concentration (log_{10}-transformed) against clay percentage (arcsine square-root transformed) in sediment by Distance at HSE and Reference Areas.

5.14 Weak Acid Extractable Barium

The concentration of weak acid extractable barium was significantly correlated with clay, therefore ANCOVA was used for analyses with clay as a covariate (Table 5.6). The assumption of homogeneity of slope was met (Field x Covariate interaction (clay) P=0.392; Table 5.14; Figure 5.16) and therefore ANCOVA was considered the appropriate analysis. However, the Year x Field interaction term was highly significant for Whole-field as was the Year X Distance interaction term for the Near-field analyses, indicating observed increases in weak acid extractable barium are likely a Project-related effect. Consistent with barium, concentrations of weak acid extractable barium were significantly different in the Near-field between the 2015 EEM and baseline as well

as between 2015 and the 2014 EEM surveys (Tukey post-hoc test; P<0.001) (Figure 5.17). Moreover, the Distance term was significant between 250 m stations and both 500 m and 1,000 m (Tukey post-hoc test; P<0.001) and as well as between 500 m and 1,000 m stations (Tukey post-hoc test; P=0.003). Overall, as with total barium there is distinct accumulation of barium in fine sediment fractions most notably around the 250 m stations since the 2011 baseline survey, in addition to stations at 500 m and 1,000 m (Figures 4.16, 5.17).

Table 5.14 Two-factor ANCOVA Table for weak-acid extractable barium and clay (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.989	0.989	40.4	<0.001*
Field	1	0.412	0.412	16.8	<0.001*
Year X Field	1	0.237	0.237	9.69	0.004*
Field X Clay	1	0.019	0.019	0.757	0.392
Residuals	26	0.636	0.025		
Near-field (2011-2015)					
Year	2	1.81	0.907	271	<0.001*
Distance	2	0.288	0.144	43.0	<0.001*
Year X Distance	4	0.373	0.093	27.9	<0.001*
Distance X square root (covariate/100)	2	0.001	0.0003	0.097	0.908
Residuals	24	0.080	0.003		
*Denotes significant result (P<0.05)					

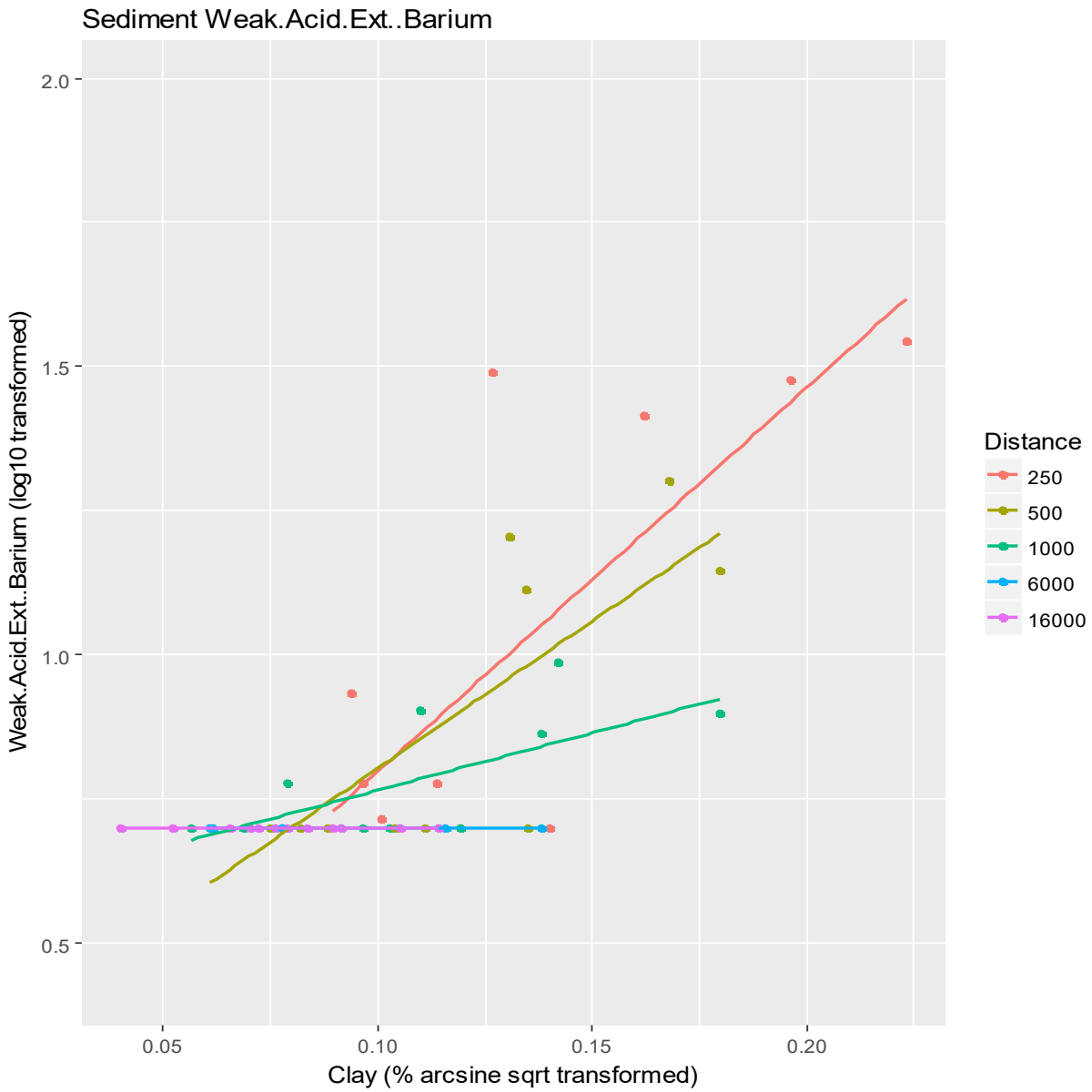


Figure 5.16 Covariate regression of weak acid extractable barium concentration (log_{10}-transformed) against clay percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas.

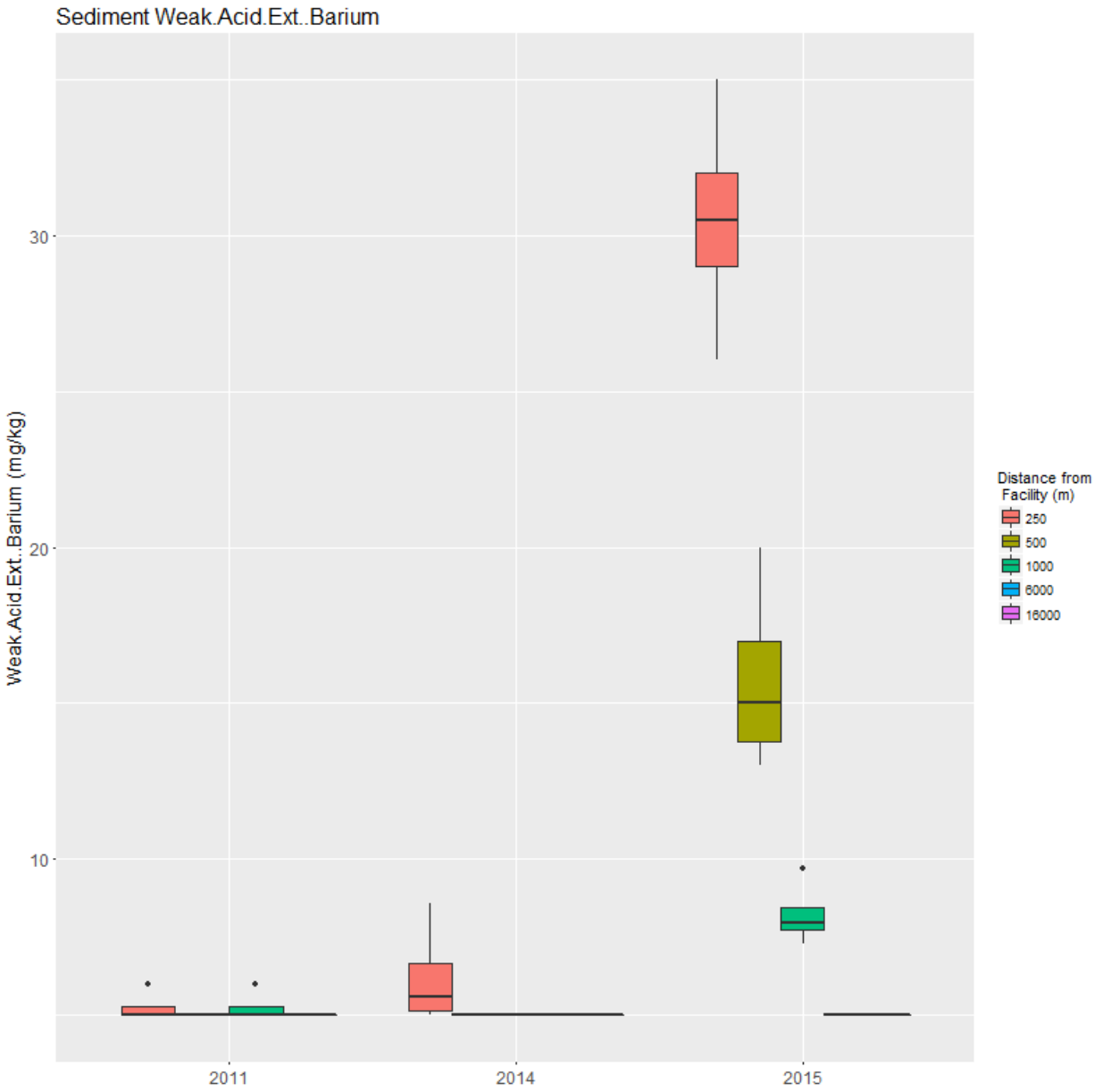


Figure 5.17 Boxplots of weak acid extractable barium (mg/kg) in sediment by Distance and Year at HSE samples.
Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.15 Analyses of organic and biological analytes in sediment

5.15.1 Fuel range hydrocarbons (>C_{10}-C_{21})

The concentration of fuel range hydrocarbons (>C_{10}-C_{21}) was positively correlated to silt and clay, therefore ANCOVA was selected for analyses with clay as a covariate as it was most strongly correlated with the concentration of fuel range hydrocarbons (Table 5.6). The non-significant Field x Clay interaction term for both Whole-field and Near-field (P=0.395 and 0.511, respectively; Table 5.15) indicated that the ANCOVA model was suitable. In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.358; Table 5.15) and therefore did not provide evidence of a Project-related effect. The concentration of fuel range hydrocarbons did vary significantly by Field (P<0.001) but not by Year (P=0.263). However, consistent with barium, and weak acid extractable barium, the Year x Distance interaction term was significant in the Near-field (P=0.039; Table 5.15) indicating a Project-related effect was likely (Figure 5.17). Overall, the patterns of significant differences of fuel range hydrocarbon accumulations are consistent with those of barium analytes; there is localized accumulation of >C_{10}-C_{21} hydrocarbons in proximity to the HSE EDC at 250 m stations as well as 500 m stations to a lesser extent (with similar slopes for these distances) and median values at 1,000 m stations are statistically indistinguishable between years (Figures 4.17, 5.18).

Table 5.15 Two-factor ANCOVA Table for fuel range hydrocarbons (>C_{10}-C_{21}) and clay (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	3.89	3.89	7.79	0.009*
Field	1	13.27	13.27	26.591	<0.001*
Year X Field	1	0.65	0.65	1.31	0.263
Field X Clay	1	0.437	0.437	0.88	0.358
Residuals	26	12.97	0.499		
Near-field (2011-2015)					
Year	2	14.45	7.225	42.28	<0.001*
Distance	2	8.596	4.3	25.15	<0.001*
Year X Distance	4	4.45	1.136	6.64	0.039*
Distance X Clay	2	0.268	0.134	0.78	0.468
Residuals	24	4.1	0.17		
*Denotes significant result (P<0.05)					

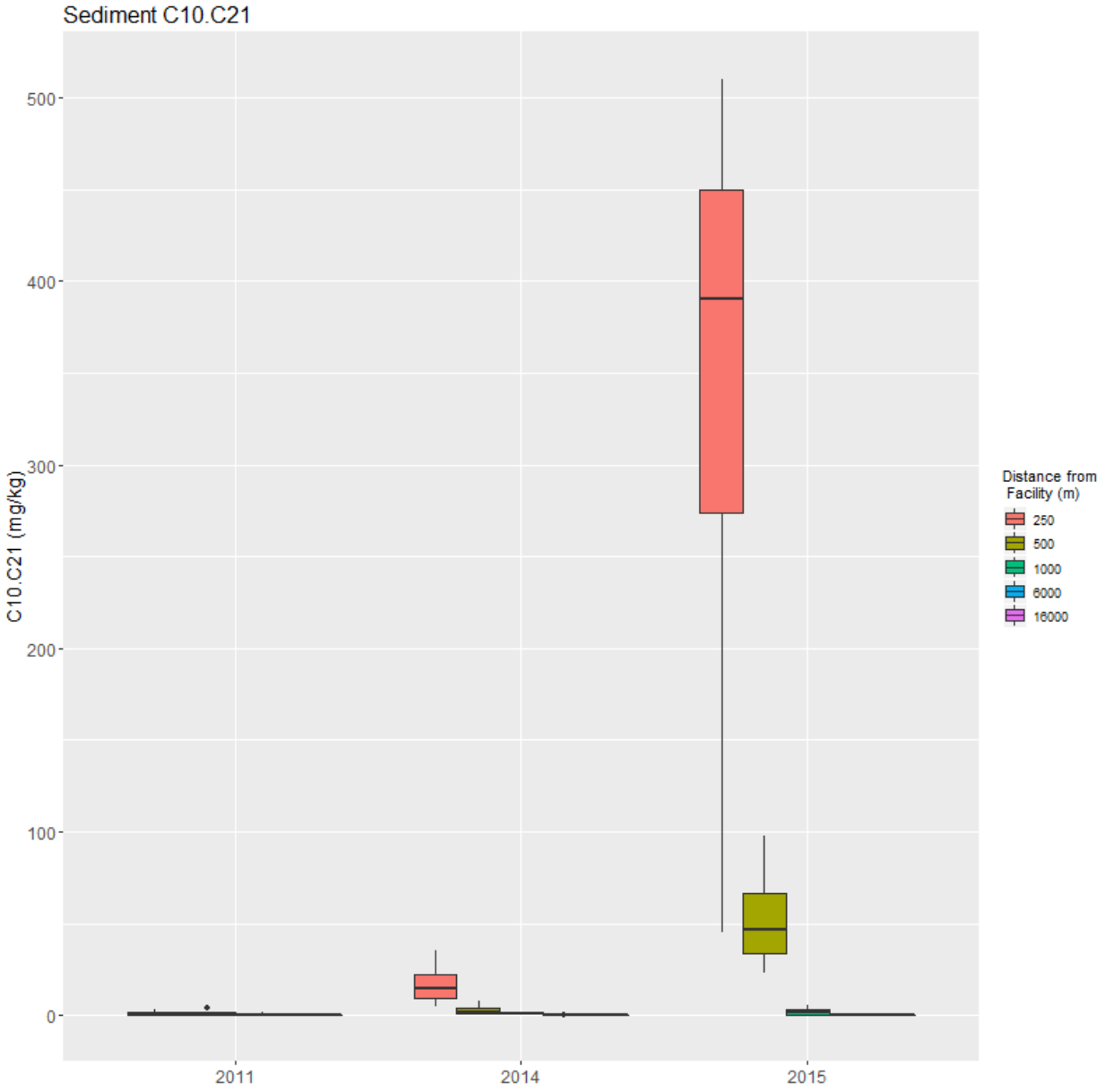


Figure 5.18 Boxplots of fuel range hydrocarbons (>C_{10}-C_{21}) (mg/kg) in sediment by Distance and Year at HSE samples.
Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

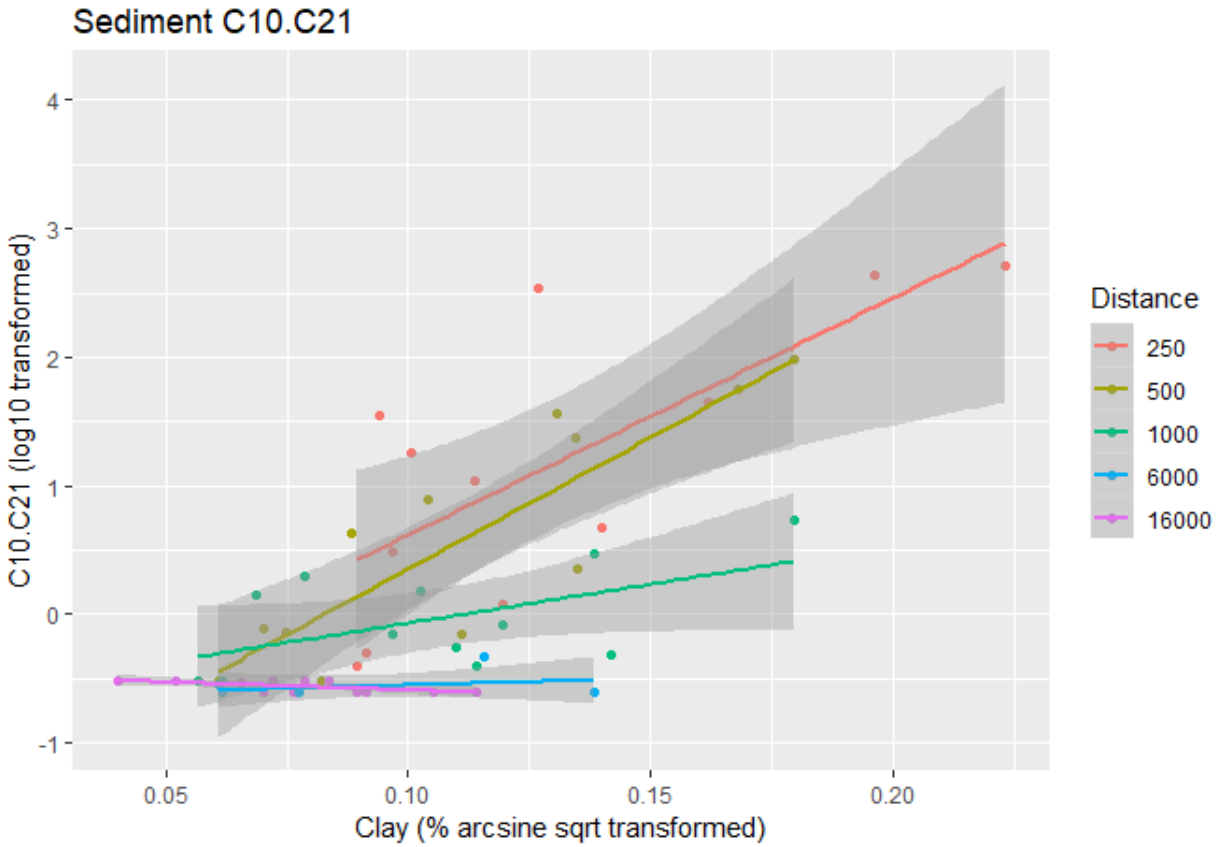


Figure 5.19 Covariate regression of fuel range hydrocarbon (>C_{10}-C_{21}) (log_{10}-transformed) against clay percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas.

5.15.2 Lube range hydrocarbons (>C_{21}-C_{32})

The concentration of lube range hydrocarbons (>C_{21}-C_{32}) was positively correlated to silt (Table 5.6) and ANCOVA was attempted for analyses. However the assumption of equality of slopes using a Field x Silt interaction term for the Whole-field was found to be significant (P=0.042; Table 5.16) therefore ANCOVA was not appropriate for this analyses and a 2X2 ANOVA was used instead for Whole-field analysis (Table 5.17). Using ANOVA, the Year x Field interaction term was not significant (P=0.437; Table 5.17) and therefore did not provide evidence of a Project-related effect. The concentration of lube range hydrocarbons did vary significantly by Field (P<0.012) but not by Year (P=0.924).

In the Near-field, the assumption of homogeneity of slope was met (Distance x Clay interaction term was not significant: P=0.998; Table 5.16) and therefore ANCOVA was considered the appropriate analysis (Table 5.16). The Year x Distance interaction term was also not significant (P=0.800; Table 5.17) and therefore also provides no evidence of a Project-related effect. The Year term was also not significant (P=0.849; Table 5.16); however, the Distance term was found to be significant (P=0.030; Table 5.16). Although concentrations of >C_{21}-C_{32} at 250 m stations were greater than those at 500 and 1,000 m stations in 2015 (Figure 4.18), the difference was not significant (Tukey HSD; P>0.05) (Figure 5.19). Overall, even though there are no statistically

significant Project-related effects, graphical examination suggests that concentrations may be increasing in proximity to the EDC since 2011 baseline (Figure 5.19).

Table 5.16 Two-factor ANCOVA Table for lube range hydrocarbons (>C_{21}-C_{32}) and silt (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.001	0.001	0.020	-
Field	1	0.642	0.642	15.4	-
Year X Field	1	0.009	0.009	0.210	-
Field X Silt	1	0.192	0.192	4.59	0.042*
Residuals	26	1.08	0.042		
Near-field (2011-2015)					
Year	2	0.020	0.010	0.165	0.849
Distance	2	0.503	0.251	4.06	0.030*
Year X Distance	4	0.101	0.025	0.409	0.800
Distance X Silt	2	0.0002	0.0001	0.002	0.998
Residuals	24	1.49	0.062		
*Denotes significant result (P<0.05)					

Table 5.17 Two-factor ANOVA Table for lube range hydrocarbons (>C_{21}-C_{32}) (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.001	0.001	0.009	0.924
Field	1	0.642	0.642	7.25	0.012*
Year X Field	1	0.055	0.055	0.623	0.437
Residuals	28	2.48	0.089		
*Denotes significant result (P<0.05)					

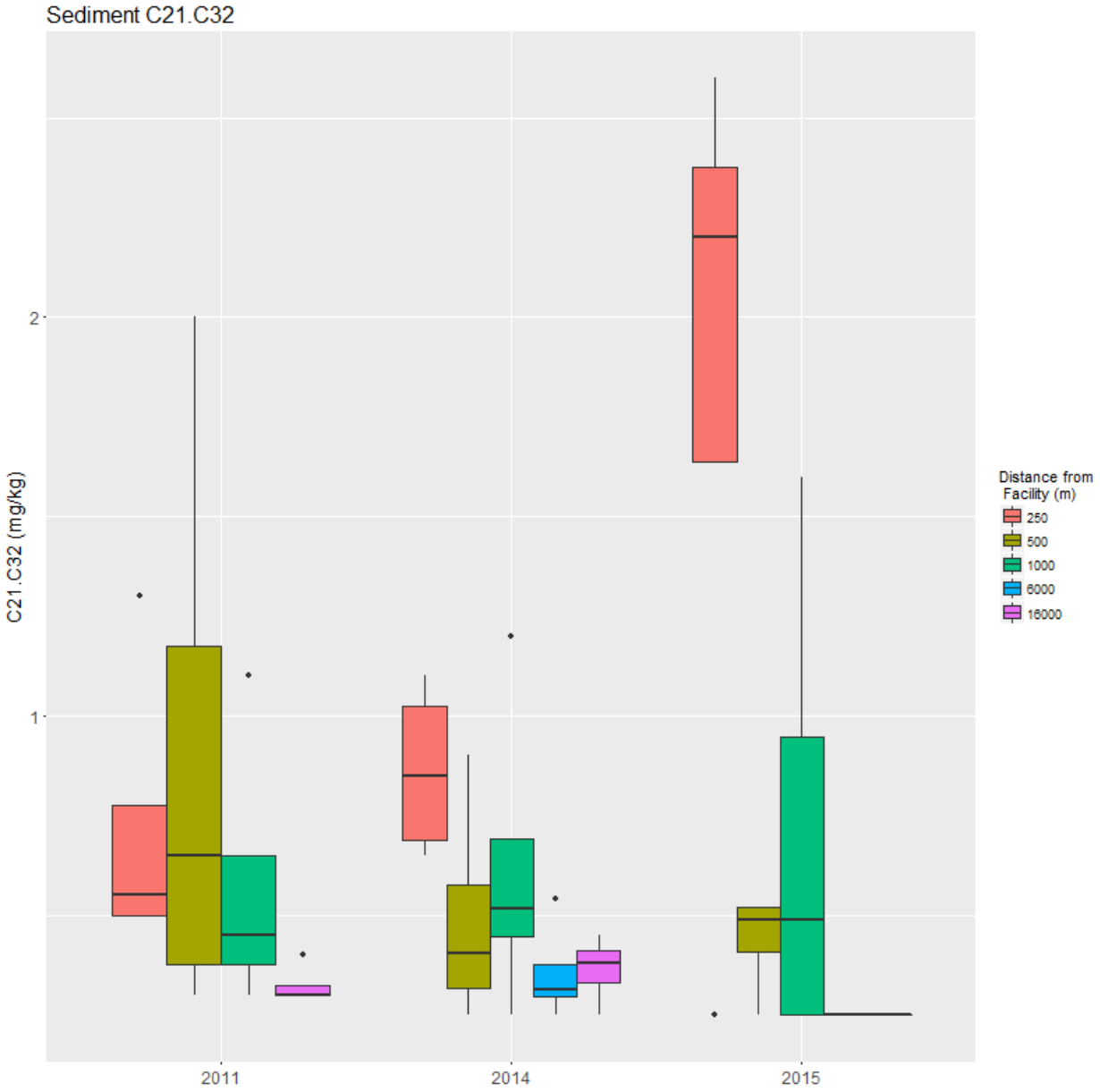


Figure 5.20 Boxplots of lube range hydrocarbons (>C_{21}-C_{32}) (mg/kg) in sediment by Distance and Year at HSE samples.
Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.16 Total Organic Carbon (TOC)

The concentration of organic carbon (TOC) was positively correlated to clay and gravel, and ANCOVA was selected for analyses with clay as a covariate as it is the fine sediment type in greater proportion in proximity to the EDC (Table 5.6) (Figure 5.3). The Field x Clay interaction term within the Whole-field as well as the Distance x Clay interaction term within the Near-field were both not significant therefore the ANCOVA model was deemed appropriate for analysis (P=0.199 and 0.146, respectively; Table 5.18; Figure 5.20). In the Whole-field analysis, the Year

x Field interaction was not significant (P=0.0195; Table 5.18) and therefore did not provide evidence of a Project-related effect. The concentration of organic carbon did vary significantly by Field (P<0.001) and by Year (P=0.014).

In the Near-field, the Year x Distance interaction term was also not significant (P=0.856; Table 5.18) and therefore did not provide evidence of a Project-related effect. The concentration of organic carbon did not vary significantly by Distance (P=0.123; Table 5.18), but did vary significantly by Year (P=0.042; Table 5.18). There were no significant differences between distances among years (Tukey post-hoc test; P>0.05) in the Near-field (Figures 5.20, 5.21). Overall, although the concentration of organic carbon varies between years, it does not appear to be in association with Project activities (Figures 4.19, 5.20).

Table 5.18 Two-factor ANCOVA Table for organic carbon and clay (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.773	0.773	6.87	0.014*
Field	1	2.32	2.32	20.6	<0.001
Year X Field	1	0.199	0.199	1.77	0.195
Field X Clay	1	0.196	0.196	1.74	0.199
Residuals	26	2.93	0.113		
Near-field (2011-2015)					
Year	2	1.02	0.512	3.62	0.042*
Distance	2	0.646	0.323	2.29	0.123
Year X Distance	4	0.186	0.047	0.329	0.856
Distance X Clay	2	0.590	0.295	2.09	0.146
Residuals	24	3.39	0.141		
*Denotes significant result (P<0.05)					

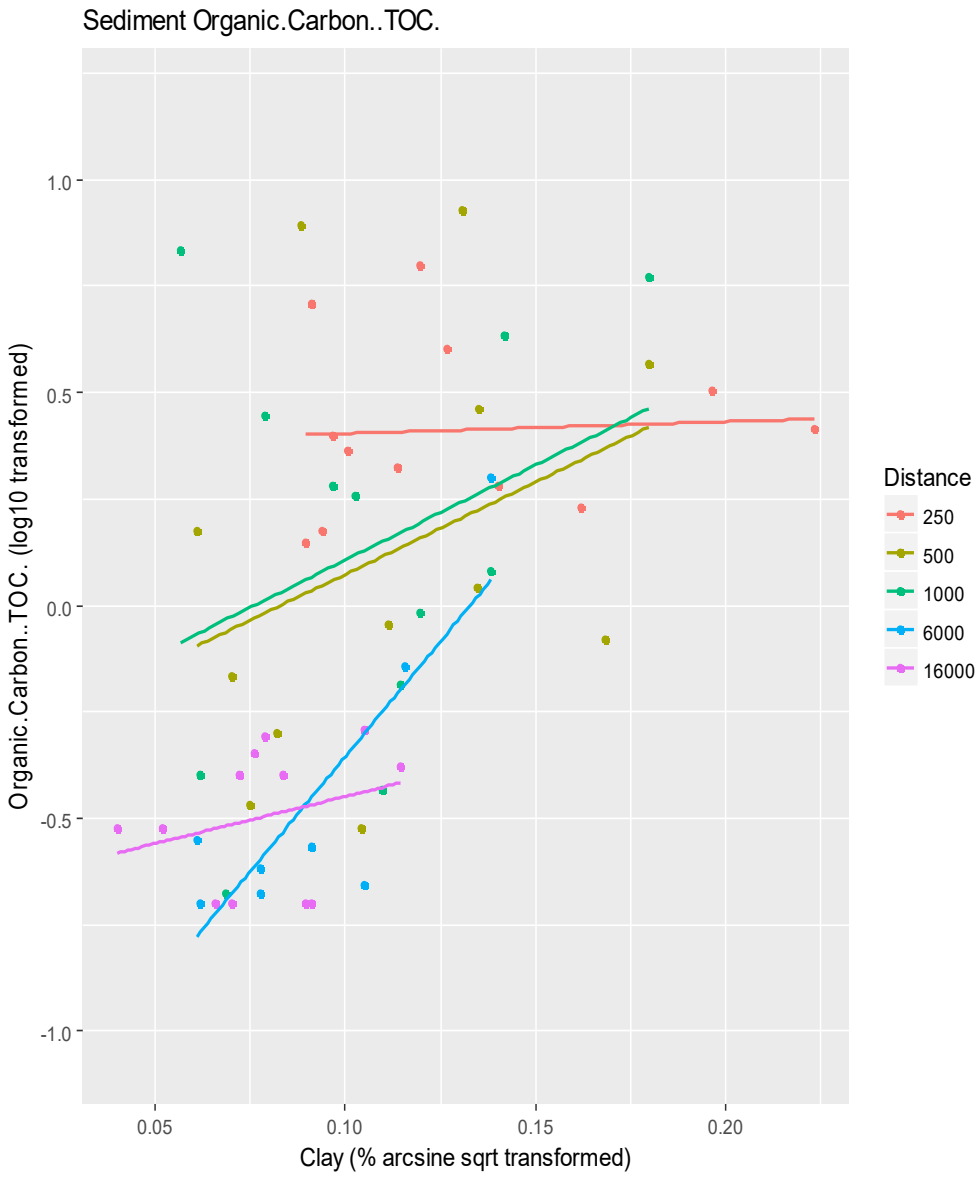


Figure 5.21 Covariate regression of organic carbon (TOC) (log_{10}-transformed) against clay percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas.

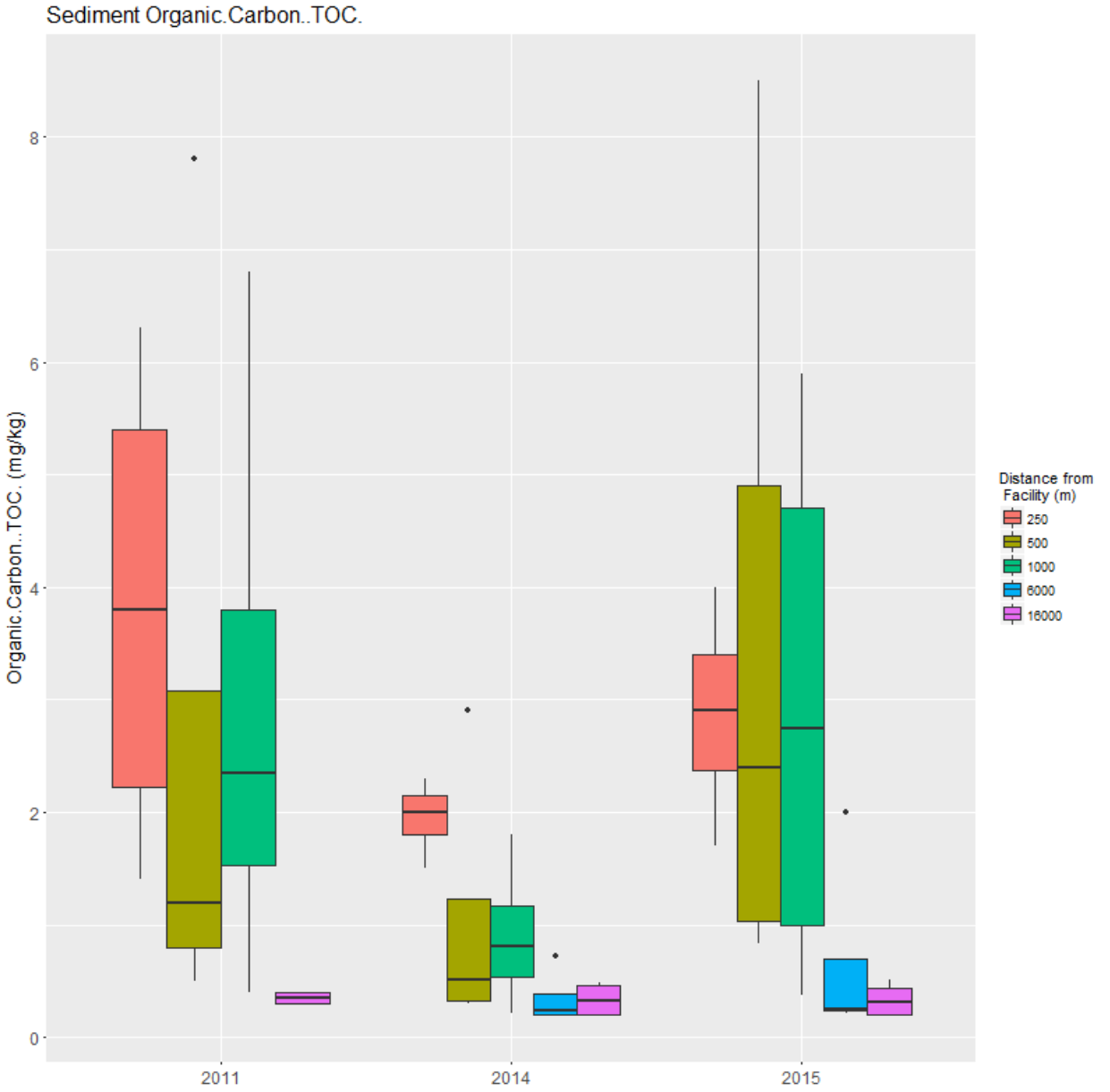


Figure 5.22 Organic Carbon (TOC) Boxplots of organic carbon (TOC) (mg/kg) in sediment by Distance and Year at HSE samples.
Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.17 Ammonia-N

The concentration of ammonia-N was correlated to gravel (Table 5.6) and ANCOVA was selected for analyses for both the Whole-field and Near-field. The Field x Gravel interaction term (Whole-field) and Distance x Gravel interaction term (Near-field) were not significant (P=0.183 and 0.830, respectively; Table 5.19; Figure 5.22) and the ANCOVA model was deemed appropriate for analyses. In the Whole-field analysis, the Year x Field interaction term was not significant (P=0.488, 0.113; Table 5.19) therefore evidence of a Project-related effect was not supported.

The Field term was significant (P=0.008; Table 5.19) with Far-field stations appearing to have consistently lower median concentrations of ammonia-N compared to the Near-field values (Figure 5.23). The Year term was not found to be significant (P=0.113; Table 5.19).

For the Near-field analysis, the Year x Distance interaction term was not found to be significant (P=0.896; Table 5.19), also providing no evidence of a Project-related effect. Additionally, the Year and Distance terms were also not significant (P=0.328 and 0.069, respectively). Overall, there has been no significant change in ammonia-N concentrations at all distances monitored since the 2011 baseline study (Figures 4.20, 5.23).

Table 5.19 Two-factor ANCOVA Table for ammonia-N and gravel (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.260	0.290	2.68	0.113
Field	1	0.880	0.880	8.15	0.008*
Year X Field	1	0.053	0.053	0.495	0.488
Field X Gravel	1	0.202	0.202	1.87	0.183
Residuals	26	2.81	0.108		
Near-field (2011-2015)					
Year	2	0.269	0.134	1.17	0.328
Distance	2	0.689	0.345	3.00	0.069
Year X Distance	4	0.123	0.031	0.267	0.896
Distance X Gravel	2	0.043	0.022	0.188	0.830
Residuals	24	2.76	0.115		
*Denotes significant result (P<0.05)					

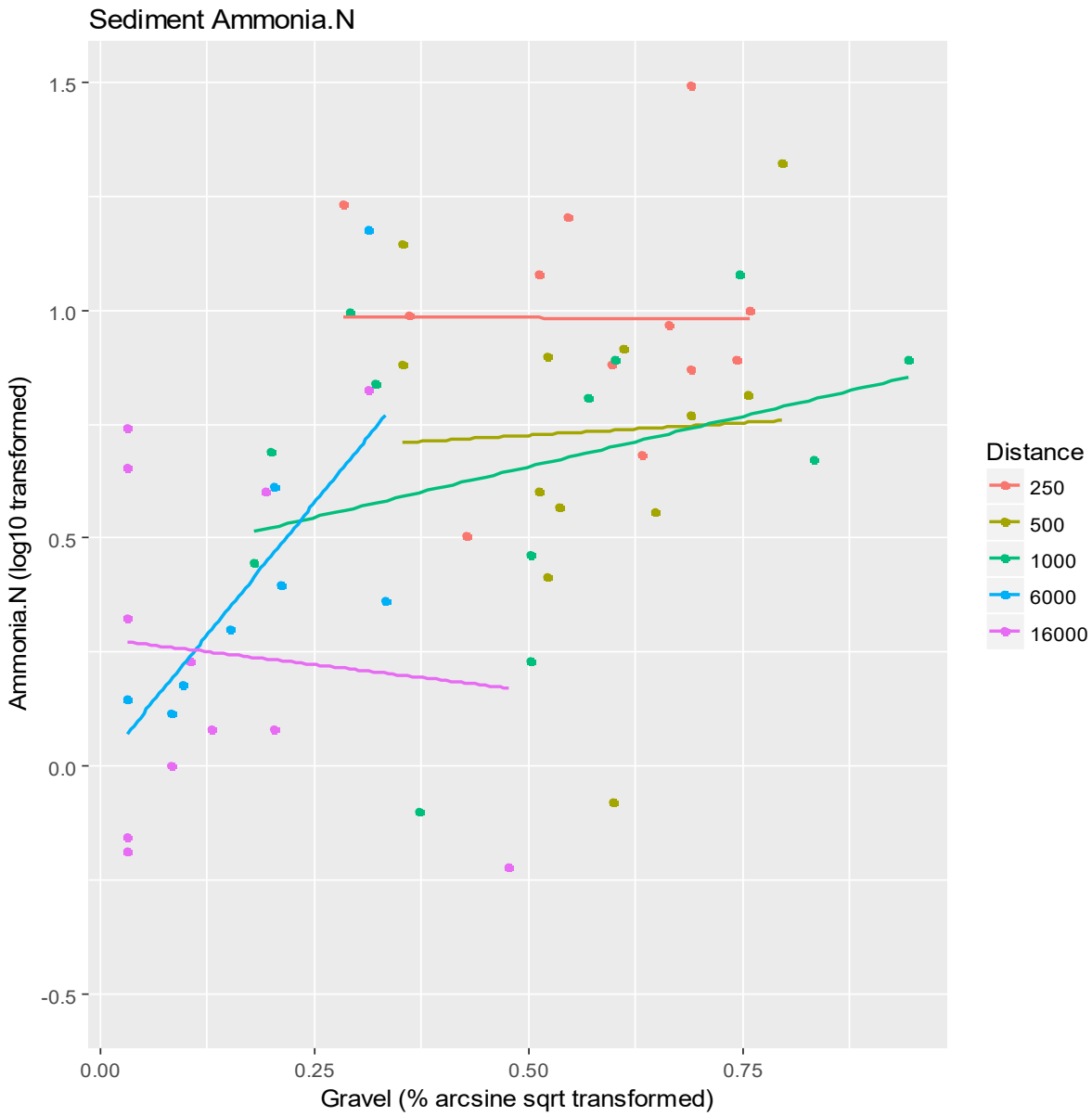


Figure 5.23 Covariate regression of ammonia-N (log_{10}-transformed) against gravel percentage (arcsine square-root transformed) in sediment by Distance (m) at HSE and Reference Areas.

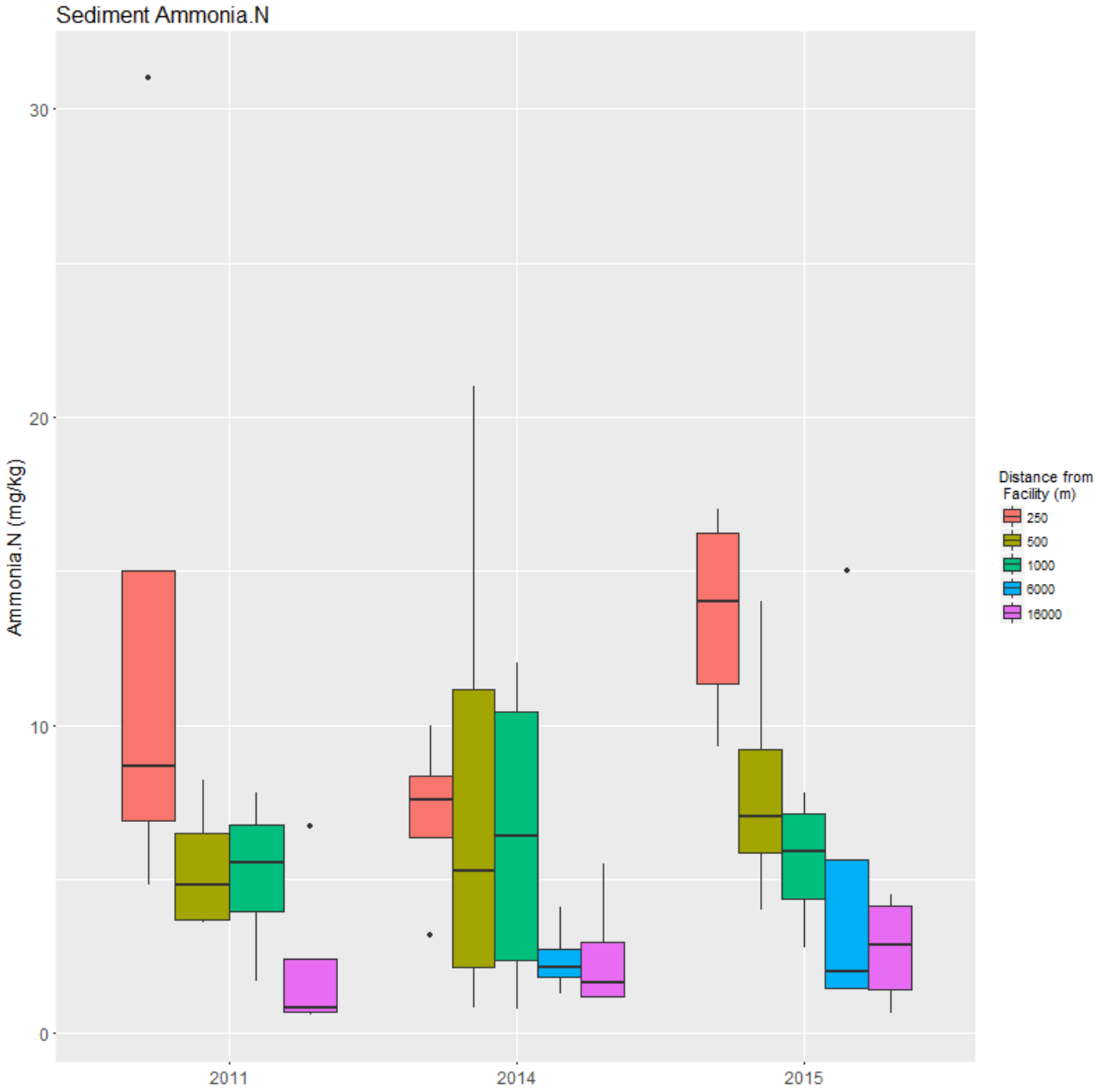


Figure 5.24 Boxplots of ammonia-N (mg/kg) in sediment by Distance and Year at HSE samples. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

5.18 Sulphide

The concentration of sulphide was not significantly correlated (r>0.05) to any sediment particle size (Table 5.6), therefore ANOVA was selected for analyses. In the Whole-field analysis, the Year X Field interaction term was not significant (P=0.080; Table 5.20) therefore there is no evidence of a Project-related effect. However, sulphide varies significantly by Year (P=0.030) and Field (P=0.033).

In the Near-field, the Year x Distance interaction term was also not significant (P=0.294; Table 5.20) and therefore providing no evidence of a Project-related effect. In addition, the Year and Distance terms were also not significant (P=0.086 and 0.434, respectively; Table 5.20; Figure 5.24). Overall, there has been no significant change in sulphide concentrations monitored around HSE since the 2011 baseline study (Figures 4.21, 5.24).

Table 5.20 Two-factor ANOVA Table for sulphide (square-root arc sine transformed)

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	1	0.125	0.125	5.24	0.030*
Field	1	0.121	0.120	5.05	0.033*
Year X Field	1	0.079	0.079	3.30	0.080
Residuals	28	0.669	0.024		
Near-field (2011-2015)					
Year	2	0.325	0.163	2.69	0.086
Distance	2	0.104	0.052	0.861	0.434
Year X Distance	4	0.315	0.079	1.30	0.294
Residuals	27	1.63	0.060		
*Denotes significant result (P<0.05)					

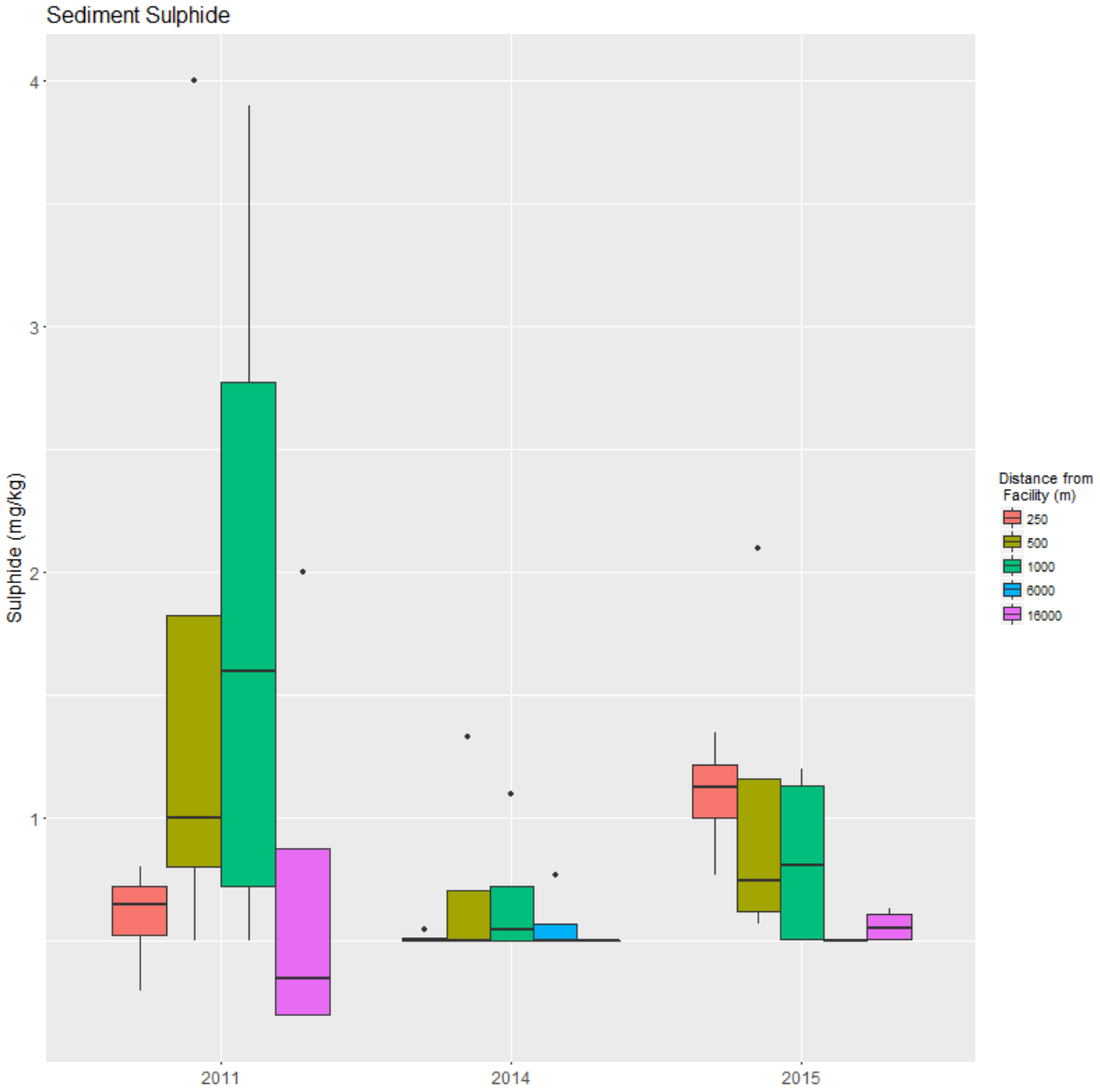


Figure 5.25 Boxplots of sulphide concentration (mg/kg) in sediment by Distance and Year at HSE samples.
Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points. Note the RDL for sulphide was lower in 2011 compared to subsequent years.

5.19 Summary of statistically significant univariate distance effects at HSE

The analytes iron, vanadium, barium, fuel and lube range hydrocarbons (>C_{10}-C_{21} and >C_{21}-C_{32} respectively) were all positively correlated with silt. Similarly, barium, weak-acid extractable barium, fuel range hydrocarbons (>C_{10}-C_{21}) and organic carbon were positively correlated with clay (Table 5.6). The increases in the Near-field are largely centralized around the 250 m stations surrounding the EDC and significant increases were observed for aluminum, iron, manganese,

vanadium, barium, weak acid extractable barium and both fuel and lube range hydrocarbon analytes. Among these, weak acid extractable barium was the only analyte to have a significant project-related effect when examined at the Whole-field level. Barium, weak acid leachable barium and fuel range hydrocarbons indicated a project-related effect in the Near-field (Table 5.21). However, these analytes are all associated with drill cuttings deposition (DeBlois, Paine, et al., 2014; Pozebon et al., 2005; Trefry et al., 2013).

Table 5.21 Summary of Statistically significant distance effects for sediment variation at HSE.

Analyte	Whole-field (2014-2015) 250, 500, 1,000, 6,000, 16,000 m stations			Near-field (2011, 2014, 2015) ≤1,000 m stations		
	Year X Field	Year	Field	Year X Distance	Year	Distance
Silt						
Clay						
Sand						
Gravel						
Aluminum						
Iron						
Manganese						
Strontium						
Uranium						
Vanadium						
Barium						
Weak acid extractable barium						
Fuel range (C_{10}-C_{21})						
Lube range (C_{21}-C_{32})						
Organic Carbon (TOC)						
Ammonia-N						
Sulphide						

Blue Shading denotes a significant effect was observed (P<0.05), grey shading denotes no statistically significant distance effect was observed.

5.20 Sediment Chemistry Multivariate Analysis

5.20.1 Methods

Multivariate visualization and statistical methods were also applied to HSE sediment chemistry to understand overarching trends and patterns of HSE sediment composition in relation to year and distance from the production facility. As with analyte-specific univariate analyses, analytes included for analysis were screened to exclude any that had more than 50% of 2015 values below RDL. The resulting list included all four sediment types (silt, clay, gravel and sand) and thirteen chemical variables (ammonia, aluminum, barium, weak acid extractable barium, chromium, iron, lead, manganese, strontium, sulphide, uranium, vanadium, total organic carbon, $>C_{10}$-C_{21} and $>C_{21}$-C_{32}). Chemical variables were log-transformed, and all variables were normalized to provide equal weight in the subsequent analyses.

The basis of the multivariate approach is to determine the similarity of sediment characteristics across samples. Similarity was defined for each possible pair of samples using Euclidean distance and the resulting matrix was used for non-parametric Multi-Dimensional Scaling (nMDS) visualizations and for hypothesis testing using PERMANOVA; a permutation-based multivariate analog of ANOVA (Anderson 2001). Non-Dimensional Scaling (nMDS) uses an algorithm to place each sample in 2D space in a way that best maintains the relative similarity distances (specifically, the ranks of distances) to all other points in the analysis. To further simplify visualization of patterns, centroids (representations of multivariate central tendency) of distance-year groupings were derived from Principal Coordinates Analysis (PCO) (Gower, 1966) and plotted using nMDS.

PERMANOVA analyses (PERMANOVA+1.0.3; 9,999 permutations) were done in a way to mirror univariate analyte-specific ANOVAs; specifically, the Euclidean Distance similarity values were modelled as a function of Distance (250 m, 500 m, 1,000 m, 6,000 m, 16,000 m) and Year (2011, 2014 and 2015) categories with the associated interaction (Distance x Year). Post-hoc pairwise tests were also conducted for resulting significant variables.

5.20.2 Results

The sediment chemistry nMDS plots of all sites (Figure 5.24) and centroids of Distance-Year categories (Figure 5.25) suggests that sediment characteristics in the 250 m distance category, and to a lesser extent 500 m, are shifting away from baseline and reference conditions. The shift also corresponds to increasing levels of most analytes (Figure 5.24). While the stress values (a measure of the adequacy of the 2D representation of the multivariate data) associated with Figure 5.24 (stress=0.12) suggests that some of the structure of the multivariate data is not well captured, the centroids depicted in Figure 5.25 maintain a similar pattern and this plot has stress levels (0.05) that represent an acceptable 2D representation. In addition to the more obvious distance class-specific shifts in time, there was a subtler shift that was apparent across years in all distance categories (Figures 5.24, 5.25).

The multivariate analysis of sediment characteristics showed a mildly significant interaction (P=0.034); supporting the accompanying nMDS plots that suggest that Project-related changes in the 250 m and 500 m distance category are occurring (Figures 5.24 and 5.25). For Distance, 250 m and 500 m and 6,000 m and 16,000 m (all P values $\leq$0.05) categories differed significantly

from each other in all years, but 250 m only differed from 1000 m after Project construction. Analyte assemblages from 500 m and 1,000 m were not significantly different in any year (P>0.312).

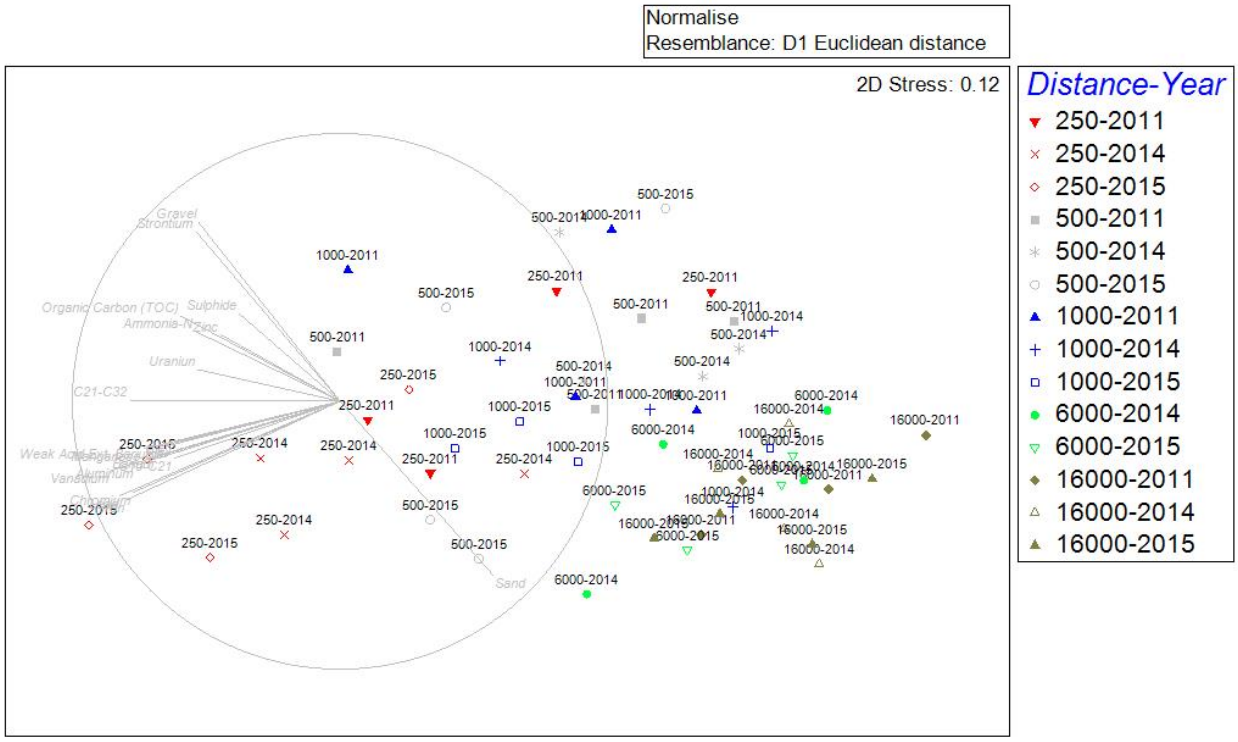


Figure 5.26 nMDS of HSE sediment chemistry across sample distances and years. Proximity of sample points reflects similarity in sediment/chemical composition. Pearson correlation vectors of analytes are superimposed to indicate correlations with the observed patterns.

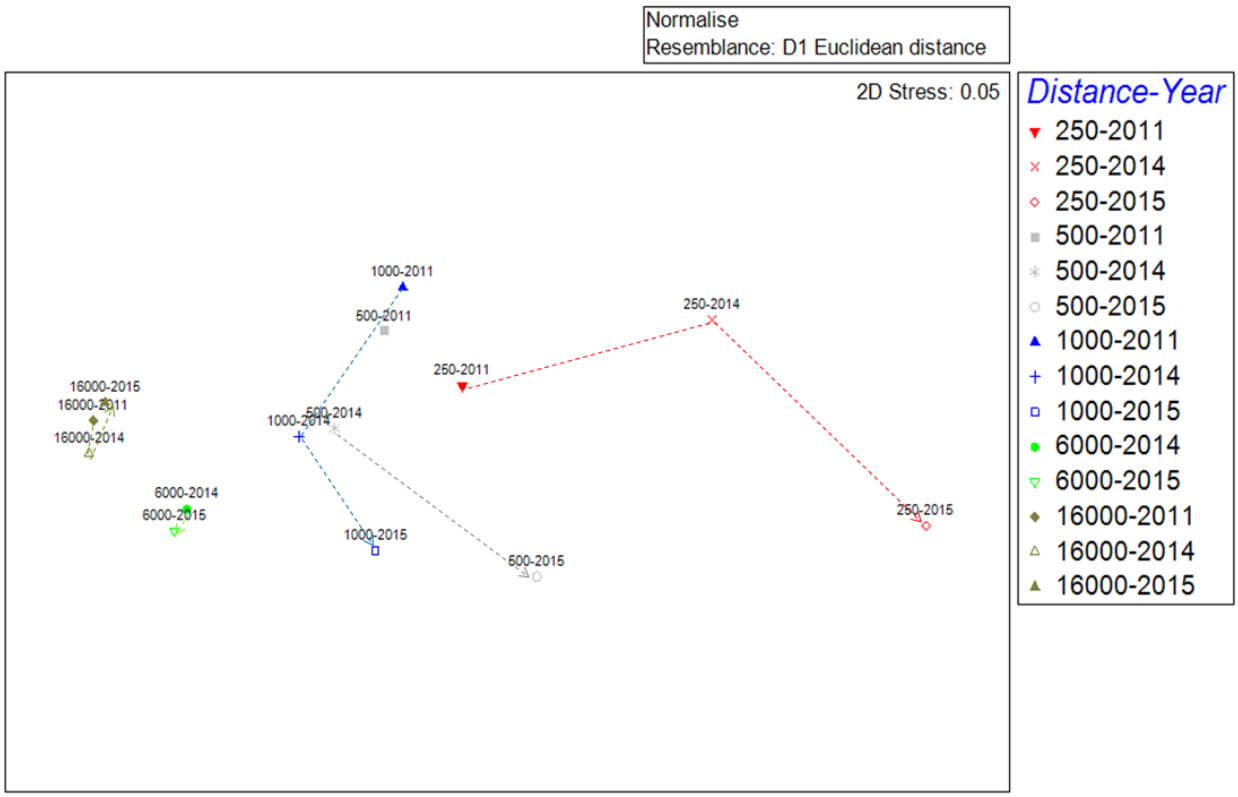


Figure 5.27 Simplified nMDS visualization of HSE sediment chemistry using centroids to represent distinct distance-year groupings.
Proximity of sample points reflects similarity in sediment/chemical composition among groupings, whereas lines indicate temporal shifts in sediment characteristics of a given distance class.

6.0 HSE 2015 SEDIMENT TOXICITY PROGRAM

Evaluation of water and/or sediment using standardized toxicity tests (e.g., bioassays) improve the capability of an EEM program to ascertain whether contaminants may be having an effect on living organisms (reviewed by Martinez-Haro et al., 2015). They are a series of monitoring tools intended to provide a sensitive (early-warning), rapid and cost-effective means to detect potential environmental risk to an ecosystem component (e.g., water and/or sediment) due to contaminants (reviewed by Martinez-Haro et al., 2015).

Three bioassays are performed as part of the EEM monitoring program:

1. A bacterial bioluminescent assay that measures the effects of contaminants in sample substrate on light production of the bioluminescent bacteria *Vibrio fischeri* (lower IC50s imply toxicity) (Microtox) (Whiteway et al., 2014);
2. Measurement of juvenile polychaete growth and survival when cultured in test sediment (PSEP, 1995); and
3. Measurement of cultured amphipod survival on test sediment (HMDC, 2013).

6.1 Sediment Toxicity Statistical Analysis

The analysis of sediment toxicity is conducted using several approaches. The initial interpretation of toxicity test results is evaluated as part of the laboratory analysis component according to the guidelines defined by Environment Canada to determine toxic vs. non-toxic responses (HMDC, 2013). Toxicity spatial data are presented using 2-D plots (as described in Chapter 4) in order to provide an indication of the general spatial trend in concentrations among years (e.g., 2011, 2014, and 2015). Bioassay values are represented as range bins with the high value stated in the legend and the low value of the range being the previous high value except in the case of the first range bin which is zero. In addition to this, statistical evaluation of the quantified results among years is conducted as outlined in the Hibernia Environmental Effects Monitoring Plan and the 2014 EEM Program (HMDC, 2013, 2015a) with the addition of multivariate analysis to examine multiple variables simultaneously. All laboratory reports are included in Volume II of this report.

6.1.1 HSE 2015 Microtox Data Exploration

The Microtox test is a sediment toxicity assay that measures the reduction of microbial luminescence of a marine bacterium (*Vibrio fischeri*) in a Microtox Solid-Phase Test (SPT) (Whiteway et al., 2014). The statistical endpoint of the test (toxic response) is the concentration of sample which is estimated to cause 50% inhibition of light production by the bacteria (i.e., the IC50) and is reported as mg/L (Environment Canada, 2002; Whiteway et al., 2014). All sampling stations undergo Microtox testing and those stations beyond 500 m from the EDC that pass the Microtox test do not require additional toxicity testing (polychaete growth and amphipod survival). A total of 20 Microtox tests were conducted on samples from 18 stations in 2015 including: twelve Near-field stations, four stations on the 6,000 m radius, and two samples from each of the Reference Areas 1-16000 and 7-16000 (Table 6.1).

Table 6.1 HSE 2015 Sediment Toxicity Test Data.

Station ID	Microtox (mg/L)	Amphipod Survival (%)	Juvenile Polychaete Survival (%)	Mean Juvenile Polychaete Dry Weight (mg/worm)	Mean Individual Growth Rate (mg/worm/day)
N-250	**5,533**	93.00	100.00	8.84	0.41
N-500	**5,637**	98.33	100.00	11.61	0.54
N-1000	**28,224**	91.67	100.00	11.89	0.56
E-250	**4,161**	93.33	100.00	18.20	0.87
E-500	**22,397**	94.00	100.00	9.63	0.44
E-1000	**9,364**	96.25	100.00	10.19	0.47
S-250	**9,445**	97.50	96.00	8.94	0.41***
S-500	**15,036**	98.00	100.00	13.25	0.63
S-1000	**28,080**	99.00	100.00	11.00	0.51
W-250	**15,270**	97.00	100.00	10.91	0.51
W-500	**40,864***	92.00	100.00	10.70	0.50
W-1000	>197,000	**	**	**	**
6000-1	**87,726***	97.00	100.00	12.44	0.59
6000-2	>197,000	98.00	100.00	13.49	0.64
6000-3	>197,000	98.00	100.00	15.90	0.76
6000-4	>197,000	99.00	100.00	12.46	0.59
1-16000a	>197,000	97.00	100.00	13.94	0.66
1-16000b	>197,000	98.00	100.00	11.58	0.54
7-16000a	>197,000	95.00	100.00	11.40	0.53
7-16000b	>197,000	98.75	100.00	14.24	0.68

Grey highlighted cells denote a toxic response (50% inhibition of light production by bacteria compared to reference sample) was observed according to guidelines outlined in Biological Test Method: Reference Method for Determining the Toxicity of a Sediment using Luminescent Bacteria in a Solid-Phase Test (EPS 1/RM/42 April 2002).
*Denotes stations that were non-toxic according to the >40,000 mg/L specified in the program design plan (HMDC, 2013).
**Amphipod survival and juvenile polychaete growth bioassays are not required on stations beyond 500 m that pass the Microtox assay (HMDC, 2013). 6,000 m stations were also assayed for Far-field reference.
*** Statistically significant difference in growth and weights, however does not meet criteria of 20% reduction in survival compared to the control stations 1 & 7-16,000a, b and therefore are non-toxic.

During the development of the Hibernia Platform EEM program, the threshold response of an IC50 toxicity value of >40,000 mg/L was identified as the threshold considered as a suitable or “pass” value with respect to Microtox sediment toxicity bioassays and this same standard is applied to the HSE EEM program (HMDC, 2013). However, samples with <20% recalculated fines and an EC50 toxicity test value > 1,000 mg/L (i.e., 50% inhibition of light production by the bacteria after five minutes of exposure is less than 1,000 mg/L (Topping, 1998)), toxicity is determined according to the guidelines outlined in Biological Test Method: Reference Method for Determining the Toxicity of a Sediment using Luminescent Bacteria in a Solid-Phase Test (EPS 1/RM/42 April

2002). This is a more conservative threshold and the results presented in Table 6.1 indicate both. Twelve of the sixteen HSE stations had a toxic response for Microtox, and with the exception of station 6000-1, all stations with a toxic response were within the HSE Near-field. However, with the threshold of >40,000 mg/L defined in the program design plan (HMDC, 2013), stations 6000-1 and W-500 were also considered non-toxic in 2015. Although in 2014 only four of the Near-field stations had a toxic response, there was no significant correlation (r>0.5) detected between the stations that were toxic nor any of the sediment chemistry analytes that were sampled or their configuration relative to the EDC. Spatially, the pattern of Microtox values detected at stations around HSE in 2015 appears very similar to what was observed during the baseline program in 2011 (Figures 6.1, 6.2).

6.2 Statistical Analyses of 2015 HSE Microtox Results

Microtox analyses were conducted as prescribed in the EEM Design Plan (HMDC, 2013). A 2x2 ANOVA was applied as a coarse-scale (Whole-field) assessment of Near-field (<1km from EDC) relative to Far-field (6,000 and 16,000 m) stations. There was a significant Year X Field interaction (P=0.046) suggestive of a coarse scale Project-related effect. Microtox IC50 median concentrations have consistently been higher (indicating greater survival) at Far-field stations relative to Near-field and this has been observed in all surveyed years including 2011 baseline (Figure 6.2). Fine-scale analysis within the Near-field indicates the Year X Field interaction is not significant (P=0.426) and provides evidence against Project-related effects for this measure. Near-field stations did vary significantly by Year (P<0.001) and Distance (P<0.001); however, examination of Figure 6.2 indicates that changes in the Near-field do not align with expectations of Project-related effects as Microtox IC50 values show greater survival (higher IC50 values) in the Near-field in EEM survey years compared to 2011 baseline values. Pearson correlation with HSE sediment chemistry data indicated there were no significant correlations (r>0.5) between Microtox values and any sediment chemistry analytes.

Table 6.2 Single-factor ANOVA Table for Microtox IC50 (square root arc sine transformed) in HSE sediment.

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	2	4.21	2.110	10.60	<0.001*
Field	1	11.40	11.400	57.30	<0.001*
Year X Field	2	1.30	0.649	3.270	0.046*
Residuals	50	9.92	0.198		
Near-field (2011-2015)					
Year	2	4.21	2.110	10.80	<0.001*
Distance	4	13.0	3.240	16.60	<0.001*
Year X Distance	7	1.41	0.201	1.030	0.426
Residuals	42	8.21	0.195		
*Denotes significant result (P<0.05)					

Figure 6.1 Two dimensional spatial and temporal pattern of Microtox IC50 values (mg/L) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

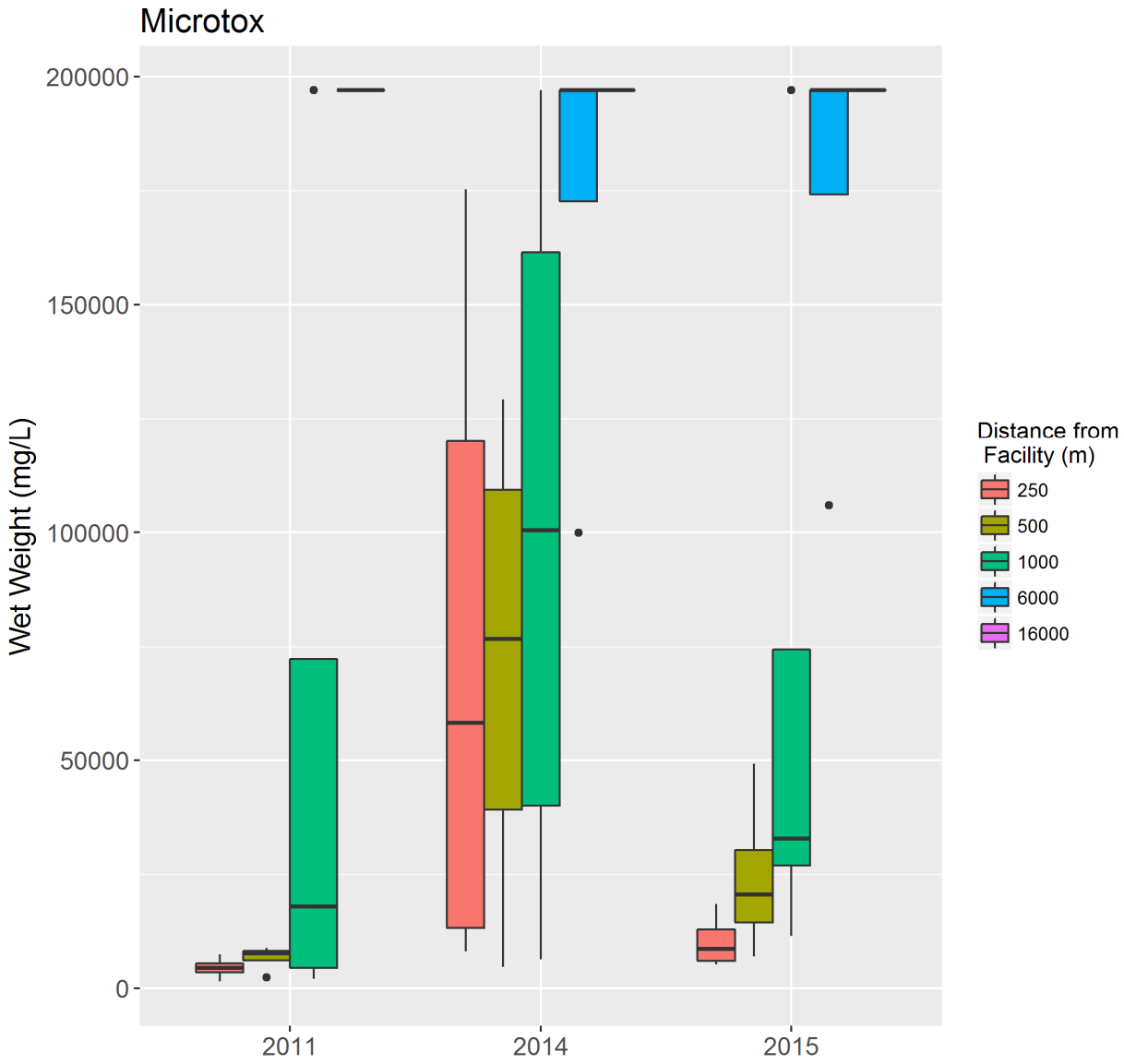


Figure 6.2 Boxplots of Microtox IC50 values in sediment by Distance and Year at HSE. Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

6.2.1 HSE 2015 Juvenile Polychaete Growth Data Exploration

The juvenile polychaete growth test is an assay to evaluate the effect of a sediment sample on the growth and survival of juvenile polychaetes. As described in the Hibernia EEM Design Plan (HMDC, 2013), this test is performed by culturing juvenile polychaetes (*Neanthes areneceodentata*) on sediment collected from each sampling station. Five, three-week old juvenile individuals are co-cultured in replicates of five sampling containers for each sediment station sample. The organisms are fed and water in each replicate container is changed at regular

intervals during the 20 day cultivation period (HMDC, 2013). The number of survivors and weight of the juvenile polychaetes is measured at the end of the assay period and statistically (t-test) compared to the response rates observed in Reference Area samples to determine toxic versus non-toxic responses (HMDC, 2013). With the exception of station W-1000 (which had a non-toxic Microtox response), the juvenile polychaete growth assay was conducted on all Near-field stations and all 6,000 m and 16,000 m Reference Area stations.

In total, nineteen (19) stations were assayed and based on polychaete results, all were considered non-toxic, and with one exception (station S-250 with 96% survival), all had 100% survival. The survival rates of the 2015 EEM program exceeded those of the 2011 baseline (Figures 6.3, 6.4).

6.3 Statistical Analyses of 2015 HSE Juvenile Polychaete Growth Results

For examination of the juvenile polychaete data between years and distances, a 2x2 ANOVA was applied as a coarse-scale (Whole-field) assessment of Near-field relative to Far-field stations. There was a significant Year X Field interaction ($P=0.027$) suggestive of a coarse scale Project-related effect. Survival rates of juvenile polychaetes have been consistently increasing in the Near-field since baseline and have remained consistently high at Far-field stations (Figure 6.4). Fine-scale analysis within the Near-field indicates the Year X Distance interaction is not significant ($P=0.060$) and provides evidence against Project-related effects for this measure. Near-field stations did vary significantly by Year ($P<0.001$) and Distance ($P=0.023$); however, examination of Figure 6.4 indicates that changes in the Near-field do not align with expectations of Project-related effects as the survival rate of juvenile polychaetes has been increasing across all Near-field stations since 2011 baseline. Pearson correlation with HSE sediment chemistry data indicated there were no significant correlations ($r>0.5$) between juvenile polychaete survival rates and any sediment chemistry analytes.

Table 6.3 Single-factor ANOVA Table for juvenile polychaete survival (square-root arc sine transformed) in HSE sediment.

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	2	0.582	0.291	13.60	<0.001*
Field	1	0.082	0.082	3.81	0.057
Year X Field	2	0.167	0.083	3.88	0.027*
Residuals	50	1.070	0.021		
Near-field (2011-2015)					
Year	2	0.582	0.291	15.30	<0.001*
Distance	4	0.240	0.060	3.16	0.023*
Year X Distance	7	0.285	0.041	2.14	0.060
Residuals	42	0.797	0.019		
*Denotes significant result (P<0.05)					

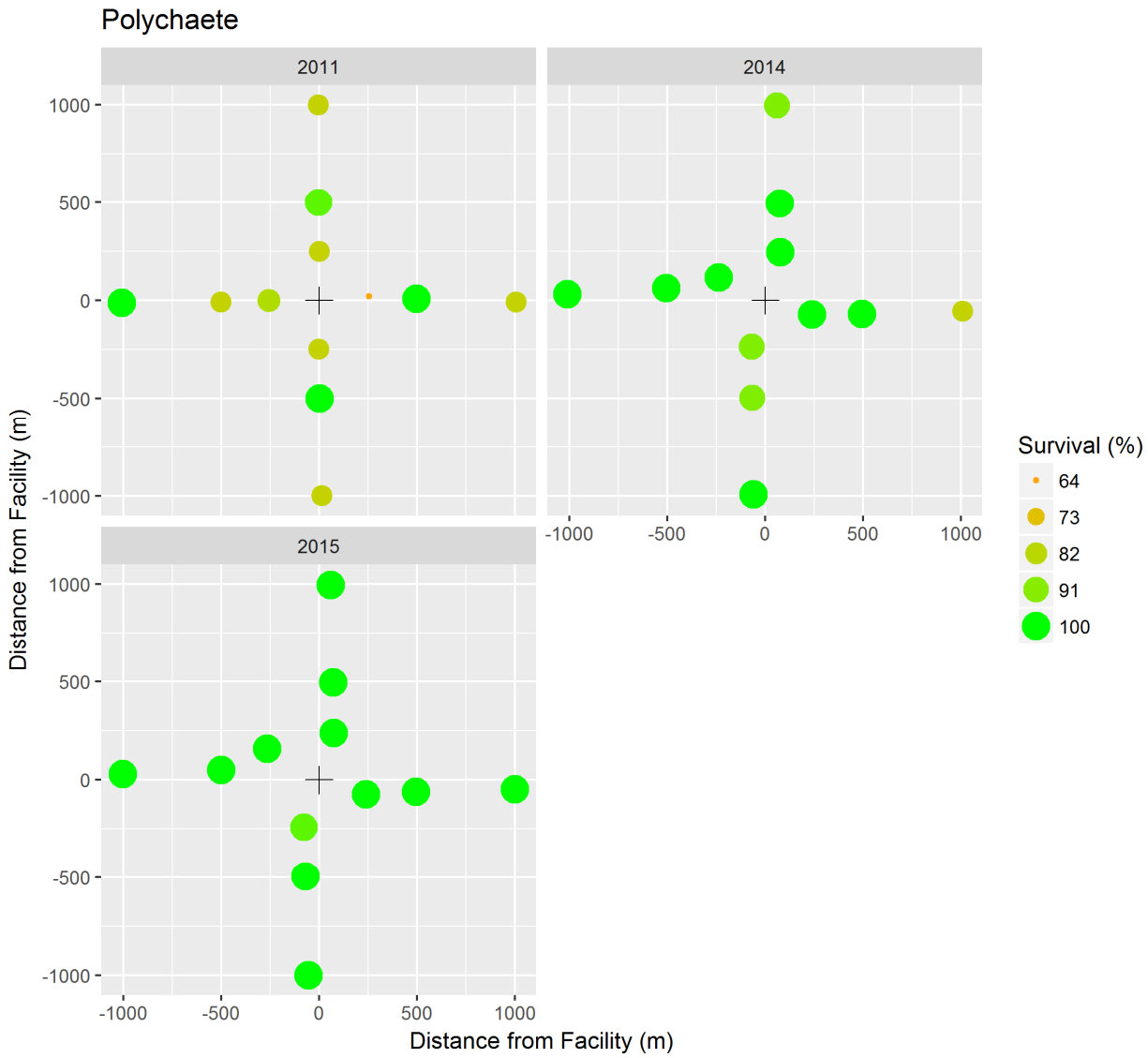


Figure 6.3 Two dimensional spatial and temporal pattern of juvenile polychaete survival (%) in HSE sediment samples within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

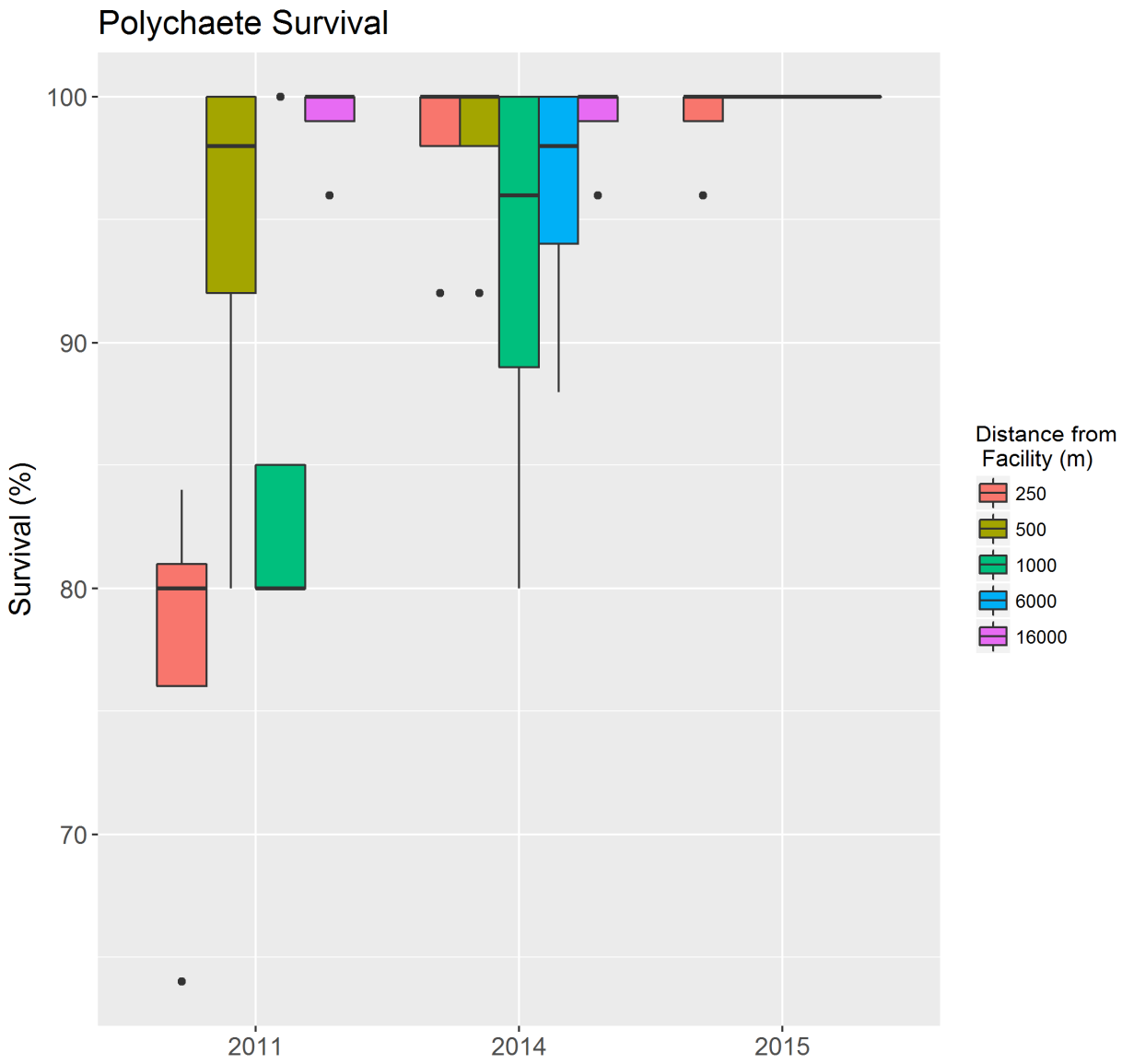


Figure 6.4 Boxplots of polychaete survival (%) in sediment by Distance and Year at HSE. Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

6.3.1 HSE 2015 Amphipod Survival Data Exploration

Amphipod bioassays test the survival rate of the organisms when cultured in test sediment according to the conditions outlined in Biological Test Method: Acute Test for Sediment Toxicity using Marine or Estuarine Amphipods (EPS 1/RM/ 26 December 1992 with October 1998 amendments) and Biological Test Method: Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods (EPS 1/RM/ 35 December 1998). Briefly, 20 amphipods (*Rhepoxynius abronius*) are cultured in five replicate containers per sediment

sampling station. For the 2015 EEM, analyses were run on three replicates per sediment sample. After a period of exposure of ten (10) days, the percent survival and percent of re-burrowing is examined between the test and control site sediments (statistical t-test comparison) to ascertain toxic versus non-toxic responses (HMDC, 2013). Reference Area sediments are treated as test samples and sediment known to support the growth and survival of the amphipods is used as a positive control for amphipod viability during the assay. The same stations that were analyzed for juvenile polychaete growth assay (see Section 6.1.2 above) underwent amphipod survival assay testing. Consistent with the results of the juvenile polychaete growth assays, all stations were considered non-toxic based on the results of amphipod bioassays with survival rates ranging between 91 and 99% for Near-field stations and 94 and 99% at Far-field stations (Table 6.1). This reflects an improvement since the 2014 EEM results and also exceeds the results observed during the 2011 HSE baseline survey program (Figure 6.5). The median values were highly consistent among all distances from the EDC that were tested and there was limited variation in results (granted there were also a lower number of replicates) (Figure 6.6).

6.4 Statistical Analyses of 2015 HSE Amphipod Survival Results

To assess the results of amphipod survival over years and distances a 2x2 ANOVA was applied as a coarse-scale (Whole-field) assessment of Near-field relative to Far-field stations. There was no significant Year X Field interaction (P=0.060) and provides evidence against coarse scale Project-related effects for this measure. Amphipod survival did vary significantly by Field (P=0.009); the 2014 Near- and Far-fields were significantly different (Tukey HSD; P=0.008). Otherwise, the median survival rates of amphipods appear to have remained relatively comparable between Near- and Far-field distances during baseline and 2015 (Figure 6.6). Fine-scale analysis within the Near-field indicates the Year X Distance interaction is not significant (P=0.272) and provides evidence against Project-related effects for this measure. Near-field stations did not vary significantly by Year (P=0.121) or Distance (P=0.098). Examination of Figure 6.6 indicates that changes in the Near-field also do not align with expectations of Project-related effects as amphipod survival rates were higher in 2015 across all Near-field stations compared to 2011 baseline. Pearson correlation with HSE sediment chemistry data indicated there were no significant correlations (r>0.5) between amphipod survival percentages and any sediment chemistry analytes.

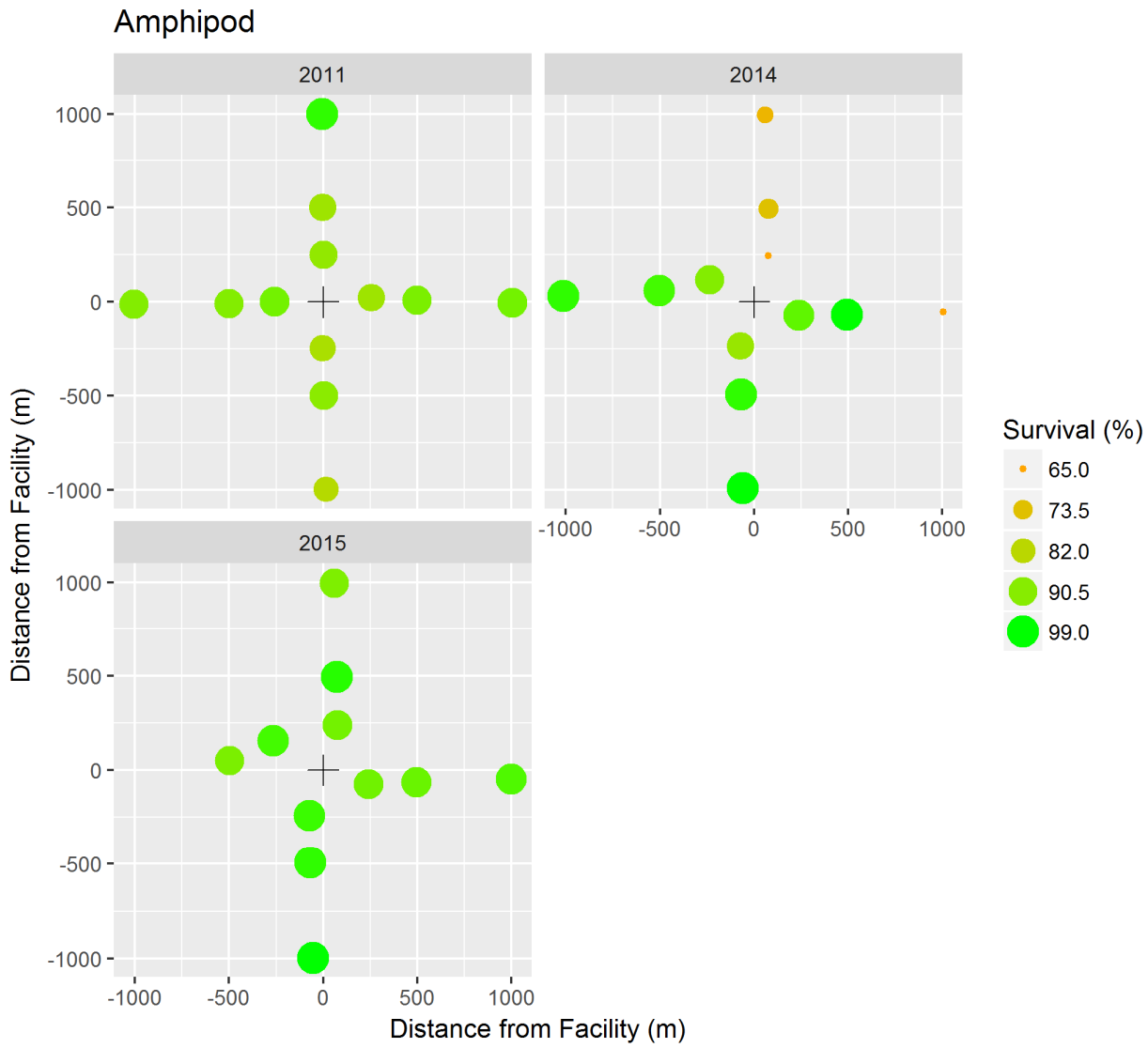


Figure 6.5 Two dimensional spatial and temporal pattern of amphipod survival (%) in HSE sediment within 1 km of the EDC in baseline (2011), and EEM programs (2014 and 2015).

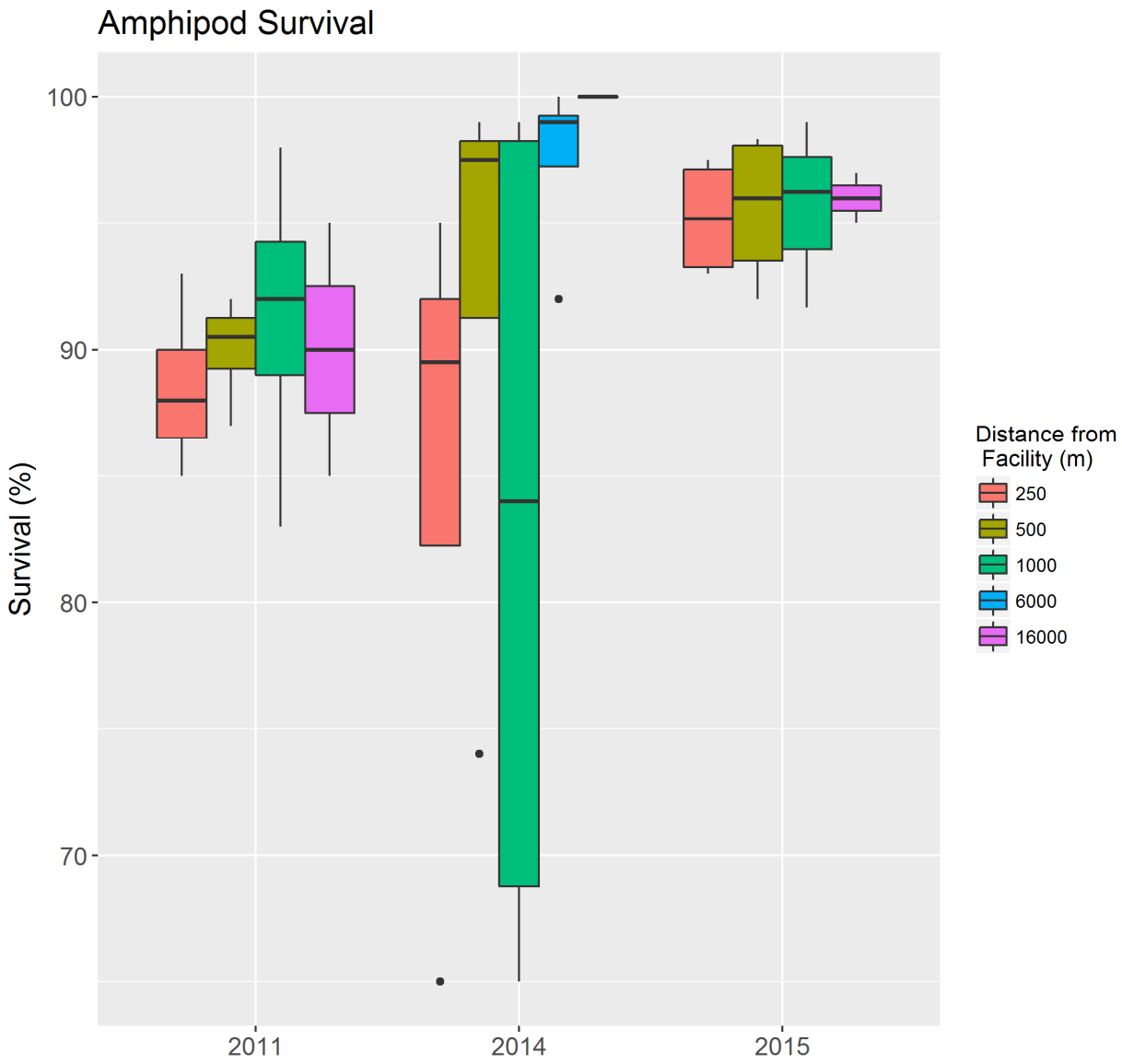


Figure 6.6 Boxplots of amphipod survival (%) in sediment samples by Distance and Year at HSE. Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points. Note stations W-1000, and 6000-1 through 6000-4 passed Microtox screening and no amphipod survival assay was necessary for these samples.

Table 6.4 Single-factor ANOVA Table for amphipod survival (square-root arc sine transformed) in HSE sediment.

Source	Degrees of freedom	Sum of Squares	Mean Square	F value	P
Whole-field (2014-2015)					
Year	2	0.087	0.043	2.26	0.099
Field	1	0.135	0.041	2.13	0.009*
Year X Field	2	0.107	0.025	1.33	0.060
Residuals	39	0.688	0.019		
Near-field (2011-2015)					
Year	2	0.087	0.291	15.30	0.121
Distance	4	0.164	0.060	3.16	0.098
Year X Distance	6	0.153	0.041	2.14	0.272
Residuals	32	0.612	0.019		
*Denotes significant result (P<0.05)					

6.4.1 Multivariate Analysis of HSE Sediment Toxicity Results

As with sediment chemistry, multivariate analyses (PERMANOVA analysis) were also applied to HSE sediment toxicity triad (Microtox, amphipod survival and juvenile polychaete growth and survival) to understand related trends and patterns in relation to time period and distance from the production facility.

PERMANOVA analysis is a statistical test for differences and to estimate components of variation due to year and site among many variables simultaneously. Toxicity data were normalized prior to calculating Euclidean distances among all pairs of sample sites. The resulting matrix was used to generate simplified 2-D non-metric multidimensional scaling (nMDS) visualizations of the data using distance-year centroids and as input into PERMANOVA models. The PERMANOVA analyses (PERMANOVA+1.0.3; 9,999 permutations) mirrored univariate analyte-specific ANOVAs; specifically, the Euclidean Distance similarity values were modelled as a function of Distance (250 m, 500 m and 1,000 m) and Year (2011, 2014 and 2015) categories with the associated interaction term (Distance x Year). Post-hoc pairwise tests were also conducted for resulting significant variables.

One site from 2015 (W-1000) was excluded because amphipod survival testing was not required at any site beyond 500 m that passed Microtox testing (HMDC, 2013). In addition to PERMANOVA analysis, to determine the set of sediment parameters that best explains the variations observed in sediment toxicity the sediment toxicity similarity values were linked to sediment characteristics (four sediment types and thirteen chemical variables: ammonia, aluminum, barium, weak acid extractable barium, chromium, iron, lead, manganese, strontium, sulphide, uranium, vanadium, total organic carbon, $>C_{10}$-C_{21} and $>C_{21}$-C_{32}) using stepwise Distance-Based Linear Modelling (PERMANOVA+1.0.3; 9,999 permutations). This method begins with a null sediment toxicity model and iteratively adds and removes sediment explanatory variables to determine the set that best explains the variations observed in sediment toxicity. The optimal set of variables that explained the greatest amount of sediment toxicity was assessed using adjusted R^2 values.

Results of these analyses are depicted as ordination plots (Figures 6.7, 6.8) of sediment toxicity data and indicate no obvious Project-related trends. Samples collected in 2015 across all Distance categories were tightly clustered in space. The ordination of all samples (Figure 6.7) suggests that the 2015 cluster generally sits intermediate to those of 2011 and 2014 but the ordination of distance-year centroids indicates that all sites on average are experiencing qualitatively similar shifts over time.

The PERMANOVA results support the nMDS plots in that the interaction term (Distance x Year), signifying potential Project-related effects, was not significant (P=0.733). The Year term was significant (P<0.001) and post-hoc pairwise comparisons indicated that each year was significantly different from all other years (all P values <0.012). Distance categories did not differ significantly (P=0.363).

The links between the sediment toxicity multivariate data and the sediment chemistry dataset, as determined through the distance-based linear model, indicated the best set of variables for explaining the pattern observed in sediment toxicity were (in order of importance) ammonia, weak acid extractable barium, chromium, zinc, total organic carbon, >C_{21}-C_{32}, and >C_{10}-C_{21} (Figure 6.7). Collectively they explained 52.6% of the observed variation.

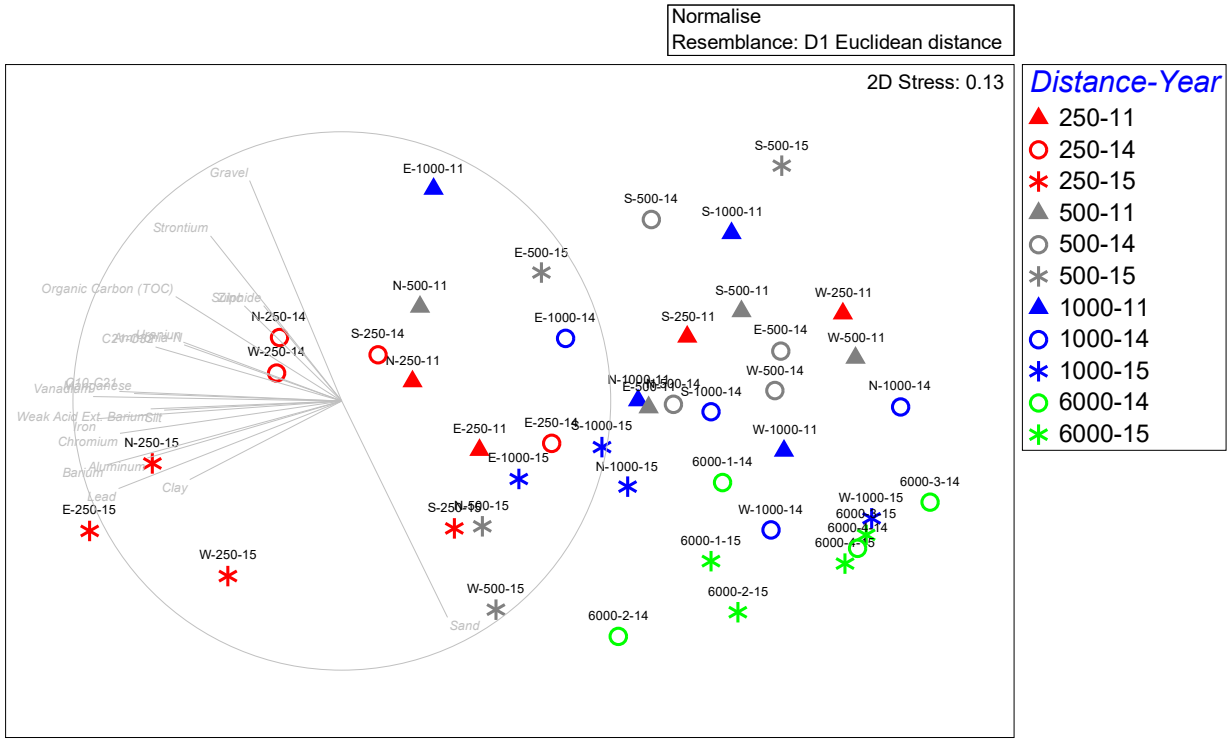


Figure 6.7 nMDS of HSE sediment toxicity data (Microtox wet weight, amphipod survival and juvenile polychaete survival) across sample distances and years. Proximity of sample points reflects similarity in sediment/chemical composition. Pearson correlation vectors of analytes are superimposed to indicate the drivers of the observed patterns.

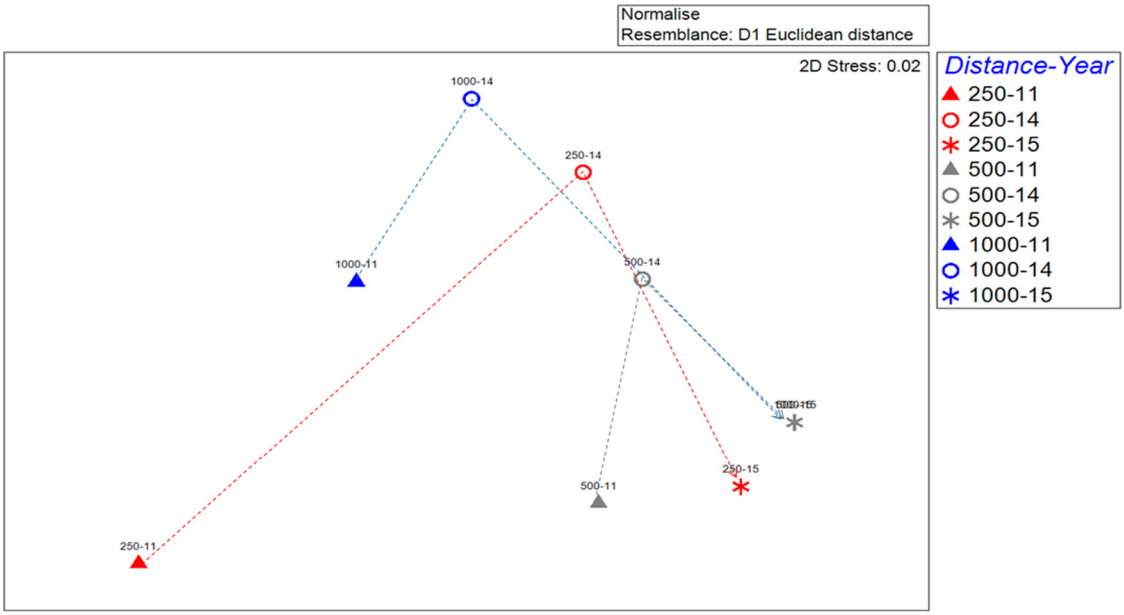


Figure 6.8 Simplified nMDS visualization of HSE sediment toxicity using centroids to represent distinct distance-year groupings.
Proximity of sample points reflects similarity in sediment/chemical composition among groupings, whereas lines indicate temporal shifts in sediment characteristics of a given distance class.

6.4.2 Summary of HSE Sediment Toxicity Analysis

The multivariate analyses of sediment chemistry analytes indicate that sediment characteristics show significant changes consistent with Project-related effects. Near-field sites, particularly those at distances of 250 m, and to a lesser extent at 500 m, appear to be shifting away from baseline / reference conditions over time and in a manner that is consistent with elevated levels of some contaminants (Chapter 5). However, sediment toxicity analyses show the Year-Distance interaction term was not significant, indicating that observed changes in sediment chemistry are not translating into Project-related effects in toxicity. Significant year to year differences across all distance categories were detected for sediment toxicity and chemical parameters in sediment that best explained the observed variation in sediment toxicity were: ammonia, weak acid extractable barium, chromium, zinc, total organic carbon, $>C_{10}$-C_{21} and $>C_{21}$-C_{32}.

Overall, despite changing sediment chemistry characteristics such as weak acid extractable barium, associated with Project-related effects, there is no significant difference in sediment toxicity results. According to amphipod and polychaete results, the quality of sediment around HSE appears to be consistent (Figure 6.1, 6.2) or improving (Figures 6.3-6.6) relative to baseline. Amphipod tests are considered a more reliable assay as they have also been shown to identify sediments that are contaminated with fuel range hydrocarbons ($>C_{10}$-C_{21}) and barium associated with synthetic based muds at other offshore production fields in the area (e.g. Terra Nova) (Whiteway et al., 2014). In contrast, Microtox continues to have unpredictable results around the Near-field that are not correlated to any specific parameter between years. Similar observations

have been reported for other EEM programs in the region. The lack of association between Microtox toxicity results and discharge from offshore operations, as well as confounding effects from among sediment parameters such as differences in fines and strontium around the Terra Nova production field, have raised into question the usefulness of this assay for environmental monitoring (Whiteway et al., 2014). Whereas other oil and gas monitoring studies describe Microtox test results as “inconclusive” (Radovic et al., 2012).

7.0 PRODUCED WATER MONITORING PROGRAM

There is no produced water monitoring program for HSE as all fluids are managed and processed on the Hibernia Platform (HMDC, 2013). This section will resume in the 2016 Hibernia EEM program report.

8.0 HSE 2015 COMMERCIAL FISH PROGRAM

The 2015 commercial fish sampling program was conducted aboard the purpose-built research vessel *RV Nuliajuk*, using a Campelen trawl towed within 2 km of the Hibernia Southern Extension subsea development and within the 50km Hibernia Reference Area (HRA) northwest of the Hibernia Platform (and distant to the 16 km Reference Areas used by the sediment program). Seven tows of 15 minute duration were conducted within 2 km of each the HSE and 50 km HRA as prescribed in the EEM design plan (HMDC, 2013). The locations of the trawl transects are illustrated in Figure 8.1. Only American plaice greater than 25 cm and free of trawl damage were retained for comprehensive sampling. The length, weight (whole and gutted), liver and gonad weights, sex, maturity and stomach contents for each American plaice were recorded. The liver, gills, heart, spleen stomach and fillet tissue was preserved for histology, bioassays, body burden and taint (taste) testing.

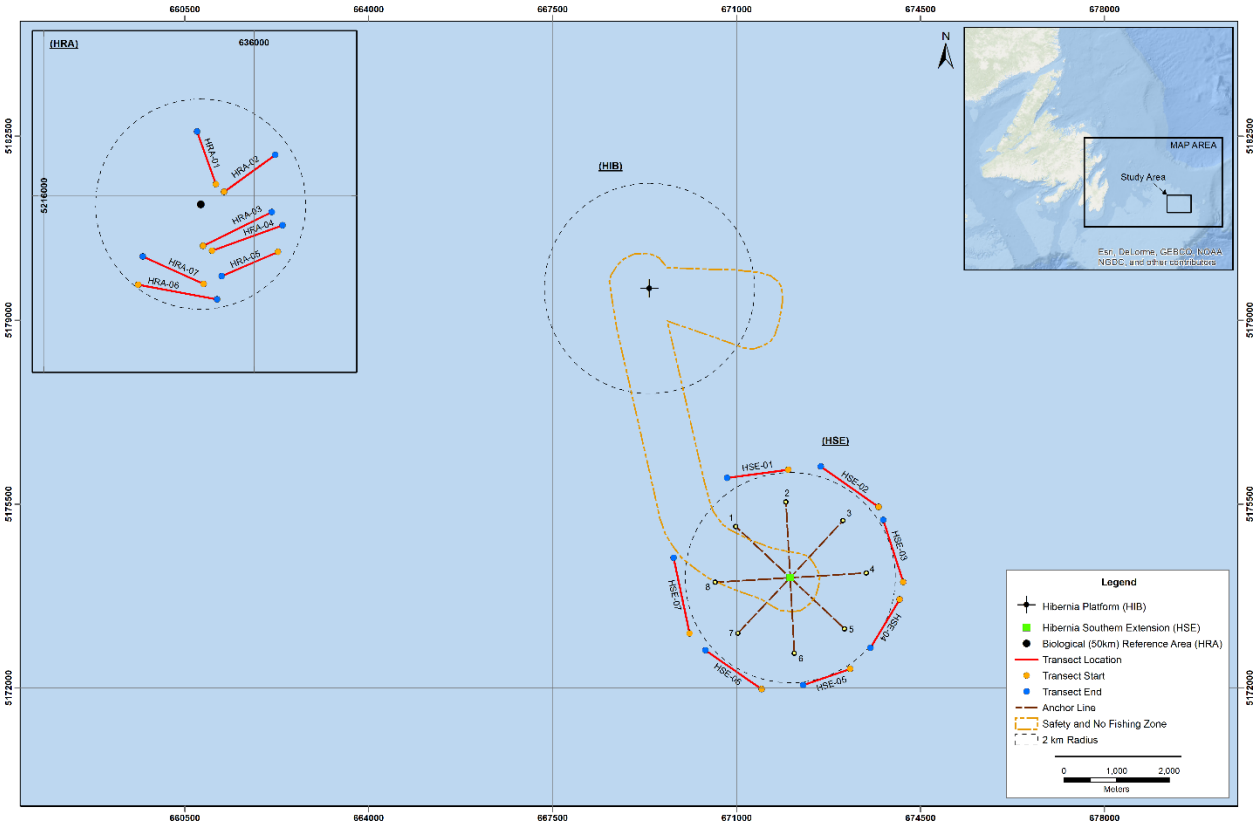


Figure 8.1 Hibernia Southern Extension 2015 commercial fish sampling program.

8.1 Fish Catches

Fish catches from the HSE and the 50 km HRA in 2015 were predominantly sand lance (*Ammodytes dubius*), American plaice (*Hippoglossoides platessoides*), yellowtail flounder (*Limanda ferruginea*) and capelin (*Mallotus villosus*) (in order of decreasing abundance). The proportions of these fish species caught were similar between sites (Figure 8.2). The highest catch per unit effort (tow) (CPUE) at HSE was 210 sand lance, 91 American plaice and 73

Yellowtail flounder on transect HSE-5, and 36 capelin on transect HSE-04. At the 50 km Reference Area the highest CPUE was 90 sand lance on trawl transect HRA-6, followed by 55 American plaice on trawl HRA-1, 23 Yellowtail flounder on HRA-2, and 21 capelin on HRA-5. The highest CPUE for American plaice larger than 25 cm was 13 individuals from the 50 km HRA (transect HRA-4) and 21 individuals from HSE (transect HSE-5). These tows also contained the highest CPUE for capelin at each sampling area. The total catches and average CPUE for fish and invertebrate species collected in trawls at HSE and the 50 km HRA are summarized in Table 8.1.

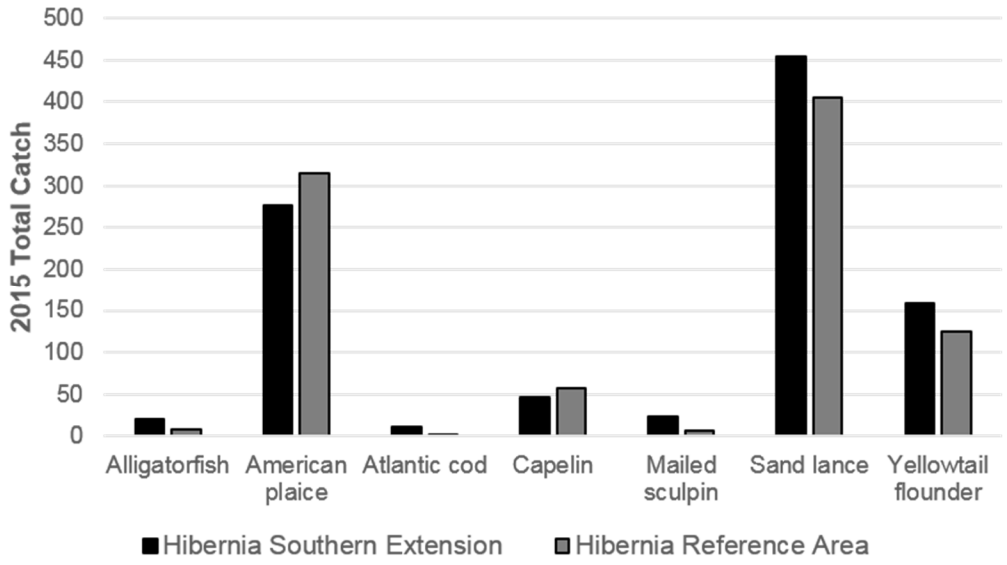


Figure 8.2 HSE Total Catch in HSE and 50 km HRA during the 2015 EEM.

The overall catch rates of American plaice from the 50 km HRA compared to the catch rates around HSE have varied since baseline and were highest in 2014. Although the catch rates of American plaice decreased in 2015 compared to 2014, they were very similar to the catch rates of 2011 (Figure 8.3). The 50 km HRA has consistently had slightly higher catch rates relative to HSE (Figure 8.3). Comparisons across years for American plaice catch data is made difficult by differing methodologies. In 2011, the *MV Aqviq* used a commercial otter trawl with a 154 mm cod end, in 2015 *MV Kinguk* used a similar trawl net with a 152 mm cod end, but in 2015 the *FRV Nuliajuk* used a Campelen 1200 trawl with a 44 mm cod end. Differences between years in this report may simply be due to differences in methodology. Catch rates for American plaice can vary considerably on the Grand Banks. In a survey conducted for American plaice in the southern half of the Grand Banks between 2002 and 2014 in the last year of the survey (2014) the trend in biomass had decreased by nearly half compared to 2013 and inter-annual fluctuations in biomass for this species were relatively common over the survey period (Nogueira, González-Troncoso, & Tolimieri, 2016).

Table 8.1 Total catch per species and catch per unit effort (trawl) at HSE and 50 km HRA in 2015.

Faunal Group	Species Name	Scientific Name	HSE		50 km RA	
			Total catch	CPUE (n=7)	Total catch	CPUE (n=7)
Fish	Alligatorfish	*Aspidophoroides monopterygius*	21	3.0	9	1.3
Fish	American plaice	*Hippoglossoides platessoides*	277	39.6	314	44.9
Fish	Mailed sculpin	*Triglops sp.*	24	3.4	7	1.0
Fish	Sand lance	*Ammodytes dubius*	454	64.9	405	57.9
Fish	Vahl's eelpout	*Lycodes vahlii*	2	0.3	0	0.0
Fish	Yellowtail flounder	*Pleuronectes ferruginea*	158	22.6	124	17.7
Fish	Atlantic cod	*Gadus morhua*	12	1.7	1	0.1
Fish	Capelin	*Mallotus villosus*	46	6.6	58	8.3
Fish	Skate	*unidentified*	1	0.1	0	0.0
Ascidian	Sea squirt	*Boltenia ovifera*	73	10.4	0	0.0
Crustacean	Shrimp	*Pandalus sp.*	317	45.3	90	12.9
Crustacean	Toad Crab	*Hyas araneus*	1	0.1	0	0.0

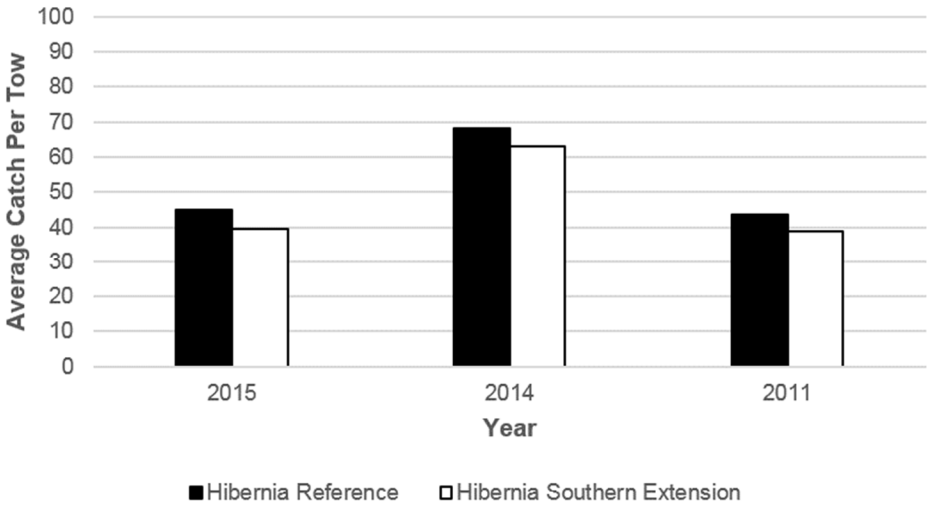


Figure 8.3 Average catch of American plaice per otter trawl tow (2011, 2014) and Campelen trawl tow in 2015 at HSE and 50 km HRA.

Seventy American plaice were collected from each surveyed location in 2015. The length-frequency distributions reveal the majority of females surveyed in 2015 were 35-45 cm in length, and the largest females surveyed were at HSE (Figure 8.4). Among male fish surveyed, nearly all were less than 40 cm in length and the largest males were also surveyed at HSE (Figure 8.4). This pattern is representative of the sexual dimorphism in size for this species (Swain & Morgan, 2001). In addition, the greater proportion of larger male and female fish sampled were collected in proximity to the HSE field (Figure 8.4).

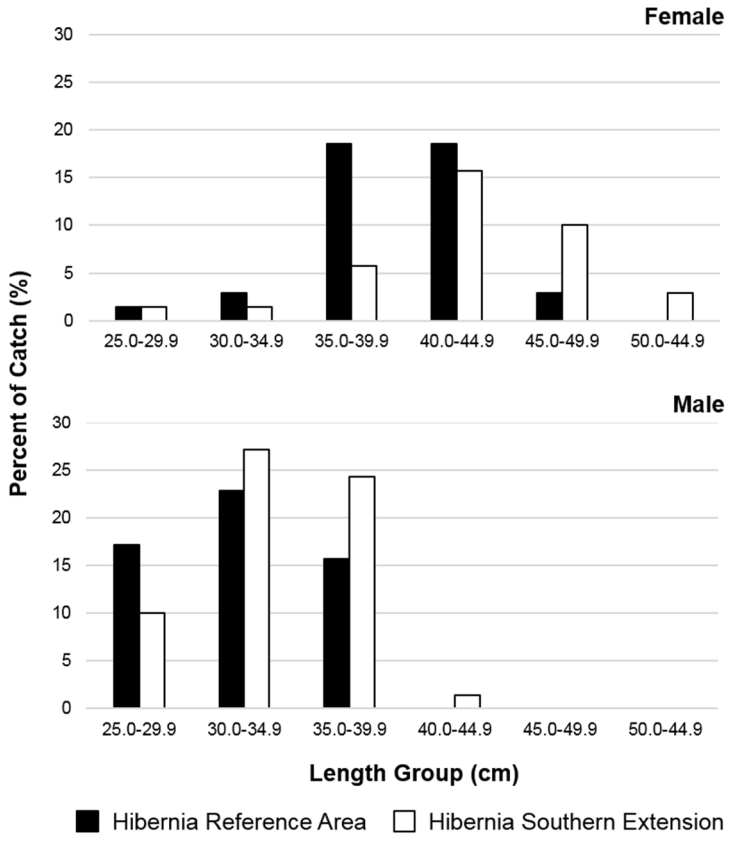


Figure 8.4 Length-frequency of Male and Female American plaice surveyed in 2015 at HSE and 50 km HRA.

8.2 Chemical profiles of American plaice tissue

Ten sets of tissue samples were collected from the livers and fillets of American plaice at each of the surveyed areas. Each fillet sample represented an individual fish, and liver samples were composites from seven individuals per sample. Samples were subjected to a suite of laboratory analyses for metals, fuel and lube range hydrocarbons (>C_{10}-C_{21} and >C_{21}-C_{32}), PAHs, and APAHs. In order to have sufficient volume of tissue to conduct all chemical analysis, the crude fat content in fillet tissues was not assayed. However, in a review of the first ten years of the Terra Nova offshore EEM program, DeBlois et al. (2014) reported fat content of American plaice fillets varied significantly ($P<0.005$) among years but not between the production field and survey area.

All tested analyte data is included in Volume II of this report and a summary of the body burden chemistry analytes that were detected (≥RDL) in HSE and/or 50 km HRA liver and tissue samples is presented in Tables 8.2 and 8.3. To obtain a meaningful descriptive statistic for samples with detected values below RDL, the value of the RDL was used for calculation so as not to present mean values below the detection limit (HMDC, 2015a). However, half RDL was used for statistical analysis as per the design plan (HMDC 2013).

Table 8.2 Summary statistics of HSE and 50 km Reference Area Liver burden data.

Parameter	RDL	Units	No. of Samples	No. = RDL	No. < RDL	No. > RDL	Mean	St. Dev	Median	Min	Max	No. of Samples	No. = RDL	No. < RDL	No. > RDL	Mean	St. Dev	Median	Min	Max
	Hibernia Southern Extension Liver											50 km Hibernia Reference Area Liver								
Metals																				
Arsenic	0.5	mg/kg	10	0	0	10	10.34	3.14	10.4	5.70	16.00	10	0	0	10	12.09	7.11	9.75	5.10	29.00
Cadmium	0.05	mg/kg	10	0	0	10	1.56	0.67	1.50	1.00	3.40	10	0	0	10	1.50	0.64	1.65	0.73	2.70
Cobalt	0.2	mg/kg	10	0	4	6	0.23	0.04	0.21	0.20	0.31	10	0	9	1	0.21	0.02	0.20	0.20	0.27
Copper	0.5	mg/kg	10	0	0	10	9.69	2.70	9.60	5.50	15.00	10	0	0	10	6.75	1.90	6.95	3.20	9.80
Iron	15	mg/kg	10	0	0	10	73.70	11.90	75.00	50.00	91.00	10	0	0	10	85.40	35.50	83.50	47.00	170.00
Manganese	0.5	mg/kg	10	0	0	10	0.77	0.10	0.76	0.66	0.98	10	0	0	10	0.69	0.10	0.715	0.55	0.81
Selenium	0.5	mg/kg	10	0	0	10	3.46	0.43	3.50	2.80	4.20	10	0	0	10	3.12	0.56	2.85	2.50	4.00
Silver	0.12	mg/kg	10	0	6	4	0.14	0.03	0.12	0.12	0.19	10	0	9	1	0.12	<0.01	0.12	0.12	0.13
Vanadium	0.5	mg/kg	10	0	8	2	0.94	1.26	0.50	0.50	4.50	10	0	6	4	0.99	0.82	0.50	0.50	3.00
Zinc	1.5	mg/kg	10	0	0	10	37.00	3.74	38.50	30.00	41.00	10	0	0	10	32.30	3.80	33.50	24.00	37.00
Mercury	0.01	mg/kg	10	0	0	10	0.06	0.02	0.06	0.03	0.083	10	0	0	10	0.06	0.02	0.05	0.026	0.096
PAH																				
2-Methylnaphthalene	0.300[a]	mg/kg	10	0	10	0	<RDL	0.00	<RDL	<RDL	<RDL	10	0	9	1	0.30	0.07	0.30	0.07	0.30
Fluoranthene	0.800[b]	mg/kg	10	0	9	1	0.82	0.05	0.80	0.80	0.80	10	0	9	1	0.82	0.00	0.80	0.80	0.80
Naphthalene	0.05	mg/kg	10	0	9	1	0.05	0.00	0.05	0.05	0.07	10	0	7	3	0.05	0.01	0.05	0.05	0.07
Petroleum Hydrocarbons																				
Fuel range >C_{10}-C_{21}	15	mg/kg	10	0	9	10	43.50	14.52	39.50	30.00	95.00	10	0	2	8	39.10	7.90	38.50	30.00	54.00
Lube range >C_{21}-C_{32}	15	mg/kg	10	0	0	10	260.00	138.00	245.00	120.00	610.00	10	0	0	10	182.00	43.20	180.00	110.00	260.00
Alkyl-PAHs																				
				None detected, all samples <RDL								None detected, all samples <RDL								

[a] Elevated PAH RDL(s) due to matrix / co-extractive interference. RDLs ranged from 0.05-0.30 mg/kg.
[b] Elevated PAH RDL(s) due to matrix / co-extractive interference. RDLs ranged from 0.05-0.80 mg/kg.

Table 8.3 Summary statistics of HSE and 50 km Reference Area Fillet body burden data.

Parameter	RDL	Units	No. of Samples	No. = RDL	No. < RDL	No. > RDL	Mean	St. Dev	Median	Min	Max	No. of Samples	No. = RDL	No. < RDL	No. > RDL	Mean	St. Dev	Median	Min	Max
Hibernia Southern Extension Fillet												**50 km Hibernia Reference Area Fillet**								
Metals												**Metals**								
Arsenic	0.5	mg/kg	10	0	0	10	3.98	2.08	3.30	1.60	8.30	10	0	0	10	4.26	1.76	3.80	1.80	6.60
Mercury	0.01	mg/kg	10	0	0	10	0.08	0.04	0.08	0.03	0.14	10	0	0	10	0.09	0.08	0.06	0.03	0.31
Selenium	0.5	mg/kg	10	0	9	1	0.54	0.14	0.50	0.50	0.94	10	0	9	1	0.51	0.04	0.50	0.50	0.63
Zinc	1.5	mg/kg	10	0	0	10	4.02	0.52	4.00	3.10	5.00	10	0	0	10	4.45	0.79	4.35	3.40	5.80
PAHs												**PAHs**								
	None detected, all samples <RDL											None detected, all samples <RDL								
Petroleum Hydrocarbons												**Petroleum Hydrocarbons**								
Fuel range $>C_{10}$-C_{21}	15	mg/kg	10	0	10	0	<RDL	0.00	<RDL	<RDL	<RDL	10	0	10	0	<RDL	0.00	<RDL	<RDL	<RDL
Lube range $>C_{21}$-C_{32}	15	mg/kg	10	0	8	2	16	2.80	15.00	15.00	24.00	10	0	10	0	<RDL	0.00	<RDL	<RDL	<RDL
Alkyl-PAHs												**Alkyl-PAHs**								
	None detected, all samples <RDL											None detected, all samples <RDL								

[a] Elevated PAH RDL(s) due to matrix / co-extractive interference. RDLs ranged from 0.05-0.30 mg/kg.
[b] Elevated PAH RDL(s) due to matrix / co-extractive interference. RDLs ranged from 0.05-0.80 mg/kg.

8.2.1 Exploration of HSE and 50 km Reference Area Tissue Data

American plaice fish tissue chemistry data was initially screened to select for analytes that were present (i.e., detected at a concentration greater than their RDL) in at least half of all samples (HMDC, 2013). Similar to previous analyses, analytes that met this initial criteria had any values less than the RDL (<RDL) included in the analysis as half their RDL value (HMDC, 2013). Following this, ANOVA tests were conducted between HSE and 50 km HRA collected fish to assess if there were significant statistical differences in detected levels of chemical analytes in tissue (HMDC, 2013).

Consistent with the sediment chemistry analysis methodology, remaining analytes having values below RDL in more than half of all samples tested were not subject to further analysis.

8.2.2 HSE Liver Metals Results

Detectable metals (any analyte >RDL) in liver tissues included arsenic, cadmium, cobalt, copper, iron, manganese, selenium, silver, vanadium, zinc and mercury (Table 8.2). These analytes were all detected at both HSE and the 50 km HRA in 2015. With the exception of cobalt and chromium, these are the same metal analytes that were also detected in liver tissues from both sampling areas in 2014. Cobalt was not detected in 2014 and chromium, which had been detected in three liver samples from HSE in 2014, was not detected in 2015.

Cobalt was detected in four out of ten composited samples at HSE and one composited sample from in the 50 km HRA; however the mean value from each survey location was 0.23 and 0.21 mg/kg relative to an RDL of 0.20 mg/kg. Silver was detected in four of ten HSE composited samples (mean= 0.135 mg/kg) and a single composite sample from the 50 km HRA (mean=0.121 mg/kg) relative to an RDL of 0.120 mg/kg). In contrast, vanadium was detected in two samples at HSE (mean=0.94 mg/kg) and four samples from the 50 km HRA (mean=0.99 mg/kg) relative to an RDL of 0.50 mg/kg (Table 8.2).

For the remaining eight analytes detected in more than half the samples analyzed, median concentrations are depicted in Figure 8.5. To assess if there are any significant difference in detectable analytes between HSE and the 50 km HRA, two-factor ANOVAs were completed (HMDC, 2013). The results for HSE liver tissues are reported in ANOVA tables for Year, Area, and Year X Area in Tables 8.4 through 8.11. Based on these analyses, arsenic, cadmium, manganese mercury and selenium all varied significantly by Year but not Area; this potentially reflects regional annual variation of these analytes in demersal fish as levels vary within the environment depending on natural and anthropogenic sources (Bosch, 2015). Moreover, these anaytes may also bioaccumulate disproportionately among fish and within fish tissues (Bosch, 2015). Copper varied significantly by Year ($P<0.001$) and by Area ($P=0.033$) but does not appear to be Project-related (Year X Area $P=0.060$). However, zinc did have a significant Year X Area interaction ($P=0.001$) and increasing values of this analyte in HSE liver samples compared to the 50 km HRA is suggestive of a potential Project-related effect (Figure 8.6; Table 8.11). The prevalence of these metal analytes in liver tissues of American plaice appears to be common on the Grand Banks. In a similar EEM monitoring program for the Terra Nova offshore production operation, over a ten-year (2002-2010) EEM survey period, several of the metal analytes reported

here including: arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were also commonly detected in American plaice composite liver samples (DeBlois, Kiceniuk, et al., 2014). In that same study, DeBlois and others (2014) reported, with the exception of manganese, concentrations were strongly positively correlated with one another.

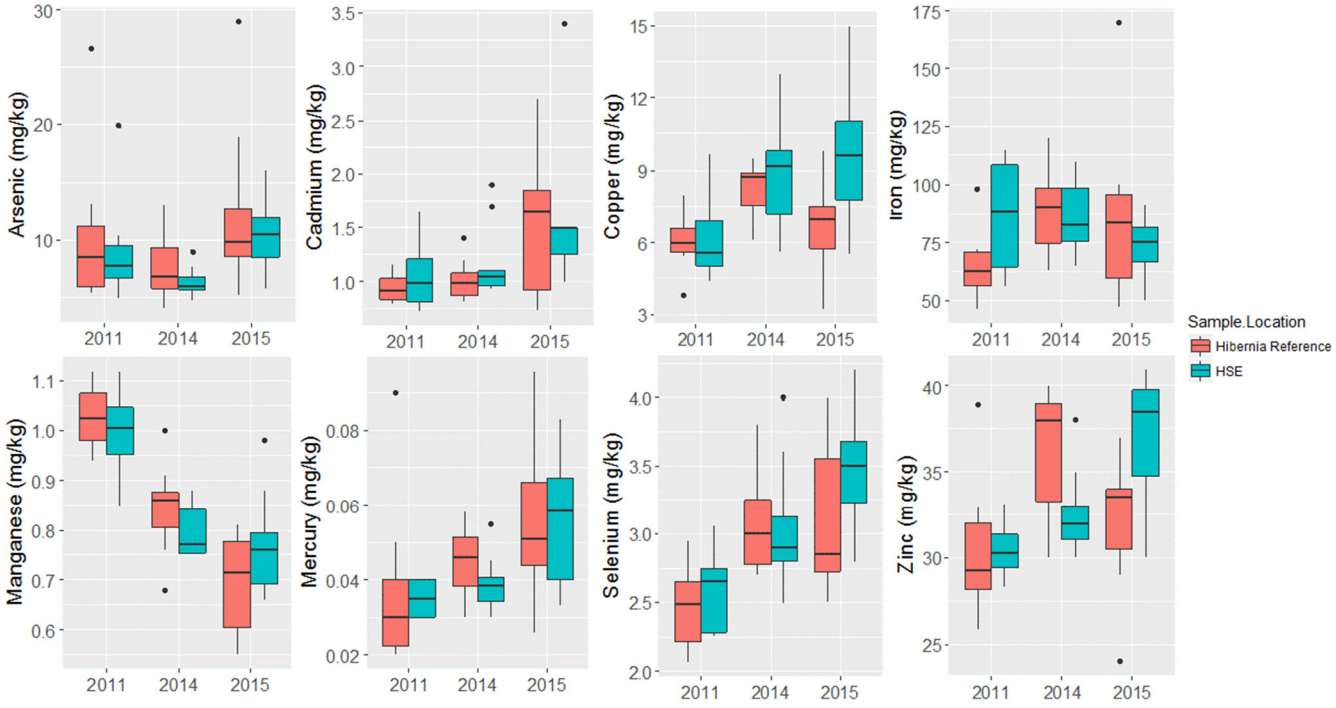


Figure 8.5 Boxplots of metal concentrations in American plaice liver tissue from HSE and 50 km HRA during 2011 baseline, and 2014 and 2015 EEM programs. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent the interquartile range. Data beyond the whiskers are represented as individual data points.

Table 8.4 Two-factor ANOVA for log_{10}-transformed arsenic concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	P
Year	2	0.355	0.178	5.770	0.006*
Area	1	0.026	0.026	0.831	0.366
Year X Area	2	0.004	0.002	0.057	0.945
Residuals	52	1.600	0.031		
*Denotes significant result (P<0.05)					

Table 8.5 Two-factor ANOVA for log_{10}-transformed cadmium concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.299	0.150	9.420	<0.001*
Area	1	0.025	0.025	1.550	0.219
Year X Area	2	0.002	0.001	0.071	0.931
Residuals	52	0.826	0.016		
*Denotes significant result (P<0.05)					

Table 8.6 Two-factor ANOVA for log_{10}-transformed copper concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.223	0.112	9.320	<0.001*
Area	1	0.057	0.058	4.810	0.033*
Year X Area	2	0.071	0.036	2.980	0.060
Residuals	52	0.623	0.012		
*Denotes significant result (P<0.05)					

Table 8.7 Two-factor ANOVA for log_{10}-transformed iron concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.064	0.032	2.700	0.077
Area	1	0.006	0.006	0.474	0.494
Year X Area	2	0.067	0.033	2.830	0.068
Residuals	52	0.613	0.012		
*Denotes significant result (P<0.05)					

Table 8.8 Two-factor ANOVA for log_{10}-transformed manganese concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.202	0.101	49.400	<0.001*
Area	1	0.00006	0.00006	0.032	0.860
Year X Area	2	0.014	0.007	3.540	0.036
Residuals	52	0.106	0.002		
*Denotes significant result (P<0.05)					

Table 8.9 Two-factor ANOVA for log_{10}-transformed mercury concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.343	0.171	8.250	<0.001*
Area	1	0.003	0.003	0.218	0.723
Year X Area	2	0.017	0.009	0.413	0.664
Residuals	48	0.997	0.021		
*Denotes significant result (P<0.05)					

Table 8.10 Two-factor ANOVA for log_{10}-transformed selenium concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.125	0.063	18.6	<0.001*
Area	1	0.006	0.006	1.71	0.197
Year X Area	2	0.008	0.004	1.12	0.333
Residuals	52	0.175	0.003		
*Denotes significant result (P<0.05)					

Table 8.11 Two-factor ANOVA for log_{10}-transformed zinc concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.037	0.018	9.640	<0.001*
Area	1	0.0004	0.0004	0.220	0.641
Year X Area	2	0.029	0.015	7.650	0.001*
Residuals	52	0.099	0.002		
*Denotes significant result (P<0.05)					

8.2.3 HSE Fillet Metals Results

In 2015 there was a notable reduction in the number of metal analytes in fish fillets; only arsenic, mercury, selenium and zinc were detected. Comparatively, chromium, iron, manganese and nickel, which had been detected in a single specimen from HSE in 2014, were not detected in any specimen from either HSE or the 50 km Reference Area. Although selenium was again detected in a single specimen at HSE (0.54 mg/kg concentration), it was also detected in a single specimen from the 50 km HRA (0.51 mg/kg concentration) relative to an RDL of 0.50 mg/kg. The remaining three metal analytes (arsenic, mercury and zinc) were detected in all ten samples from both areas (HSE and 50 km HRA). The concentration of these analytes in fish fillet tissue since baseline is depicted in Figure 8.6.

The ANOVA results for arsenic and mercury concentrations in American plaice fillet tissues in 2015 revealed no significant Project-related effects (Year X Area interaction P>0.05) (Tables 8.12, 8.13). Arsenic varied significantly by Year (P=0.002) but not by Area (P=0.403) and levels were statistically indistinguishable from 2011 baseline values (Tukey HSD; P=0.220). In contrast, the concentrations of mercury varied significantly by Area (P=0.011) but not by Year (P=0.173),

however median concentrations in both areas in 2015 are below those recorded in 2011 baseline (Figure 8.6). Consistent with HSE liver tissues, zinc concentrations in fillets also had a significant (P<0.001) Year X Area interaction, which although suggestive of a potential Project-related effect for this measure as the detected concentrations differ significantly between the two areas (Table 8.14), the effect appears to result in a slight decrease in the median value of zinc in fillet tissues at HSE relative to those sampled from the 50 km HRA (Figure 8.6).

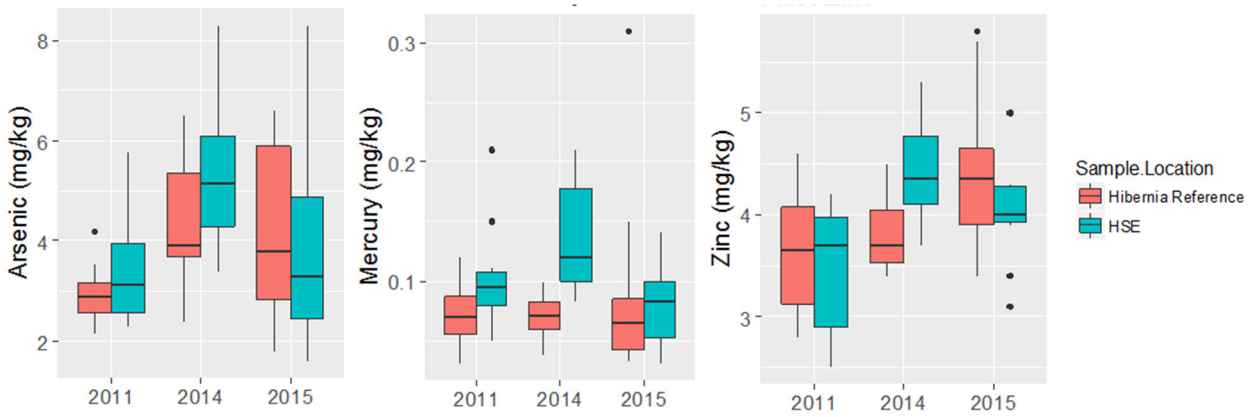


Figure 8.6 Boxplots of metal concentrations in American plaice fillet tissue from HSE and 50 km HRA during 2011 baseline, and 2014 and 2015 EEM programs. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent the interquartile range. Data beyond the whiskers are represented as individual data points.

Table 8.12 Two-factor ANOVA for log10-transformed arsenic concentration in fillet tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.339	0.169	6.910	0.002*
Area	1	0.017	0.017	0.710	0.403
Year X Area	2	0.053	0.027	1.090	0.344
Residuals	54	1.320	0.025		
*Denotes significant result (P<0.05)					

Table 8.13 Two-factor ANOVA for log_{10}-transformed mercury concentration in fillet tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.156	0.078	1.81	0.173
Area	1	0.298	0.298	6.94	0.011*
Year X Area	2	0.192	0.096	2.23	0.117
Residuals	54	2.320	0.043		
*Denotes significant result (P<0.05)					

Table 8.14 Two-factor ANOVA for log_{10}-transformed zinc concentration in fillet tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.074	0.037	8.620	<0.001*
Area	1	0.00002	0.00002	0.005	0.946
Year X Area	2	0.031	0.015	3.560	0.035*
Residuals	54	0.232	0.004		
*Denotes significant result (P<0.05)					

8.2.4 Hydrocarbons in HSE Tissues

In 2015 all composite liver samples from HSE contained detectable concentrations of fuel (>C_{10}-C_{21}) and lube range hydrocarbons (>C_{21}-C_{32}). At the 50 km HRA, eight of ten composite liver samples had detectable concentrations of fuel range hydrocarbons and all had detectable levels of lube range hydrocarbons, consistent with previous years. The mean concentration of fuel range hydrocarbons at HSE was 47.9 mg/kg, compared to 39.1 mg/kg for the 50 km HRA. Mean concentrations were 25.5 and 19 mg/kg in the HSE and 50 km HRA, respectively in 2014 (Table 8.2 and Figure 8.7). ANOVA analysis of hydrocarbon concentrations in liver reveal a significant Year X Area interaction (P=0.03; Table 8.15) suggestive of a potential Project-related effect for this analyte. This represents a change in trend for this analyte as a significant Year X Area interaction was also observed for in composite liver samples from American plaice in the 2014 EEM program, though 2014 was lower than 2011 and 2015 was higher than 2014 (HMDC, 2015a).

Lube range (>C_{21}-C_{32}) hydrocarbons were also detected in all liver samples from HSE and the 50 km HRA in 2015. ANOVA analysis indicated this was significant by Year (P<0.001) and by Area (P<0.001) but does not appear to be Project-related (Year X Area P=0.856; Table 8.16). The mean concentrations detected were 260 and 182 mg/kg from HSE and 50 km HRA samples, respectively. This represents an increase in each survey area compared to the mean concentrations for these analytes observed in 2014, (118.9 at HSE and 96.7 mg/kg at the 50 km HRA respectively). The difference between years was significant (Tukey HSD; P<0.001); however, the presence of these compounds in liver tissues are not uncommon. The 2014 Hibernia EEM indicated that there are no significant differences in liver hydrocarbons between the Hibernia Platform and the reference area over monitoring years. During a ten year period (2002-2010), American plaice composite liver samples from Terra Nova and its associated Reference Area have frequently contained compounds in the >C_{10}-C_{21} hydrocarbon range and consistently contained compounds in the >C_{21}-C_{32} range (DeBlois, Kiceniuk, et al., 2014). From this same

study, gas chromatography mass spectrophotometry (GCMS) analysis of hydrocarbon compounds in 2008 detected potential petrogenic contamination in the >C_{21}–C_{32} range in a single Reference Area sample of fish tissue (DeBlois, Kiceniuk, et al., 2014). The majority of GCMS-detected hydrocarbon compounds in remaining liver samples were consistent with those of natural compounds such as squalene (DeBlois, Kiceniuk, et al., 2014).

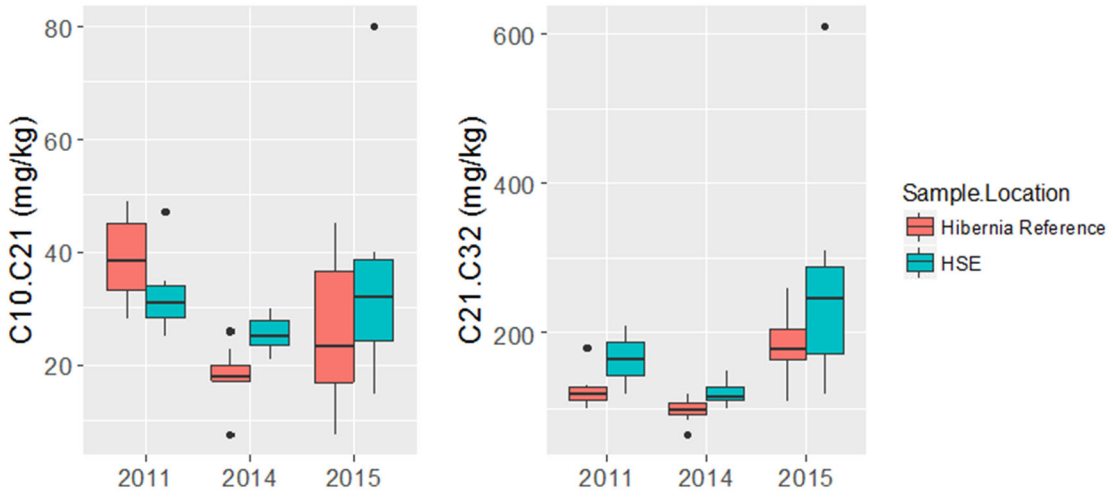


Figure 8.7 Boxplots of hydrocarbon concentrations in American plaice liver tissue from HSE and 50 km HRA during 2011 baseline, and 2014 and 2015 EEM programs. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent the interquartile range. Data beyond the whiskers are represented as individual data points.

No fuel range (>C_{10}-C_{21}) hydrocarbons were detected in filet samples from HSE in 2015. Two fillet samples out of ten in the HSE area had lube range (>C_{21}-C_{32}) hydrocarbons detected in them at concentrations of 24 and 26 mg/kg (relative to an RDL of 15 mg/kg); none were detected from the 50 km HRA samples. This analyte has not been detected in fish fillets previously at HSE; however, detection of >C_{21}-C_{32} hydrocarbons has occurred infrequently in American plaice fillet samples in the Terra Nova Offshore monitoring program from the same region of the Grand Banks (DeBlois, Kiceniuk, et al., 2014). Hydrocarbon concentrations have also shown variability in American plaice tissues based on season, sampling location, size, and lipid content (Hellou and Warren 1997; Hellou et al 2006).

Table 8.15 Two-factor ANOVA for log_{10}-transformed fuel range hydrocarbons (>C_{10}-C_{21}) concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.538	0.269	9.39	<0.001*
Area	1	0.118	0.118	4.13	0.047*
Year X Area	2	0.220	0.110	3.84	0.03*
Residuals	54	1.550	0.028		
*Denotes significant result (P< 0.05)					

Table 8.16 Two-factor ANOVA for log_{10}-transformed lube range hydrocarbons (>C_{21}-C_{32}) concentration in liver tissue from American plaice collected at HSE and 50 km HRA.

Source	Degrees of freedom	Sum of Squares	Mean Square	F- value	P
Year	2	0.814	0.407	34.200	<0.001*
Area	1	0.194	0.194	16.300	<0.001*
Year X Area	2	0.004	0.002	0.156	0.856
Residuals	54	0.642	0.012		
*Denotes significant result (P< 0.05)					

8.2.5 Summary of Chemical Profiles of American Plaice Tissues

Among American plaice tissues sampled from HSE and the 50 km HRA in 2015, metal analytes that continue to be prevalent in tissues include arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc. These analytes are generally consistent with those reported for a ten-year period at Terra Nova (DeBlois, Kiceniuk, et al., 2014). Moreover, the concentrations of metal analytes in liver and fillet tissues generally appear to vary between years as opposed to between areas, consistent with observations at Terra Nova (DeBlois, Kiceniuk, et al., 2014). There has been an increase in the detection of hydrocarbon compounds in the fuel (>C_{10}-C_{21}) and lube range (>C_{21}-C_{32}) in both tissue types since the onset of the program. However, among American plaice sampled from the southeastern region of the Grand Banks, detection of these analytes appears to be relatively common and are likely derived from natural hydrocarbon compounds as reported for production operations at Terra Nova (DeBlois, Kiceniuk, et al., 2014).

8.3 Taste Panels

In Health Canada's List of Contaminants and Other Adulterating Substances in Foods, arsenic's maximum limit in fish protein is 3.5 ppm (3.5 mg/kg) which is exceeded at HSE and the 50km HRA in this EEM program (Table 8.3). However, arsenic comes in two broad categories: inorganic and organic, with inorganic considered far more toxic than organic (Francesconi 2010). The US EPA published a report stating inorganic arsenic is roughly 4 percent of total arsenic present in wild fish populations (US EPA 1997). As this EEM program measures total arsenic, even assuming a conservative 10 percent portion of inorganic arsenic in total arsenic the highest concentration recorded would be 0.83 mg/kg and 0.66 mg/kg in fish fillets HSE and 50km HRA, respectively. Therefore, these fillets were deemed safe for human consumption.

Chemical analysis of American plaice tissues that are sampled for the EEM program may not necessarily detect an overall difference in sensory perception of the sampled tissues. Therefore, sensory evaluations are performed using two qualitative assays; the triangle test and the Hedonic Scaling test (HMDC, 2013).

The Triangle Test is used to qualitatively assess American plaice filet samples for any disparities in sensory perception between samples derived from fish collected from the HSE study area versus the 50 km HRA (HMDC, 2013). As described in Chapter 3, a panel of 24 people are each provided three unidentified fish tissue samples (homogenized and cooked to 35°C) and are asked to discriminate one from the other two. The test is ranked according to the number of panelists

who are correctly able to discriminate the outlier sample. For the 2015 EEM program, only 9 of 24 panelists were able to correctly discriminate samples and these results are not significant (α = 0.05). Comments associated with the triangle test are summarized in Table 8.17.

The second sensory test performed is the Hedonic Test to evaluate a preferential taste between two samples; one from each sampling area (also homogenized and cooked to 35°C). Preferences are ranked on a scale of according to 'dislike extremely' (1) to 'like extremely' (9). The data were subjected to ANOVA analysis and were also not significant (P=0.601).

Overall, there were no significant differences in the sensory evaluation tests between American plaice fillet samples collected from HSE and the 50 km Reference Area for the 2015 EEM program.

Table 8.17 Comments from 2015 HSE Triangle Test.

50 km Hibernia Reference Area	Hibernia Southern Extension
Correctly Identified as Odd Sample	**Correctly Identified as Odd Sample**
The middle, 559 (RA) tasted terrible! Like it was 'off'.	Bland.
Incorrectly Identified as Odd Sample	**Incorrectly Identified as Odd Sample**
Don't like as much.	Did not like this sample.
Hard to tell any difference.	Lighter, fresher flavour and odour.
Much stronger fishy taste than other two, odour was fairly close.	961 (SA) had a lighter taste.
Very slight difference between 397 (RA) and 529 (SA). Sample 126 (RA) is the odd and preferred sample.	Guessed, really could not tell definitely. Very little difference in samples.

Note: Sample identification numbers in comments were randomly assigned as identifiers for panellist comments.

9.0 2015 HSE FISH HEALTH PROGRAM

The HSE Fish Health Program is conducted to qualitatively assess commercial fish species (American plaice, *Hippoglossoides platessoides*) collected in the vicinity of the HSE drill centre relative to fish collected from the HRA located approximately 50 km northwest of the Hibernia production field (Chapter 8, Figure 8.1). Fish were collected using an otter trawl aboard the Fisheries Research Vessel *Nuliajuk*, and a minimum of seven trawls were conducted within a 2 km radius at each of the study areas; HSE and the 50 km HRA. The biological characteristics (including length, weight, sex, maturity, weight of organs sampled) of each fish was collected are recorded, tissue subsampling was conducted and health indicators assessed as prescribed in the HMDC Design Plan (HMDC, 2013, Sections 2.3 and 3.3) and described in subsequent sections below. These parameters are analyzed separately for each gender to account for sexually dimorphic growth rates and rates of maturation between male and female American plaice (Swain & Morgan, 2001). All raw data pertaining to in this chapter is included in Volume II.

9.1 Maturity Stages

During the 2015 HSE EEM biological cruise, 18 female and 32 male American plaice were collected from the HSE study area, and 22 females and 28 males were sampled from the 50 km HRA. The ratio of females to males (F:M) was not significantly different between the Reference and Study areas (P=0.424; Fisher's exact test).

The sexual maturity stages of each gender were characterized according to the index and procedures used by DFO (Templeman, Hodder, & Wells, 1978). Fish maturation was indexed according to the size and extent of differentiation of the gonads relative to the size of the fish and the appearance of the gametes (e.g. opaque vs. translucent). Males were indexed into categories according to immature (100), through to mature (180), and frequencies (percentages) of maturity stages were compared between HSE and the 50 km HRA using Fisher's exact test.

There was a greater proportion of spent males (L-110) at HSE (21.9%) compared males surveyed from the 50km HRA (0.0%) and this difference was significant (P=0.026; Table 9.1). There were no other statistically significant differences in male maturity stages between the two sampling areas otherwise.

There was no significant difference (P>0.05) between the proportions of female American plaice surveyed between HSE and the 50 km HRA in 2015 (Table 9.2).

Table 9.1 Frequencies (%) of maturity stages of male American plaice from the 2015 HSE EEM biological survey.

Area	N	Immature (100)	Spent L (110)	Mat P (140)	Partly Spent (150)	Spent P (160)	Spent P Mat N (170)	Mat N (180)
50 km Hibernia Reference Area	28	17.9	0.0	60.7	17.9	0.0	0.0	3.6
Hibernia Southern Extension	32	3.1	21.9	56.3	18.8	0.0	0.0	0.0
P-Value*		0.088	0.026	0.796	0.756	1.000	1.000	0.467
Notes: Maturity stages were defined according to DFO Procedures (Templeman et al., 1978). *P-Value obtained with the Fisher Exact Test								

Table 9.2 Frequencies (%) of maturity stages of female American plaice from the 2015 HSE EEM biological survey.

Area	N	Immature (500)	Spent L (510)	Mat A-P 520	Mat B-P (530)	Mat C-P (540)	Partly Spent P (550)	Spent P (560)
50 km Hibernia Reference Area	22	4.5	59.1	0.0	9.1	13.6	0.0	13.6
Hibernia Southern Extension	18	0.0	61.1	16.7	22.2	0.0	0.0	0.0
P-Value*		1.000	1.000	0.083	0.381	0.238	1.000	0.238
Notes: Maturity stages were defined according to DFO Procedures (Templeman et al., 1978). *P-Value obtained with the Fisher Exact Test								

9.2 Biological Characteristics

Morphometric examination of American plaice surveyed included comparison of the total length, gutted body weight, liver and gonad weights and age of fish sampled between HSE and the 50km HRA. The statistical tests used for comparison of means between sampling areas were the Unpaired t-test, or the non-parametric Mann-Whitney Rank Sum test for sample groups that were not normally distributed (HMDC, 2015a). In addition to comparison of morphometric characters, condition indices were also compared as a metric to assess the energetic status of individual animals (Stevenson & Woods, 2006). The three condition indices applied for the Hibernia program are Fulton's Condition Index (FCI), hepatosomatic index (HSI) and gonadosomatic index (GSI) (HMDC, 2015a). Fulton's condition index is an indicator of overall body mass (length/ weight relationship) (Stevenson & Woods, 2006). The HSI is an indicator of liver mass relative to the size of the fish and provides an indication of an animals' energy stores (Jan & Ahmed, 2016). The GSI is an indicator of gonad size relative to the size of the fish and monthly variations provide an indicator of reproductive seasonality (Jan & Ahmed, 2016).

Comparison of American plaice morphometrics sampled between each surveyed area reveals the size of male fish surveyed in 2015 was similar between the two areas (Table 9.3). The only statistically significant difference between the two areas was the HSI means were significantly (P=0.010) greater among the HSE males compared to those collected around the 50 km HRA.

In contrast, comparison of female American plaice morphometric traits between the two areas revealed several significant differences (Table 9.4). Females collected from HSE were significantly longer (P=0.017), heavier intact (P=0.009), heavier gutted (P=0.044), had heavier livers (P=0.050) and were on average approximately two years older than females surveyed from the Reference Area (P=0.007; Table 9.4). There was no significant difference between any of the condition indices between the 50km HRA and HSE survey females (P>0.05; Table 9.4).

However, among these morphometric characteristics reported in Tables 9.3 and 9.4, certain dependents are likely to co-vary with a given variable. For example, the gutted weight of fish is generally expected to increase with length; and liver and gonad weight are expected to increase with gutted weight (irrespective of GSI and HSI). To control for this, ANCOVA analysis of the log-log regression of the variable on the covariate was used to assess the significance of the adjusted means between sampling areas. In essence, this is another approach for assessing the equivalent of a condition factor. Among male American plaice collected from HSE and the 50 km 50 km HRA in 2015, only the adjusted means between liver weight and gutted weight was significantly different (P=0.013; Table 9.5) consistent with the results of evaluation of the mean HSI values (Table 9.3). Comparable analysis for female fish found no significant differences (P>0.05; Table 9.6) between any of the same variables and covariates, also consistent with the analyses of condition indices in Table 9.4.

Table 9.3 Biological Characteristics and Condition Indices of Male American Plaice (all maturity stages pooled) from the 2015 Hibernia EEM biological Survey.

Parameter	50 km HRA	HSE	P-Value[d]	Test Used
No. of Fish	28	32		
Length (cm)	32.1 ± 3.4	33.4 ± 3.6	0.236	MW
Total Body Weight (g)	280 ± 101.8	313.8 ± 107.4	0.310	t
Gutted Body Weight (g)	268.4 ± 119.7	262.5 ± 100.2	0.783	t
Liver Weight (g)	3.6 ± 1.7	4.2 ± 1.8	0.161	t
Gonad Weight (g)	3.4 ± 2.3	3.9 ± 2.6	0.621	t
Age (years)	6.4 ± 1.1	6.1 ± 1.9	0.331	t
Fulton's Condition Index[a]	0.8 ± 0.3	0.7 ± 0.1	0.134	t
HSI[b]	1.4 ± 0.4	1.6 ± 0.4	**0.010***	t
GSI[c]	1.3 ± 0.6	1.4 ± 0.6	0.447	t

Notes: All data are expressed as mean of raw values ± one standard deviation, * denotes P<0.05;
[a] Calculated as 100 x gutted body weight/length^3
[b] Calculated as 100 x liver weight/gutted body weight
[c] Calculated as 100 x gonad weight/gutted body weight
[d] p-Value obtained with the Unpaired t-test (t) or Mann-Whitney (MW) Rank Sum test

Table 9.4 Biological Characteristics and Condition Indices of Female American Plaice (all maturity stages pooled) from the 2015 Hibernia EEM biological Survey.

Parameter	50 km HRA	HSE	P-Value[d]	Test Used
No. of Fish	22	18		
Length (cm)	39.2 ± 4.1	43 ± 5.4	**0.017***	t
Total Body Weight (g)	529.2 ± 142.8	761.7 ± 320.8	**0.009***	t
Gutted Body Weight (g)	441.1 ± 142.9	568.1 ± 220.1	**0.044***	t
Liver Weight (g)	6.9 ± 2.2	9.6 ± 4.0	**0.050**	MW
Gonad Weight (g)	20.5 ± 17.7	36.3 ± 43.9	0.166	t
Age (years)	8.8 ± 1.8	10.7 ± 2.5	**0.007***	MW
Fulton's Condition Index[a]	0.7 ± 0.1	0.7 ± 0.1	0.737	t
HSI[b]	1.7 ± 0.8	1.8 ± 0.8	0.739	t
GSI[c]	4.7 ± 4.2	6.3 ± 6.7	0.381	t

Notes: All data are expressed as mean of raw values ± one standard deviation, * denotes P<0.05;
[a] Calculated as 100 x gutted body weight/length^3
[b] Calculated as 100 x liver weight/gutted body weight
[c] Calculated as 100 x gonad weight/gutted body weight
[d] p-Value obtained with the Unpaired t-test (t) or Mann-Whitney (MW) Rank Sum test

Table 9.5 Adjusted Means of Male American Plaice (all maturity stages pooled) from the 2015 Hibernia Southern Extension Survey.

Variable	Covariate	Adjusted Means		P-Value[a]
		50 km HRA	HSE	
Gutted weight	Length	264.7	236.9	0.062
Liver Weight	Gutted weight	3.44	4.16	**0.013***
Gonad weight	Gutted weight	2.95	3.40	0.259

Notes: Adjusted means are predictive mean variable at overall mean covariate
[a] P-Value obtained after ANCOVA analysis of log-log regression of variable on covariate.
* Denotes significant (P<0.05)

Table 9.6 Adjusted Means of Female American Plaice (all maturity stages pooled) from the 2015 Hibernia Southern Extension Survey.

Variable	Covariate	Adjusted Means		P-Value[a]
		50 km HRA	HSE	
Gutted weight	Length	467.18	463.04	0.932
Liver Weight	Gutted weight	7.46	8.25	0.371
Gonad weight	Gutted weight	19.90	19.85	0.993

Notes: Adjusted means are predictive mean variable at overall mean covariate
[a] P-Value obtained after ANCOVA analysis of log-log regression of variable on covariate.
* Denotes significant (P<0.05)

As a subset of all fish surveyed from both areas, the biological characteristics of the maturity stage most prevalent between the two study areas, Spent females L (510) (Table 9.2), were also compared. Among females classified in this maturity index, both length (P=0.018) and age (P=0.028) were significantly different (Table 9.7) with females from HSE generally being slightly older and larger relative to those at the 50 km HRA.

Table 9.7 Biological Characteristics and Condition Indices of Female American Plaice Spent During the Previous Year (F510) from the 2015 HSE Survey.

Parameter	50 km HRA	HSE	P-Value[d]	Test Used
No. of Fish	13	11		
Length (cm)	39.0 ± 3.3	42.4 ± 6.1	**0.018***	MW
Total Body Weight (g)	523.5 ± 127.1	703.1 ± 297.6	0.073	MW
Gutted Body Weight (g)	429.2 ± 144.1	575.8 ± 257.6	0.147	MW
Liver Weight (g)	7.1 ± 2.2	9.5 ± 4.3	0.148	MW
Gonad Weight (g)	14.7 ± 7.1	19.5 ± 11.8	0.271	MW
Age (years)	8.5 ± 1.6	10.5 ± 2.8	**0.028***	MW
Fulton's Condition Index[a]	0.7 ± 0.2	0.7 ± 0.1	0.952	t
HSI[b]	1.8 ± 1.0	1.8 ± 0.9	0.819	t
GSI[c]	3.8 ± 2.9	3.3 ± 1.5	0.574	t

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

9.3 Gross pathology

No indications of disease, abnormalities or lesions were evident on fish sampled during the 2015 EEM program. General assessments were conducted on the eyes, skin, fins, gills, heart, liver, gonads, spleen, and body cavity. A few parasitic copepods were noted on gills as well as nematodes (roundworms) in some of the viscera, but the incidence of these parasites was not quantified.

9.4 Hematology

Blood flows continuously through the body and integrates multiple levels of biological organization including the physiology, histology, cytology and hormonal regulation within and among organs and tissues (Corrêa, Abessa, Santos, da Silva, & Seriani, 2016). As a result, hematological changes are strongly related to the response of fish to environmental variations and are therefore considered good indicators of fish health (Corrêa et al., 2016). Blood smears were collected as part of the EEM design plan for examination of differential cell types and condition of red blood cells (HMDC, 2013). The hematology (blood-smear) samples collected during the 2015 EEM biological cruise were not suitable for analysis. A similar technical challenge occurred during the previous (2014) EEM survey (HMDC, 2015a). However, it is a challenge that will be addressed in future EEM programs.

9.5 Mixed Function Oxygenase Activity

Fish liver detoxification enzymes, the mixed function oxygenases (MFOs), are a family of membrane-bound enzymes that facilitate the transformation of aromatic and lipophilic compounds into more water-soluble ones for excretion (Hodson et al., 1991; Van Der Oost, Beyer, &

Vermeulen, 2003b). Measurement of MFO activity is used as a monitoring tool to indicate the presence of industrial chemical contamination in fish (Hodson et al., 1991; Van Der Oost et al., 2003b). To quantify MFO, the fluorometric activity of one of the most important biotransforming enzymes in this group, ethoxyresorufin-O-deethylase (EROD), is measured via spectrophotometry (Brooks, Pampanin, Harman, & Merete, 2015; Hodson et al., 1991) according to the EEM design plan (HMDC, 2013). Basal EROD activity and response to exposure of a contaminant can vary between genders and sexual maturity may have the greatest influence on this response in certain species of fish (Kirby, Neall, & Tylor, 1999; Mathieu et al., 2011). Median EROD values were nearly three-fold greater among males of all maturity stages compared to females (Figures 9.1, 9.2). However, analysis of hepatic EROD levels in sampled males (maturity stages combined) in 2015 found no significant difference between HSE and the 50km HRA (P=0.818; Figure 9.1). There was also no significant difference in hepatic EROD levels among females (all maturity stages combined) between HSE and the 50km HRA in 2015 (P=0.977; Figure 9.2). Likewise among spent females L (510), which were the most prevalent maturity stage between the two study areas, there was also no significant difference between specimens collected from both sampling areas (P=0.417; Figure 9.3).

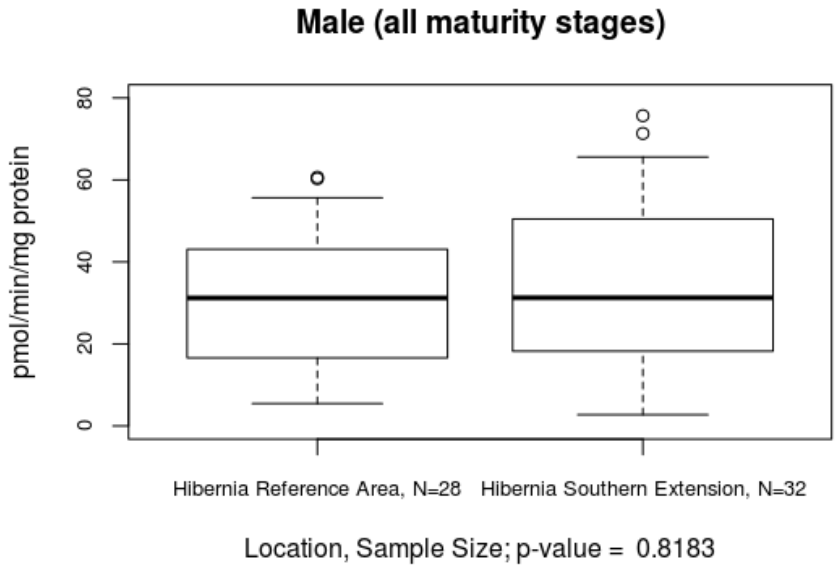


Figure 9.1 Boxplots of EROD activity in the liver of male American plaice (all maturity stages combined) at HSE and 50 km HRA.
Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

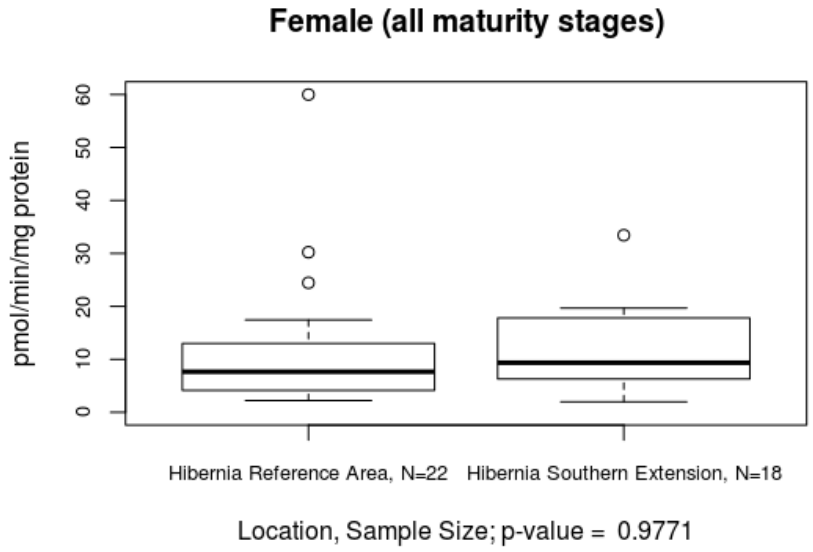


Figure 9.2 Boxplots of EROD activity in the liver of female American plaice (all maturity stages combined) at HSE and 50 km HRA.
Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

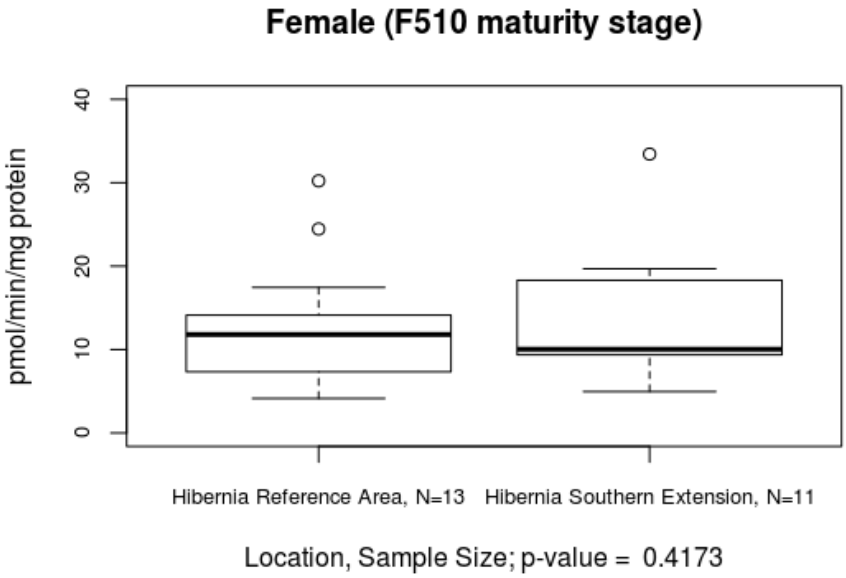


Figure 9.3 Boxplots of EROD activity in the liver of the most prevalent maturity stage of American plaice at HSE and 50 km HRA, F510 females.
Horizontal lines represent median catch rates, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

9.6 Histopathology

Chronic exposure of fish to crude oils is known to produce histopathological changes (reviewed by Khan, 1990; Khan & Kiceniuk, 1984). Consequently, fish liver and gill histopathology is being used more commonly in biological monitoring and assessment programs (Mathieu et al., 2011). Potential effects of exposure to contaminants may not necessarily be broadly apparent (macroscopically) among surveyed fish. Therefore, to survey for evidence of fine-scale pathological abnormalities in specimens, microscopical histological examinations of tissue samples have been conducted. Briefly, fish tissue samples were preserved in formalin, embedded in wax, sectioned into thin (6 µm) slices and mounted on slides according to standard histological methods (HMDC, 2013).

The histological parameters examined for American plaice tissue samples collected from HSE and the 50km HRA were assessed microscopically for the presence of different lesions. The liver lesions identified are listed in Tables 9.8 and defined according to standard methods (Khan, 1990; Khan et al., 1994; Khan & Kiceniuk, 1984; Khan, 1995). In 2015, there were several forms of hepatic lesions (cellular abnormalities) observed among specimens including bile duct hyperplasia, nuclear pleomorphism, clear cell foci, hepatocellular carcinomas, macrophage aggregates and hepatocellular vacuoles (Table 9.8). However, there were no significant differences observed between the prevalence of these pathologies at either HSE or the 50km HRA ($P>0.05$; Table 9.8) and therefore none are considered Project-related effects.

Histopathology is highly dependent on level of expertise with potential for inter-observer variability (as reviewed by Wolf et al. 2015). Nuclear pleomorphism, megalocytic hepatosis, and clear cell foci have not been detected in previous Hibernia EEM years. However, as these lesions are not significantly different from the reference area, the higher prevalence of lesions in 2015 is likely due to observer variability rather than an effect of the Project. Comparisons between HSE and previous Hibernia Platform reports are not possible, as they were assessed by another laboratory.

Table 9.8 Number of American Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions in the 2015 HSE Survey

Lesions	50 km HRA (n = 50)		HSE (n = 50)		P-Value
	Fish Affected	Prevalence	Fish Affected	Prevalence*	
Normal tissue	15	30%	12	24%	0.653
Nonspecific necrosis	0	0%	2	4%	0.495
Bile duct hyperplasia	8	16%	11	22%	0.611
Nuclear pleomorphism	9	18%	11	22%	0.803
Megalocytic hepatosis	0	0%	0	0%	1.000
Eosinophilic foci	0	0%	0	0%	1.000
Basophilic foci	0	0%	0	0%	1.000
Clear cell foci	8	16%	16	32%	0.100
Hepatocellular carcinoma	7	14%	4	8%	0.525
Benign tumor	0	0%	0	0%	1.000
Cholangioma	0	0%	0	0%	1.000
Cholangiofibrosis	0	0%	0	0%	1.000
Increase in mitotic activity	0	0%	0	0%	1.000
Macrophage aggregates[a]	8	16%	7	14%	1.000
Macrophage aggregates[b]	0	0%	0	0%	1.000
Hydropic vacuolation	0	0%	0	0%	1.000
Hepatocellular vacuoles	28	56%	33	66%	0.412

[a] Defined as scores less than 3 on a 0-7 relative scale
[b] Defined as scores more than 3 on a 0-7 relative scale
*Denotes a significant difference between sampling areas (P<0.05)
**Prevalence is the percentage of fish affected

Gill samples were examined microscopically and characterized according to the lesions listed in Table 9.9 (HMDC, 2013). A low incidence of several lesions were observed, including thin lamellae, distal hyperplasia (localized thickening), epithelial lifting, tip hyperplasia, telangiectasia, basal hyperplasia, fusion, oedema (excess fluid) (Table 9.9). However, there was no significant difference between the prevalence of these pathologies observed among American plaice sampled from either HSE or the 50 km HRA (P>0.05; Table 9.9) and therefore none are considered Project-related effects.

Table 9.9 Percentages of Secondary Lamellae Affected by Lesions and Scale of Affected Lesions in the Gill Tissues of American Plaice from the 2015 HSE Survey

Lesion	HSE (n=50)	50 km HRA (n=50)	P-Value
Percentage of Secondary Lamellae Affected by Lesions			
Thin lamellae	0.05 ± 0.24	0.12 ± 0.38	0.301
Distal Hyperplasia	0.19 ± 0.44	0.27 ± 0.62	0.632
Epithelial Lifting	0.14 ± 0.49	0.16 ± 0.97	0.472
Tip Hyperplasia	0.16 ± 0.27	0.11 ± 0.22	0.269
Telangiectasia	0.05 ± 0.26	0.00 ± 0.04	0.552
Basal Hyperplasia	0.26 ± 0.64	0.33 ± 0.71	0.472
Fusion	0.71 ± 1.34	1.06 ± 1.8	0.602
Oedema	0.06 ± 0.17	0.03 ± 0.09	0.147
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.10 ± 0.36	0.24 ± 0.59	0.141
Notes: All data are mean percentage of lamellae presenting the lesion ± standard deviation p-Value obtained with the Mann-Whitney Rank Sum test on arcsine square root-transformed percentages of the lesions *Denotes a significant difference between sampling areas (P<0.05)			

9.7 Summary

The only statistically significant difference in fish health indices among American plaice that were surveyed in 2015 was mean HSI values that were significantly higher among males at HSE relative to that of the Reference Area (Tables 9.3, 9.10). With the exception of female fish on average being older and slightly larger at HSE compared to those at the 50 km HRA (Table 9.4), all other morphometric characters, condition indices, biological assays and histopathological examinations were not significantly different between fish collected from both locations. Similar observations have been made in a comparable fish health monitoring program conducted at the Terra Nova production field (Mathieu et al., 2011). Approximately 500 fish were examined over a five year period (2000-2006) for condition, visible skin and organ lesions, hepatic EROD levels, haematology, a variety of histopathological indices in liver and gills (Mathieu et al., 2011). With the exception of a slight elevation of hepatic EROD levels observed in fish from the Terra Nova Development site in 2002, the suite of other health bioindicators were largely similar or generally absent between the Development and Reference sites for the Terra Nova program, supporting the hypothesis of no significant Project effects on the health of American plaice from that program (Mathieu et al., 2011). Several fish health indicators have varied significantly between the Hibernia Platform and the 50 km HRA across monitoring years including HIS, GSI, EROD and liver histopathology that has largely been attributed to natural variation (HMDC 2017).

Table 9.10 Summary of Statistically Significant Results for HSE Fish Health Indicators in American Plaice.

Indicators	2011	2014	2015
Fulton's Condition Factor	No	No	No
Hepatosomatic Index (HSI)	No	No	Yes
Gonadosomatic Index (GSI)	Yes	No	No
Gross Pathology	No	No	No
Hematology	Yes	-	-
Mixed Function Oxygenase (MFO)	No	No	No
Liver Histopathology	No	No	No
Gill Histopathology	No	No	No

10.0 DISCUSSION AND INTERPRETATION

The Hibernia Program is committed to conducting an environmental effects monitoring (EEM) program to detect changes in the surrounding environment that may be attributed to the Project (HMDC, 2013). The baseline characterization of the Hibernia Southern Extension (HSE) production field was conducted in 2011 and the first year of the Environmental Effects Monitoring (EEM) program was completed in 2014 after the initiation of drilling in January of that year (HMDC, 2015a). The HSE EEM program consists of sediment and commercial fish sampling components to assess the chemistry and toxicity of sediment quality, and the health, size and body burden chemistry of fish (as per Table 3.1). The results of the Year 2 (2015) EEM program for HSE are discussed below with particular emphasis given to parameters that may be associated with drilling operations at HSE (e.g., Project-related effects), such as barium and hydrocarbons (DeBlois, Paine, et al., 2014a; Trefry et al., 2013; Whiteway et al., 2014).

10.1 Sediment

Bottom substrata are where organic pollutants and chemical contaminants tend to accumulate (Hyland et al., 2005) and quantifying metals in sediment provides an indication of sediment quality (Larner et al., 2008). Metals can accumulate on many substrate particle sizes; high concentrations of metals are more commonly associated with finer sediment fraction material because of their relatively large surface areas as main sites for collecting inorganic compounds (reviewed by Horowitz, 1985). In addition, clay-size particles can function as “mechanical” substrates (layers) on which trace metals can physically concentrate without chemical interaction with the sediment particle (reviewed by Horowitz, 1985).

Overall, the predominant sediment type at HSE is sand (mean of all HSE stations 80%), followed by gravel, clay and silt respectively. Since the 2011 baseline survey, the proportion of sand in sediment samples within the Near-field (≤ 1,000 m) appears to be increasing in each successive survey program (Figure 4.2). Sand has been negatively correlated with every sediment chemistry analyte examined in 2015 (Table 5.6), and is less commonly associated with elevated concentrations of organic matter (Sparkes et al., 2015).

In contrast, several analytes were significantly positively correlated (r>0.5) with silt and clay. The analytes iron, vanadium, barium, fuel and lube range hydrocarbons (>C_{10}-C_{21} and >C_{21}-C_{32} respectively) were all significantly positively correlated (r>0.5) with silt while barium, weak-acid extractable barium, fuel range hydrocarbons (>C_{10}-C_{21}) and organic carbon were significantly positively correlated (r>0.5) with clay (Table 5.6). In 2011, variations in barium and fuel range hydrocarbon concentrations were associated with higher concentrations of silt. All other analytes were screened-out of further statistical analysis.

The increases among these analytes in the Near-field observed in 2015 were largely centralized around the 250 m stations surrounding the EDC. Of the analytes listed above, only barium, weak acid barium and fuel range hydrocarbons likely had a Project-related effect.

10.2 Barium

Barium sulphate (a.k.a. barite, $BaSO_4$) is one of the main, and least toxic, components of drilling muds; it has extremely low solubility and is used as a marker for identifying drilling mud in sediment by quantifying its changes in concentration (Bakhtyar & Gagnon, 2012; DeBlois, Tracy, et al., 2014; Neff, 2008; Trefry et al., 2013). The concentration of barium has increased significantly around the HSE EDC since the 2011 baseline survey (Figure 5.14) and indicate a Project-related effect (significant Year X Distance interaction) in the Near-field (Table 5.13). The highest concentrations of barium (2,900, 2,600 and 2,500 mg/kg respectively) were at stations N-250, E-250 and W-250, this was more than a six-fold increase in detected levels for this analyte in 2015 over the previous EEM (2014) survey. Additionally, HSE 2015 barium levels were higher than levels detected during the Hibernia Platform EEM for all years (except 1994 and 2000 where highest levels were > 3,000 mg/kg) (HMDC, 2017).

Consistent with this, the spatial distribution of weak-acid extractable barium has also significantly increased around the EDC since baseline. Weak acid extractable barium was the only analyte to have a significant Project-related effect when examined at the Whole-field level (Table 5.14). This increase appears to be the most pronounced change among all the analytes and the increased concentration is evident at least to the 500 m stations (Figures 4.16, 5.16). The highest concentrations of weak-acid extractable barium were 35, 31 and 30 mg/kg at stations E-250, W-250 and N-250 respectively, the highest concentration of WA Ba is a four-fold increase over that of the previous (2014) EEM. Observed increases in barium and weak acid extractable barium are considered Project-related effects as the Year X Distance interactions in the Near-field analyses were also highly significant ($P<0.001$) for both (Tables 5.13, 5.14). SBM drill cutting discharges from the HSE between September 2014 to August 2015 were estimated to be 7.12 tonnes/day. Barium and weak acid leachable barium are analytes associated with drill cuttings deposition and accumulation in the Near-field (DeBlois, Paine, et al., 2014b; Pozebon et al., 2005; Trefry et al., 2013).

10.3 Hydrocarbons

Fuel range hydrocarbons indicated a Project-related effect in the Near-field (Tables 5.15, 5.21). Similar to barium described above, the spatial abundance of fuel range hydrocarbons ($>C_{10}$-C_{21}), appears to have increased most notably around the EDC since the 2011 baseline survey (Figure 4.17); mean concentrations of fuel range hydrocarbons have increased progressively from 1.18 mg/kg in 2011, to 5.37 mg/kg in 2014 and 78.04 mg/kg in 2015. Statistical analysis indicates that these significant increases are a Project-related effect. Likewise, the highest concentrations detected in 2015 were 510, 430 and 350 mg/kg at stations E-250, N-250 and W-250 respectively. However, fuel range hydrocarbons are another analyte associated with drill cuttings deposition and accumulation in the Near-field (DeBlois, Paine, et al., 2014b; Pozebon et al., 2005; Trefry et al., 2013).

The spatial distribution of lube range hydrocarbons ($>C_{21}$-C_{32}) in 2015 appeared to be largely similar to that of fuel range hydrocarbons. The stations proximal to the EDC had the highest concentrations of lube range hydrocarbons including E-250, N-250 and W-250 (2.6, 2.3 and 2.1 mg/kg respectively). However, statistical analysis indicates that these increases are not a Project-

related effect in the Whole-field or Near-field (Tables 5.16, 5.17). Overall the pattern of increasing concentration around the EDC appears to be generally similar to that of fuel range hydrocarbons although to a lesser extent; the mean concentration of lube range hydrocarbons has increased since baseline (0.73 mg/kg in 2011 vs 0.80 mg/kg in 2015).

10.4 Other Organics

Sulphide and ammonia analysis were conducted in whole sediment (HMDC, 2013). Sediment sulphides provide an indicator of biological response associated with excessive organic enrichment in the benthic marine environment (reviewed by Hamoutene, 2014). The breakdown of excessive amounts of organic matter in marine sediment can produce oxygen depleted conditions (low dissolved oxygen) thereby promoting buildup of toxic by-products of anaerobic metabolism such as ammonia and sulphide (Hyland et al., 2005; Kanaya, Uehara, & Kikuchi, 2016). Increasing organic content of sediment is often covarying with sediment particle size as well as other chemical stressors (Hyland et al., 2005). Moreover, the physiochemical parameters associated with the breakdown of hydrocarbons in marine sediment (dissolved sulphide, volatile solids, organic carbon, nitrogen and particle size) tend to covary together (Steichen et al., 1996; Whiteway et al., 2014). In their review of critical points of total organic carbon (TOC) in the benthic marine environment, Hyland and others (2005) examined macrofaunal and TOC data from marine systems around the northern hemisphere (including the North Atlantic) for patterns of association consistent with conceptual model predictions. This was completed to predict critical TOC concentrations that could be associated with risks of adverse biological impacts such as reduced species richness due to biological loading. They concluded that risks are likely to be low at TOC concentrations less than approximately 10 mg/g and high at concentrations exceeding approximately 35 mg/g. The mean concentrations of total organic carbon (TOC) were low at both the HSE field 2.5 mg/g (Table 4.1) and at the 1- and 7-16,000 m HRA 0.3 mg/g (Table 4.2). There was no evidence of a Project-related effect for any of these organic analytes.

10.5 HSE 2015 Sediment Chemistry Summary

Overall in the HSE 2015 EEM stations W-250, N-250 and E-250 were most commonly associated with higher detected levels of analytes. The majority of these effects are confined to the Near-field surrounding the EDC, and in most cases (with the exception of weak acid extractable barium), the levels at stations 500 m and beyond are statistically indistinguishable from the Far-field (6,000 m and 16,000 m) stations. Multivariate analysis of sediment chemistry results showed a mildly significant interaction ($P<0.05$); supporting the accompanying nMDS plots that suggest that Project-related changes in the 250 m and 500 m distance category are occurring (Figures 5.24 and 5.25). Multivariate analysis revealed that for Distance, 250 m and 500 m and 6,000 m and 16,000 m (all P values ≤ 0.05) categories differed significantly from each other in all years, but 250 m only differed from 1,000 m from 2014 onwards, which coincides with the onset of West Aquarius drilling operations at HSE. Alterations in the Near-field would be expected during drilling operations; significant increases in barium and hydrocarbon analytes are typical at Near-field stations (within approximately 250 m) from offshore drilling operations (DeBlois, Paine, et al., 2014b; Pozebon et al., 2005; Trefry et al., 2013) and these are confirmed as statistically significant Project-related effects based on the HMDC study design.

10.6 HSE 2015 Sediment Toxicity Analyses

Evaluation of water and/or sediment using standardized toxicity tests (e.g., bioassays) improve the capability of an EEM program to ascertain whether contaminants may be having an effect on living organisms (reviewed by Martinez-Haro et al., 2015). Benthic fauna are ideal candidate species because they live in close association with sediment substrate where contaminants tend to accumulate (Hyland et al., 2005). Three bioassays were conducted as part of HSE 2015 EEM program: Microtox, juvenile polychaete growth and survival, and amphipod survival.

Overall, despite changes in sediment chemistry characteristics, the results of sediment toxicity assays indicate no significant Project-related effects. Rather, according to amphipod and polychaete assay results, the quality of sediment around HSE appears to be consistent (Figure 6.1, 6.2) or improving (Figures 6.3-6.6) relative to baseline. The amphipod tests in particular are considered a more reliable assay as it has also been shown to identify sediments that are highly contaminated with fuel range hydrocarbons ($>C_{10}$-C_{21}) and barium associated with synthetic based muds at other offshore production fields in the area (e.g. Terra Nova) (Whiteway et al., 2014). In contrast, Microtox continues to have unpredictable results around the Near-field that are not correlated to any specific parameter between years. However, similar observations pertaining to Microtox have been reported for other EEM programs in the region. Specifically, the lack of association between Microtox toxicity results and discharge from offshore operations such as differences in fines and strontium around the Terra Nova production field, have called into question the usefulness of this assay for environmental monitoring (Whiteway et al., 2014). Moreover, other offshore oil and gas monitoring studies also describe Microtox test results as “inconclusive” (Radovic et al., 2012).

10.7 HSE 2015 Biological Survey

The overall catch rates of American plaice from the 50 km HRA compared to the catch rates around HSE have varied since baseline and were highest in 2014. Although the catch rates of American plaice decreased in 2015 compared to 2014, they were very similar to catch rates of 2011 (Figure 8.3). The 50 km HRA has consistently had slightly higher catch rates relative to HSE (Figure 8.3). The majority of larger fish sampled were females (Figure 8.4). This pattern is representative of the sexual dimorphism in size for this species (Swain & Morgan, 2001). In addition, the greater proportion of larger male and female fish sampled were collected in proximity to the HSE field.

10.7.1 Liver Metals

Detectable metals (anything ≥RDL) in liver tissues included arsenic, cadmium, cadmium, copper, iron, manganese, selenium, silver, vanadium, zinc and mercury (Table 8.2). These analytes were all detected at both HSE and the 50km HRA in 2015. With the exception of cobalt and chromium, these are the same metal analytes that were detected in liver tissues from both sampling areas in 2014. Cobalt was not detected in 2014 and chromium, which had been detected in three liver samples from HSE in 2014, was not detected in 2015. Zinc was the only analyte to have a significant Year X Area interaction (P=0.001) and increasing values of this analyte in HSE liver

samples compared to the 50km HRA is suggestive of a Project-related effect (Figure 8.6; Table 8.11).

The prevalence of these metal analytes in liver tissues of American plaice appears to be common on the Grand Banks. In a similar EEM monitoring program for the Terra Nova offshore production operation, over a ten-year (2002-2010) EEM survey period, several of the metal analytes reported here including: arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were commonly detected in American plaice composite liver samples (DeBlois, Kiceniuk, et al., 2014). In that same study, DeBlois and others (2014) reported, with the exception of manganese, concentrations were strongly positively correlated with one another.

10.7.2 Fillet Metals

Metals are naturally present in the environment and it is important to note that not all metals are hazardous to fish and humans (e.g. iron, copper, zinc and selenium) (Bosch, 2015). Moreover, uptake of metals can vary broadly among fish species, within species and within an individual organ (Bosch, 2015). There was a notable reduction in the number of metal analytes detected in fish fillets in 2015 with only arsenic, mercury, selenium and zinc detected. Comparatively, chromium, iron, manganese and nickel, which had been detected in a single specimen from HSE in 2014, were not detected in any specimen from either HSE or the 50 km HRA in 2015. Although selenium was again detected in a single specimen at HSE (0.54 mg/kg concentration), it was also detected in a single specimen from the 50 km HRA (0.51 mg/kg concentration) relative to an RDL of 0.5 mg/kg. The remaining three metal analytes (arsenic, mercury and zinc) were detected in all ten samples from both areas (HSE and 50km HRA). Zinc was the only analyte to have a significant Year X Distance interaction ($P<0.05$) in the Near-field; however, the results appear to indicate an actual decrease in the median value of zinc at HSE relative to those sampled from the 50km HRA (Figure 8.6) and therefore would not be considered consistent with a Project-related increase in zinc contamination. No barium was detected in any tissue samples from HSE or the 50 km HRA (Chapter 8).

10.7.3 Liver Hydrocarbons

In 2015 all composite liver samples from HSE contained detectable concentrations of fuel ($>C_{10}$-C_{21}) and lube range hydrocarbons ($>C_{21}$-C_{32}). At the 50 km HRA, eight of ten composite liver samples had detectable concentrations of fuel range hydrocarbons and all had detectable levels of lube range hydrocarbons, consistent with previous years. Fuel range ($>C_{10}$-C_{21}) hydrocarbon concentrations in liver had a significant Year x Distance interaction ($P<0.05$; Table 8.15) in the Near-field indicating a Project-related effect for this analyte. This represents a continuing trend for this analyte as a significant Year x Distance interaction was also observed in composite liver samples from American plaice in the 2014 EEM program (HMDC, 2015a).

Lube range ($>C_{21}$-C_{32}) hydrocarbons were also detected in all liver samples from HSE and the 50 km HRA in 2015. ANOVA analysis indicated this was significant by Year ($P<0.001$) and by Distance ($P<0.001$) but is not a Project-related effect (Year x Distance interaction term was not significant $P>0.05$; Table 8.16).

American plaice composite liver samples from Terra Nova and its associated Reference Area have frequently contained compounds in the >C_{10}-C_{21} hydrocarbon range and consistently contained compounds in the >C_{21}-C_{32} range (DeBlois, Kiceniuk, et al., 2014). From this same study, gas chromatography mass spectrophotometry (GCMS) analysis of hydrocarbon compounds in 2008 detected potential petroleum derived hydrocarbon contamination in the >C_{21}–C_{32} range in a single Reference Area sample of fish tissue (DeBlois, Kiceniuk, et al., 2014). The majority of GCMS-detected hydrocarbon compounds in remaining liver samples were consistent with those of natural compounds such as squalene (DeBlois, Kiceniuk, et al., 2014).

10.7.1 Fillet Hydrocarbons

No fuel range (>C_{10}-C_{21}) hydrocarbons were detected in filet samples from HSE in 2015. Two fillet samples out of ten in the HSE area had lube range (>C_{21}-C_{32}) hydrocarbons detected in them at concentrations of 24 and 26 mg/kg (relative to an RDL of 15 mg/kg); none were detected from the 50 km HRA samples. This analyte has not been detected in fish fillets previously at HSE; however, detection of >C_{21}-C_{32} hydrocarbons has occurred infrequently in American plaice fillet samples in the Terra Nova Offshore monitoring program from the same region of the Grand Banks (DeBlois, Kiceniuk, et al., 2014).

10.7.2 Sensory/Taint Testing

Sensory evaluation panelists were not able to qualitatively discriminate American plaice fillet samples derived from fish collected from the HSE study area versus the 50 km HRA. For the 2015 EEM program, only 9 of 24 panelists could correctly discriminate samples and these results are not significant ($\alpha = 0.05$) according to the Triangle Test. The second sensory test performed (the Hedonic Test) was to evaluate if a preferential taste could be discriminated between each sampling area. There was no significant difference in the ratings of samples from either area (P=0.601).

10.8 Fish Health

The effects of crude oil exposure on organs of adult fish have been described in several laboratory studies (Arinc, Sen, & Bozcaarmutlu, 2000; Hodson et al., 1991; Marty et al., 2010). In contrast, studies describing the histopathological effects of environmental exposure to oil spills have rarely been documented (reviewed by Marty, Okihiro, Brown, Hanes, & Hinton, 1999). Therefore, it is important to assess the presence or absence of health effects under natural ecological conditions of exposure to inform environmental and fisheries management decisions (Mathieu et al., 2011).

10.8.1 Biological Characteristics and Condition of Fish

Morphometric examination of American plaice included comparison of total length, gutted body weight, liver and gonad weights and age of fish sampled between HSE and the 50 km HRA. Condition indices were also compared as a metric to assess the energetic status of individual animals (Stevenson & Woods, 2006). The three condition indices applied for the Hibernia program were Fulton's Condition Index (FCI), hepatosomatic index (HSI) and gonadosomatic index (GSI) (HMDC, 2015a). Comparison of morphometrics of American plaice sampled between each

surveyed area revealed the size of male fish surveyed in 2015 was similar between the two areas (Table 9.3). The only statistically significant difference between the two areas was median HSI values which were significantly (P=0.010) greater among males collected from the 50 km HRA compared to those from HSE.

In contrast, comparison of female American plaice morphometric traits between the two surveyed areas revealed several significant differences (Table 9.4). Females collected from HSE were significantly longer, heavier intact (whole), heavier gutted, had heavier livers and were on average approximately two years older than females surveyed from the Reference Area (P<0.05; Table 9.4). However, there was no significant difference between any of the condition indices between 50 km HRA and HSE surveyed females (P>0.05; Table 9.4).

10.8.2 Pathology

Gross pathology of the surveyed fish found no indications of disease, abnormalities or lesions evident on fish sampled during the 2015 EEM program. A few parasitic copepods were noted on gills as well as nematodes (roundworms) in some of the viscera, however the incidence of these parasites was not quantified.

10.8.3 Haematology

Similar to the 2014 EEM survey (HMDC, 2015a), the hematology (blood-smear) samples collected during the 2015 EEM biological cruise were not suitable for analysis (see section 9.4).

10.8.4 Mixed Function Oxygenase (MFO) Activity

To quantify MFO, the fluorometric activity of one of the most important biotransforming enzymes in this group (EROD), is measured via spectrophotometry (Brooks et al., 2015; Hodson et al., 1991). Basal EROD activity and response to exposure of a contaminant can vary between genders, and sexual maturity may have the greatest influence on this response in certain species of fish (Kirby et al., 1999; Mathieu et al., 2011). Median hepatic EROD levels were nearly three-fold greater among males of all maturity stages compared to females (Figures 9.1, 9.2). However, analysis of 2015 hepatic EROD levels in males (all maturity stages combined) found no significant difference between livers collected from HSE and the 50 km HRA (P=0.818; Figure 9.1). There was no significant difference in 2015 hepatic EROD levels among females (all maturity stages combined) collected from the HSE and the 50 km HRA (P=0.977; Figure 9.2).

10.8.5 Histopathology

Chronic exposure of fish to crude oils is known to produce histopathological changes (reviewed by Khan, 1990; Khan & Kiceniuk, 1984). In 2015, there were several forms of hepatic lesions (cellular abnormalities) observed among specimens including bile duct hyperplasia, nuclear pleomorphism, clear cell foci, hepatocellular carcinomas, macrophage aggregates and hepatocellular vacuoles (Table 9.8). However, there were no significant differences observed between the prevalence of these pathologies at HSE compared to the 50 km HRA (P>0.05; Table 9.8).

Additional histopathology results were noted in the 2015 EEM that were not seen in previous years, including nuclear pleomorphism and clear cell foci. Histopathology in 2015 was conducted by Dr. Rasul Khan, an experienced researcher on the effects of contaminants on fish health (i.e. Khan 1990, 1995). Inter-observer variability is highly dependant on the expertise of the assessor (as reviewed by Wolf et al. 2015). As these lesions were not significantly different between HSE and the reference area in 2015, the higher prevalence of these lesions is likely due to observer variability and not an effect of the project. Going forward, comparisons across years will be conducted in years where the same assessor is used for fish histopathology.

10.8.6 Fish Health Summary

The only significant difference in fish health indices among American plaice in 2015 was median HSI values that were significantly higher at among males at HSE relative to those from the 50 km HRA (Tables 9.3, 9.10). HSI is an indicator of liver mass relative to the size of the fish and provides an indication of an animals' energy stores (Jan and Ahmed 2016). Though fish at HSE were no larger, they may have larger stores of energy, potentially from an artificial reef effect at HSE. With the exception of female fish on average being older and slightly larger at HSE compared to those at the 50 km HRA (Table 9.4), all other morphometric characters, condition indices, biological assays and histopathological examinations were not significantly different. Similar observations have been made from a comparable fish health monitoring program conducted at the Terra Nova production field (Mathieu et al., 2011). Approximately 500 fish were examined over a five year period (2000-2006) for condition, visible skin and organ lesions, hepatic EROD levels, haematology, a variety of histopathological indices in liver and gills (Mathieu et al., 2011). With the exception of a slight elevation of hepatic EROD levels observed in fish from the Terra Nova Development site in 2002, the suite of other health bioindicators were largely similar or generally absent between the Development and Reference sites for the Terra Nova program, also supporting the hypothesis of no significant Project effects on the health of American plaice from that program (Mathieu et al., 2011).

10.9 EEM Interpretation

The design of the EEM program is consistent with that of the Hibernia Platform in that critical elements of the receiving marine environment are being monitored to provide timely and beneficial information to detect any potential deleterious effects to the marine environment (HMDC, 2013). The monitoring hypotheses for the HSE EEM program are consistent with those of the Hibernia Platform EEM program and are stated in the *Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring Plan* (HMDC, 2013) as follows:

No. 1. Marine Fish Health

- H_0 = Approved releases of solids and liquids from HSE's drilling operations will not result in significant adverse environmental effects on marine fish (as assessed by fish health indicators and integrative assessment).
- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in significant adverse environmental effects on marine fish (as assessed by fish health indicators and integrative assessment).

No significant adverse environmental effects (as assessed by fish health indicators and integrative assessment) were found in the 2015 HSE EEM survey. Overall, the results of body burden (Chapter 8), and fish health assays (Chapter 9) were statistically indistinguishable between HSE and 50 km HRA samples. Therefore, the 2015 EEM data do not reject the null hypothesis No.1.

No. 2. Marine Fish Habitat

- H_0 = Approved releases of solids and liquids from HSE's drilling operations will not result in significant adverse environmental effects on marine fish habitat (as evaluated by sediment toxicity assays and integrative assessment).
- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in significant adverse environmental effects on marine fish habitat (as evaluated by sediment toxicity assays and integrative assessment).

Although several analytes associated with drill cuttings discharges (such as barium and fuel range hydrocarbons) have increased significantly in the Near-field since 2014, the effects are primarily localized at 250 m stations around the EDC (Chapters 4 and 5). Moreover, the quality of benthic substrate as assessed by the juvenile polychaete and amphipod survival assays have surpassed levels observed during baseline in 2011 (Chapter 6), and accordingly, it can be interpreted that no significant adverse environmental effects on fish habitat have resulted. Therefore, the 2015 EEM data do not reject the null hypothesis No.2.

No. 3. Marine Fish Taint

- H_0 =Approved releases of solids and liquids from HSE's drilling operations will not result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.
- H_A = Approved releases of solids and liquids from HSE's drilling operations will result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.

According to the sensory assays, panelists could not discriminate any taint contrast between American plaice fillet samples derived from HSE and the 50 km HRA. In addition, the levels of chemical analytes in American plaice liver and fillet tissues derived from HSE and the 50 km HRA were statistically indistinguishable with the exception of zinc being slightly lower in tissues from HSE. Therefore, the 2015 EEM data do not reject the null hypothesis No.3.

11.0 RECOMMENDATIONS AND CONCLUSIONS

Opportunities to improve the EEM program have been identified and are described as follows:

11.1 Sediment

Sediment monitoring: For several analytes such as aluminum, iron, manganese and vanadium that did not have a significant Project-related effect, there is a noted trend of increasing concentrations that should continue to be monitored.

Statistical analyses: Continue to implement multivariate analyses for statistical assessment of cumulative sediment chemistry and toxicity interactions. Consider integration of the spatial depiction of sediment analyte concentrations (two-dimensional plots) into the statistical examination section to present the sediment data more succinctly and cohesively. Toxicity bioassays: Microtox results are variable between survey years, have no correlation with sediment chemistry analytes and results are inconsistent with those of other toxicity bioassays at HSE. Moreover, the other toxicity assays rely on sentinel organisms such as amphipods who are among the most sensitive benthic fauna to contaminants (Swartz, Ditsworth, Schults, & Lamberson, 1986; Whiteway et al., 2014). The use of the Microtox assay should be revaluated with consideration of other studies which have described the test as inconclusive (Radovic et al., 2012) and called into question its usefulness within the context of offshore oil and gas environmental monitoring programs (Whiteway et al., 2014).

11.2 Biological

Body burden and taint testing: Certain analytes such as arsenic and mercury are commonly detected in fish fillet tissues, and concentrations vary interannually simultaneously within the Whole-field (HSE and 50 km HRA). Moreover, many of these same analytes reveal a similar pattern in association with the Terra Nova Program also on the Grand Banks (DeBlois, Kiceniuk, et al., 2014). Although the level of mercury detected in fillets is below the prescribed maximum defined by Health Canada of 0.5 mg/kg in the edible portion of retail fish (Health Canada, 2016), as a precaution, it should be considered that the sensory/taint evaluations not be conducted until after the body burden data has been reviewed for the sampling year (for all analytes). In the event that elevated detection levels are reported for fillet samples, restrictions towards eligible panelists may need to be considered (e.g. not recommended to participate if within a sensitive community category or potential for adverse interactions with certain medications).

Gross pathology: Consider incorporating a prescriptive protocol for documenting the gross pathology of fish being surveyed prior to dissection. A referenced standard would facilitate detection of subtle changes in the gross pathology of fish. For example, detecting changes in the abundance of parasites that are likely to be associated with gill filament deformities, as well as evidence of simultaneous parasitic infestations within hosts which is associated with a greater prevalence of infestation among populations of fish (Eaves, Ang, & Murray, 2014). Moreover, exposure to contaminants may also predispose fish to having reduced immunity towards diseases and parasites (Holdway, 2002). Documenting differences in the prevalence and abundance of parasites between study and Reference Area may provide additional evidence towards

interannual changes being regarded as more Whole-field or regional if associated with Project operations.

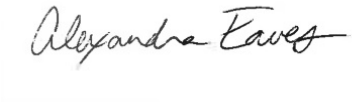
11.3 Conclusion

Overall, Project-related effects observed in the sediment monitoring program are consistent with results observed at other offshore oil and gas development locations and also show a highly localized effect (DeBlois, Paine, et al., 2014b; Pozebon et al., 2005; Trefry et al., 2013). The results of the fish health surveys and body burden analyses reveal that in general, there are no significant differences observed between fish collected from HSE compared to those collected from the 50 km HRA. Moreover, fish from either sampling area were organoleptically indiscernible. Therefore, all three null hypotheses of the HSE EEM program (HMDC, 2013) cannot be rejected based on the 2015 HSE EEM survey.

Yours sincerely,

Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited

Prepared by:



Alexandra Eaves, Ph.D.
Senior Scientist

Reviewed by:

James McCarthy, M. Sc.; Ph.D. Candidate
Associate Biologist

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