HIBERNIA MANAGEMENT AND DEVELOPMENT COMPANY LTD.

HIBERNIA ENVIRONMENTAL EFFECTS MONITORING PROGRAM (2020)

VOLUME I – INTERPRETATION

MARCH 21, 2023

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HIBERNIA MANAGAMENT AND DEVELOPMENT COMPANY LTD.
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FINAL

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Effective September 21, 2022, Wood Environment & Infrastructure Solutions Canada Limited is now operating as WSP E&I Canada Limited.

IMPORTANT NOTICE

EXECUTIVE SUMMARY

Hibernia Platform is committed to conducting an environmental effect monitoring (EEM) program designed to detect changes in the surrounding environment that may be attributed to the project. The EEM program consists of sediment, water, and commercial fish sampling components to assess the chemistry and toxicity of sediment quality, and the health, size, taste, and body burden chemistry of fish. The 2020 sampling year represents the 12th sampling year for Hibernia Platform.

SEDIMENT COMPONENT

Sediment was collected using a box corer at predetermined sites as set out in the EEM design plan. The Hibernia Platform and Hibernia Southern Extension (HSE) are considered single point sources for discharges, sediment stations are arranged at varying distances with greater sampling near the centre. Hibernia Platform has eight radii at various distances between 250 m and 6,000 m from the source. The primary stations are set in four main lines radiating out from the platform out to 6,000 m (north, south, east, and west), and the remaining four radii extending to 1,000 m (northeast, northwest, southeast, and southwest). HSE has a similar pattern, with four radii extending to 1,000 m in the north, east, west, and south. There are also four far-field stations 6,000 m from HSE. Two reference stations also exist 16,000 m from the Hibernia Platform to the west and north. Data analysis and comparisons were made between distance bins including Near-Field (<1,000 m), Mid-Field (1,000-3,000 m), Far-Field (>3,000 m) and Total (<10,000).

Sediments from these stations are sampled for particle size, total metals (including barium), hydrocarbons (total petroleum (TPH), polycyclic aromatic (PAHs), total inorganic (TIC) and organic (TOC) carbon, sulphide, and ammonia as nitrogen. Sediment collected is also used to assess potential toxicity on amphipod survival, juvenile polychaete growth and survival, and a Petrotox assay. The 2020 EEM is the first-time sediments were assessed under the updated Design Plan.

Physical and Chemical Characteristics

In the 2020 EEM program, many of the Project-related effects identified in the Hibernia Platform production field is the result of a downward trend of analyte concentrations. This downward trend was observed in concentrations of barium, WAM barium, and fuel and lube range hydrocarbons. In the HSE field, a downward trend was also observed in concentrations of clay, barium, WAM barium, and fuel and lube range hydrocarbons. The peak in concentrations observed in the 2018 EEM could be attributed to the increased SBM daily discharge recorded during the end of the drilling period at HSE (drilling ceased at HSE in 2017 between EEM programs).

Toxicity

Under the new screening criteria, no Hibernia Platform sediments were screened in for toxicity testing and only two HSE stations were screened in. The two screened-in stations were both within 250 m from HSE and only sediments from one station was deemed toxic (S-250). Reduced amphipod and polychaete survivability is likely due to elevated metals and fuel range hydrocarbons (>C_{10}-C_{21}) in sediments collected at S-250. This is an improvement from previous EEMs which would have multiple toxic responses.

WATER COMPONENT

For the 2020 water quality monitoring, samples were collected approximately 50 and 150-m from the produced water discharge outlet from the Hibernia Platform and reference areas 16,000 m away from the platform. Sampling depths were based on CTD profiles at N-50.

Physical and Chemical Characteristics

Reviewing all the results, the surface and mid-depth stations approximately 50 m from the discharge point appear to have the highest percentage of analytes above the detection levels with some other stations (150-3 surface and 150-2 mid depth) showing occasional values above detection levels. For metals, all values were below CCME guidelines with the exception of mercury at one station (50-2 surface sample). The value was 0.017 µg/L and the CCME guidelines is 0.016 µg/L. Mercury was below the detection limit in all other samples. For hydrocarbons, all values were also below guidelines. Benzene and toluene were detected at the surface of stations 50-2 and 50-3, the mid depth of station 50-3 and surface of 150-3. $>C_{10}$-C_{16}, $>C_{16}$-C_{21}, $>C_{21}$-C_{32}, and modified TPH were also detected at 50-3 (mid depth). For PAHs, all stations within the 50 m range had some detections of PAHs at the surface and mid-depth. Stations 150-2 (mid depth) and 150-3 (surface depth) also had some detections of PAHs. There was no detection of PAHs at the reference stations.

Dispersion

The percent dispersion calculation showed a similar pattern to physical and chemical characteristics. For metals, the highest concentrations with the potential to be project-induced were 0.3% of the produced water values at approximately 50 m from the discharge point (the closest station(s) to the discharge point). For hydrocarbons, the same stations had detections of benzene, toluene and $>C_{10}$-C_{16} and $>C_{16}$-C_{21} hydrocarbons with the highest percent dispersion of 2.03% at the 50-m distance. Produced water dispersion environmental assessment predictions indicated that near-field dilution ratio would range from 10:1 to 60:1 (depending on the scenario) with a produced water concentration of 1-0.03% between 0-50m, less than 0.11% at 50 to 100 m, less than 0.004% at 100-250 m, and less than 0.01% at 250-1250 m. Analysis potential project-related analytes (i.e., have higher concentrations within 50 m of the platform) show dispersion rates within those predicted in the model with the lowest dilution ratio (worst-case) of 49:1 and the highest percent concentration (worst-case) of 2% (both for $>C_{16}$-C_{21} Hydrocarbons at 50-3 Mid).

Toxicity

The toxicity testing of produced water on the platform as part of environmental compliance monitoring had mixed results, with Microtox showing the produced water as being less toxic than previous studies, and the sea urchin fertilization showing the produced water as being more toxic (that is, a lower concentration to have an effect). However, the percent dispersion calculations seem to indicate that the concentrations in the receiving environment at all stations monitored would be lower than the concentrations need to induce a toxicity effect. The only exception to this is one analyte ($>C_{16}$-C_{21}) at one station (middle sampling depth of 50-3) had a value of 2.03% produced water concentration (the lowest percent concentrations of produced water deemed to have an effect (<1.56%)). All other stations and analytes that appeared to be affected by the produced water discharge had values of 1.04% or less.

The results indicate that the effects are localized mostly to within 50-m of the discharge and even those concentrations at those distances are likely to be non-toxic (based on toxicity testing). The only potential exception to this would be station 50-3 (mid-depth). Note that 50-3 is the closest station to the discharge as the other two close stations (50-1 and 50-2) were moved slightly due to the proximity to the platform structures.

COMMERCIAL FISH COMPONENT

American plaice was chosen as the fish species of interest, as it is abundant near the Hibernia Platform and is a commercially caught species. Trawls are conducted within roughly a 5 km radius from the Hibernia Platform, as well as within an 8 km radius at a Reference Area roughly 50 km away from the platform. These sites are compared to assess if the project has any effect on American plaice. Chemical profiling is done using fillets and liver tissues taken from fish in both areas, and total metals and hydrocarbons (including PAHs) are analyzed. For the fish health component, maturity stage, biological characteristics, gross pathology, haematology, mixed-function oxygenase, and gill and liver histopathology are compared between areas. Comparisons are also made between years for certain components, where appropriate.

Chemical Profiles of American plaice

Consistent with past EEM years, American plaice tissue sampled at the Hibernia Field and Reference Area in 2020 had arsenic, mercury, and zinc above their RDLs in all samples. No significant differences between the Hibernia Platform and Reference Area were noted in 2020. Comparison across EEM years found a significant difference between years for all three metals, and zinc had a significant interaction term indicating a potential project induced change.

For liver composites, eight metals have been consistently detected in all EEM years (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc). In 2020, only manganese was found to differ between areas and was higher at the Reference Area. A two-way ANOVA found that arsenic, cadmium, copper, iron, manganese, and selenium were significantly different between years, with all metals but manganese lower in 2020 compared to 2019. Zinc significantly differed between sites and years with higher values at the Reference Area compared to the Hibernia Field, and higher values in 1999 compared to other sampling years. No interaction terms were significant for any variable.

Hydrocarbons in all three ranges ($>C_{10}$-C_{16}, $>C_{16}$-C_{21}, and $>C_{21}$-C_{32}) were screened in for 2020, and no significant differences were detected between the Hibernia Field and Reference Area. The lower and upper fuel ranges were combined into $>C_{10}$-C_{21} to allow comparison to previous EEM years. Hydrocarbons in both ranges significantly differed between years, with values in 2020 for $>C_{10}$-C_{21} hydrocarbons higher than any other sampling year. Hydrocarbons in the $>C_{21}$-C_{32} range are higher in 2020 compared to 2016 or 2018, but lower than 2015 values which had the highest values of any EEM year. No PAHs were detected in any liver composites in 2020, those some samples have exceeded RDLs in past years.

Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2020. As sample sizes for male fish are very low in 2020, statistical analyses have very little power for distinguishing differences between sites.

For biological characteristics, no significant variations between sites existed for male and female American plaice sampled in 2020. After accounting for covarying factors using ANCOVAs, female fish gutted weight significantly differed between sites. Cross-year comparisons for both male and female fish, year was significantly different for every index with the exception of male HSI. Additionally, male GSI varied significantly between sites, with higher values at Hibernia Field compared to the Reference Area.

For gross pathology, there were no significant differences among any of the parameters examined individually for males or females, aside from skin for female plaice being higher at the Reference Area. Significant differences were found for site and year for all Health Assessment Index (HAI) modifications for both male and female fish, with the exception of HAI mod. 2 for female fish which differed by year but not site. No HAI modification for either sex had significant interaction terms.

For haematology, no significant difference was found between sites for neutrophils, however lymphocytes and thrombocytes both significantly differed. Lymphocytes were higher at the Hibernia Field, while thrombocytes were higher at the Reference Area. For the cross-year comparison, significant differences were found between years for all cell types, with lower values in 2020 for neutrophils and thrombocytes, and higher in 2020 for lymphocytes. Site was also significantly different for lymphocytes and thrombocytes, with lymphocytes higher at the Hibernia Platform and thrombocytes higher at the Reference Area.

For MFO, female fish significantly differed between the Hibernia Field and Reference Area in 2020. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, no significant differences between sites existed for 2020. A MANOVA with six liver histology factors showed significant differences between years and in the interaction term. Hepatocellular carcinoma, macrophage aggregates (0-3), medium hepatocellular vacuoles, and large hepatocellular vacuoles all significantly differed between years, and macrophage aggregates (0-3) had a significant interaction term.

For gill histopathology, no significant differences were detected between sites in 2020. However, a MANOVA for seven gill histology factors detected significant results across site, year, with a significant interaction term. Significant differences between sites were largely due to tip hyperplasia (higher at the Reference Area) and thin lamellae (higher at the Hibernia Field). All seven gill histologies significantly differed between years, with generally lower values in 2020 and high values in 2016. Basal and distal hyperplasia, fusion, and thin lamellae had significant interaction terms.

ACKNOWLEGEMENTS

The 2020 Hibernia and HSE EEM programs were conducted under contract to Hibernia Management and Development Company Ltd. (HMDC) under the guidance of Robert Dunphy, Environmental Advisor for HMDC, and managed by Kevin Baldwin as Associate / Program Manager, Metocean Services, at WSP E&I Canada Limited (WSP), formerly Wood Environment and Infrastructure Solutions, a Division of Wood Canada Limited, in St. John's, Newfoundland and Labrador Canada.

The biological survey program was conducted aboard the Fishing Vessel *Aqviq* with Captain Lloyd Price and crew. Fish processing and sampling was conducted by WSP personnel including Shaun Garland, Justin So, Michael Teasdale, Kyle Millar, Ashton Verge and; Julek Chawarski of Edgewise Environmental.

Fish health samples were processed, and gill samples were analyzed by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University and managed by Stephen Hill, and liver samples were analyzed by Dr. Rasul Khan.

The sediment sampling program was conducted aboard the Avalon Sea with the assistance of her crew. Fugro GeoServices Inc. provided geopositional services for sediment collections by Kelly Newell and Andrew Walsh. WSP sampling crew included Michael Teasdale, Justin So, Andrew Peddle, Lara Miles, Kyle Millar and Brett Barter. WSP shore support included Kevin Baldwin, Shaun Garland, and Narcissus Walsh.

Laboratory quantification of chemical analytes in sediment and tissues as well as particle size analysis was conducted by Bureau Veritas and managed by Heather Macumber (Bedford Nova Scotia). Sediment toxicity assays were performed by Avalon Laboratories and managed by Suzette Winter (St. John's Newfoundland and Labrador). Fish fillet taint testing was conducted by the Marine Institute of Memorial University and managed by Kim Snelgrove and Heather Manuel (St. John's Newfoundland and Labrador). Sediment quality, toxicity data was analyzed by Lara Miles and Steven Beale and water chemistry data was analyzed by Michael Teasdale. Fish heath and tissue chemistry (body burden) data was analyzed by Kyle Millar. GIS technical support was provided by Juanita Abbott. The Volume I Interpretation report was written by Michael Teasdale, Lara Miles, Kyle Millar, Steven Beale, Shaun Garland, and Justin So. The Volume II Methods and Results was compiled by Shaun Garland and Justin So. Senior Independent Review was conducted by James McCarthy.

ACRONYMS, ABBREVIATIONS, AND UNITS

Acronyms and Abbreviations	
2-D	Two-Dimensional
AIC	Akaike information criterion
AKA	Also known as
ANCOVA	Analysis of Co-Variance
ANOVA	Analysis of Variance
APAH	Alkylated Polycyclic Aromatic Hydrocarbons
$BaSO_4$	Barium sulphate, also known as barite
BTEX	Benzene, toluene, ethylbenzene, and xylene
C	Carbon
$CaCO_3$	Calcium carbonate (total hardness)
CAPP	Canadian Association of Petroleum Producers
CCME	Canadian Council of Ministers of the Environment
CDRF	Cold-Ocean Deep-Sea Research Facility
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CPUE	Catch per Unit Effort
CRI	Cuttings Re-Injection
CVAA	Cold Vapor Atomic Absorption
DFO	Fisheries and Oceans Canada
EA	Environmental Assessment
EC	Environment Canada
EC50	50% Effective concentration
ECCC	Environment and Climate Change Canada
EDC	Excavated Drill Centre
EEM	Environmental Effects Monitoring
EMCP	ExxonMobil Canada Properties
EROD	Ethoxyresorufin-O-deethylase
FCI	Fulton's Condition Index
FRV	Fisheries Research Vessel
GBS	Gravity Based Structure
GC/FID	Gas Chromatography/Flame Ionization Detector
GC/MS	Gas chromatography–mass spectrometry
GSI	Gonadosomatic Index
H_0	Null hypothesis
H_A	Alternative hypothesis
HAI	Health Assessment Index
HIB	Hibernia Platform
HMDC	Hibernia Management and Development Company Ltd.
HRA	Hibernia Reference Area
HSD	Honest Significant Difference (or Tukey HSD)

HSE	Hibernia Southern Extension
HSI	Hepatosomatic Index
IC25	25% Inhibiting Concentration
IC50	50% Inhibiting Concentration
ICP/MS	Inductively Coupled Plasma Mass Spectrometry
ISQG	Interim Sediment Quality Guidelines
LC50	50% Lethal concentration
LOEC	Lowest observable effect concentration
MANOVA	Multivariate Analysis of Variance
MFO	Mixed-Function Oxygenases
MUN	Memorial University of Newfoundland
N	Nitrogen
N/A	Not Applicable
NAD	North American Datum
NAF	Non-Aqueous Fluids
NaOH	Sodium hydroxide
NL	Newfoundland and Labrador
nMDS	Non-metric multidimensional scaling
NOEC	No observable effects concentration
OCI	Ocean Choice International
OCNS	Offshore Chemical Notification Scheme
OLS	Offshore loading system
OWTG	Offshore Waste Treatment Guidelines
PAH	Polycyclic Aromatic Hydrocarbons
PEL	Probable Effect Levels
PERMANOVA	Permutational Multivariate Analysis of Variance
PIRI	Partnership in Risk-Based Corrective Action Implementation
PSA	Particle Size Analysis
QA/QC	Quality Assurance/Quality Control
RDL	Reported Detection Limits
Redox	Oxidation/Reduction Potential
SBM	Synthetic-Based Mud
SIMPER	Similarity Percentage Analysis
SOC	Synthetic oil on cuttings
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TPH	Total petroleum hydrocarbons
US EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
WAM	Weak-acid extractable (leachable) metal
WBM	Water-Based Mud

Units	
%	Percent
°C	Degrees Celsius
µg	Microgram
µm	Micrometre
cm	Centimetre
g	gram
hr	Hour
kg	Kilogram
km	Kilometre
L	Litre
m	Metre
mg	Milligram
min	Minute
mm	Millimetre
mV	Millivolt
n	Sample Size
pmol	Picomole
ppm	Parts per Million

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1.0 INTRODUCTION

The Hibernia Management and Development Company 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 2019a). This report presents the results for the 2020 Field Program for both the Hibernia Platform and Hibernia Southern Extension (HSE) based on the approved methods and plans from the EEM Design Plan (HMDC 2019a). For the Hibernia Platform, the 2020 program represents the 12th Production-Stage EEM field program. The initial baseline characterization program occurred in 1994 with subsequent production-phase programs in 1998, 1999, 2000, 2002, 2004, 2007, 2009, 2011, 2014, 2016, 2018 and 2020 (present survey results). For HSE, the baseline field program occurred in 2011 with EEM sampling commencing following the initiation of drilling in Year 1 (2014), Year 2 (2015), Year 3 (2016), Year 4 (2018) and Year 5 (2020; present survey results). Drilling at HSE was completed in April 2017.

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 m 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 producing operations, White Rose (operated by Husky Energy), and Hebron (Operated by ExxonMobil Canada Properties). Another operation within the Jeanne d'Arc basin and within the vicinity of the Hibernia field is Terra Nova field (operated by Suncor Energy). The Terra Nova field is not currently producing oil and gas, however the subsea infrastructure remains is a production ready state (Figure 1-1).

The Hibernia geological formation was originally estimated to contain approximately one billion barrels of oil. Recent, estimates indicate a potential total oil reserve of 1.419 billion barrels with over one billion barrels of oil produced to date. The primary drilling center, the Hibernia Platform, had an average daily production of 118,164 barrels of crude oil per day in 2020 (C-NLOPB 2021).

The Hibernia Platform is affixed on top of a gravity based structure (GBS) – a 111 m tall multi-celled cement column constructed with internal chambers with an oil storage capacity of 1.3 million barrels (HMDC 2021). The combined structure is positioned on the seabed with the topside structure standing 224 m high, a production capacity of 230,000 barrels of crude oil per day with crew capacity of approximately 270 personnel (HMDC 2021).

The Hibernia Platform first produced oil in November 1997. To extend oil reserves and the operating life of the Hibernia field the HSE excavated drill center (EDC) subsea development was installed. This allowed access to more distant sections of the reservoir through installation of the EDC and a tieback system to the Hibernia Platform (HMDC 2021b).

The HSE is located 7 km southeast of the Hibernia Platform (Figure 1-1). To avoid any impacts from icebergs, the HSE EDC has been constructed as a 10 m deep excavation in the seafloor. Excavation for the EDC was completed in 2014 with the drilling installation completed in April 2017. The HSE installation has the capacity for up to five production wells and up to six subsea water injection wells (HMDC 2021b).

The water injection wells are part of a single subsea water injection manifold for pressure maintenance and oil recovery (HMDC 2021b). The water injection wells were drilled by the West Aquarius, a semi-submersible mobile offshore drilling unit (MODU); whereas the production wells were drilled from the Hibernia Platform by extended reach. The 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 1-2). This EEM report includes the combined 2020 EEM field program for Hibernia and HSE.

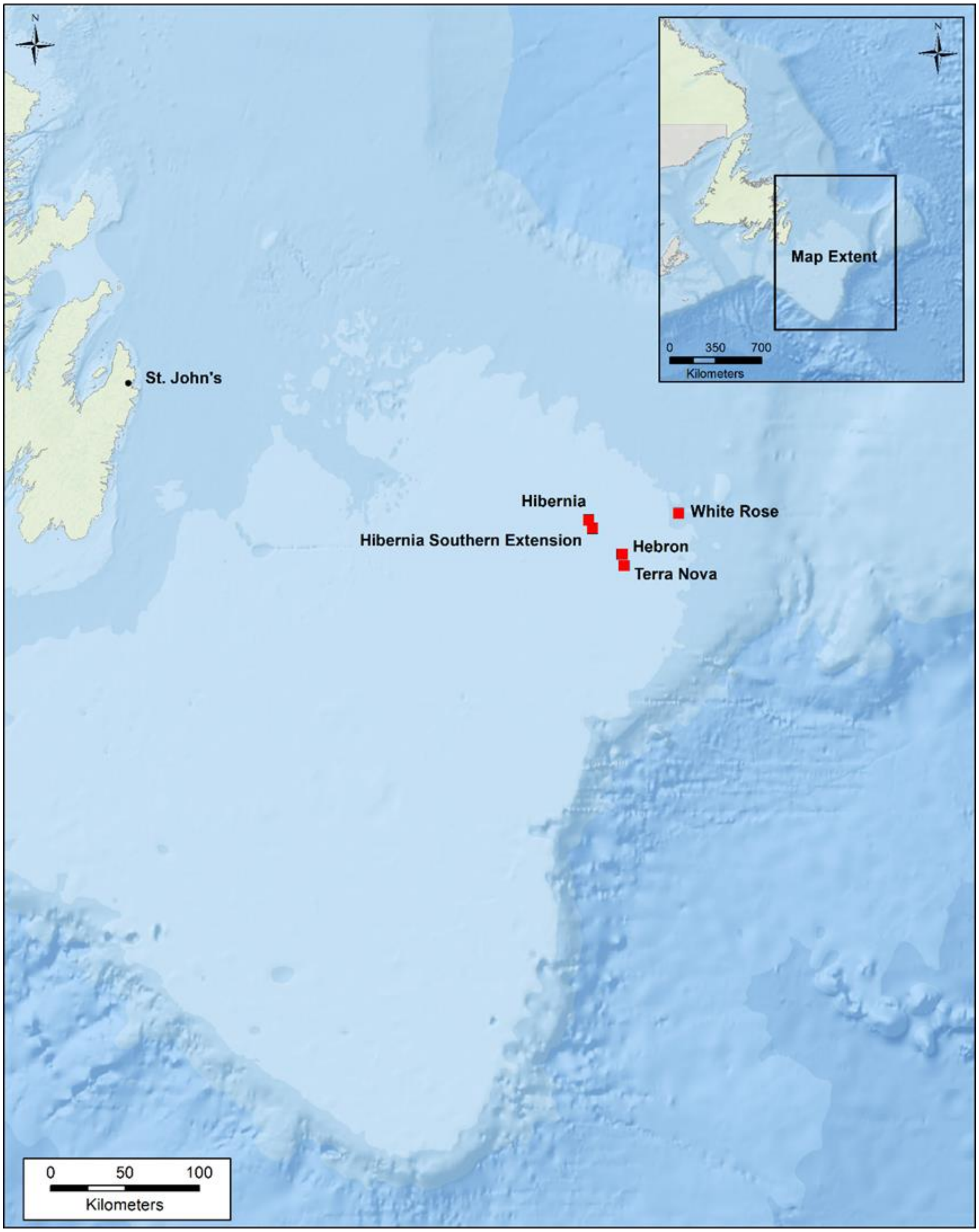


Figure 1-1: Location of the Hibernia production field in relation to St. John's, Newfoundland and Labrador, Canada (inset) and proximity to other offshore operations on the Grand Banks.

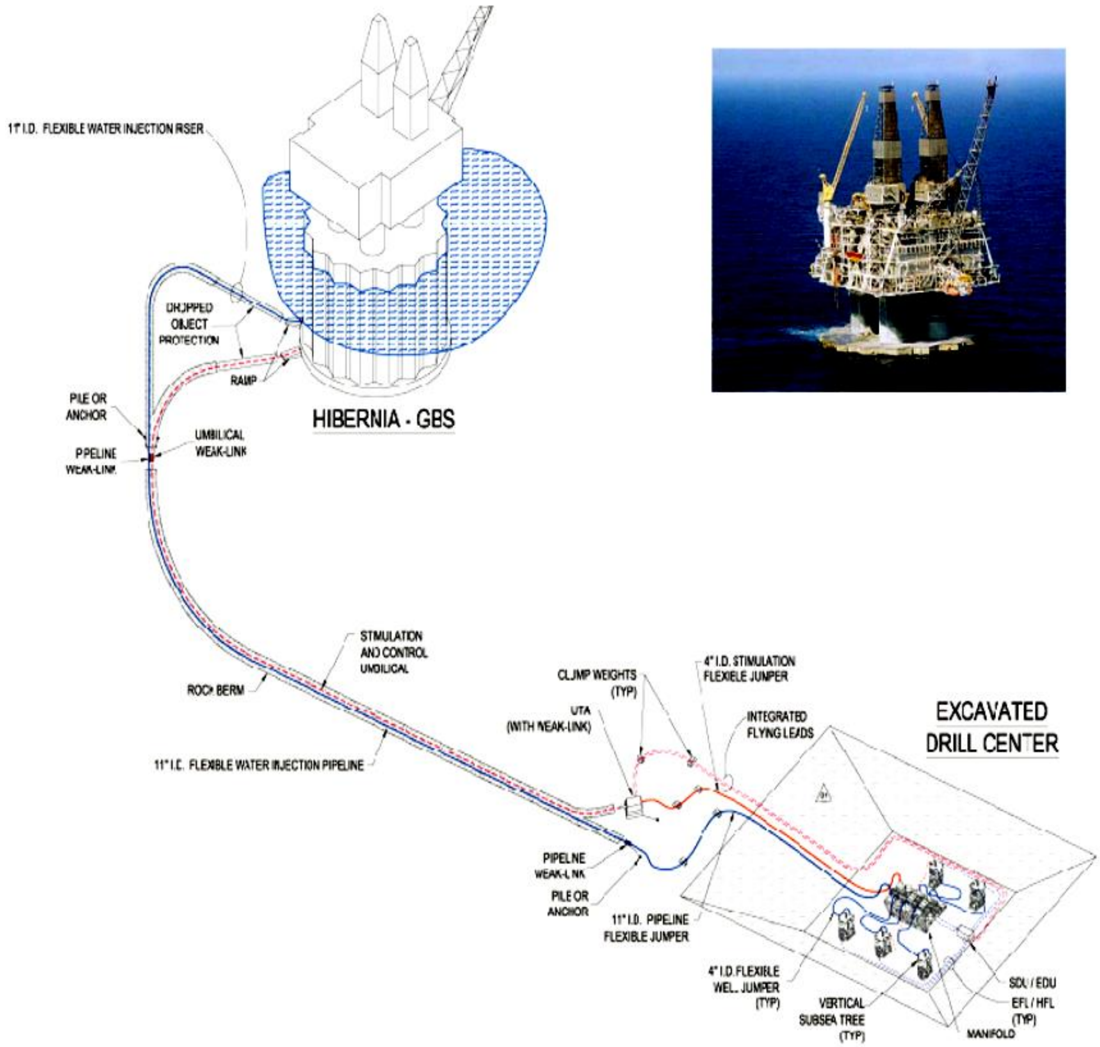


Figure 1-2: Diagram of HSE excavated drill centre and subsea tie-back system connecting to Hibernia Platform (shown in inset) (HMDC 2021b).

1.2 Project Commitments

HMDC is committed to conducting an environmental effects monitoring (EEM) program to detect potential changes in the surrounding environment that can be attributed to the project (HMDC 2019a). Therefore, a monitoring design plan was developed, 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 2019a).

The EEM program is one of a series of environmental protection procedures outlined in HMDC's Operational Plan which includes Emergency Response Management and Environmental Compliance Monitoring (HMDC

2017a). The EEM program serves two key functions; to detect potential project induced changes in the receiving environment from Hibernia and HSE operational activities, and to confirm the effectiveness of discharge limits put forth in the Environmental Compliance Monitoring Plans for the project (HMDC 2017a).

1.3 EEM Program Objectives

The program objectives are listed in the EEM program design plan as follows (HMDC 2019a):

- Fulfill regulatory information requirements and address legitimate public concerns;
- Provide early warning of potential project-induced change to the natural environment;
- Meet 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 technical and non-technical reviewers.

These objectives are intended to assess project related activities as they relate to normal operations (Section 2.0). 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 2019a).

2.0 REGULATED AND 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 for offshore petroleum drilling and production operations. These standards and practices are outlined in the Offshore Waste Treatment Guidelines (OWTG) (NEB et al. 2010). The OWTG are applicable to waste materials including effluents, emissions and solid wastes with discharge limits defined in an offshore operator's Environmental Protection Plan. Discharges at the Hibernia Platform are monitored according to Paragraph 9(j) of the Newfoundland Offshore Petroleum Drilling and Production Regulations (Government of Canada 2014). Operations at Hibernia and HSE are required to comply with discharge levels and volumes on a continuous basis according to the operator's Environmental Compliance Monitoring Plan (ECMP) (a component of the Environmental Protection Plan). The discharge locations for the Hibernia Platform are illustrated in Figure 2-1 and Figure 2-2. Discharges are separated into solid (muds and cuttings) and liquid discharges.

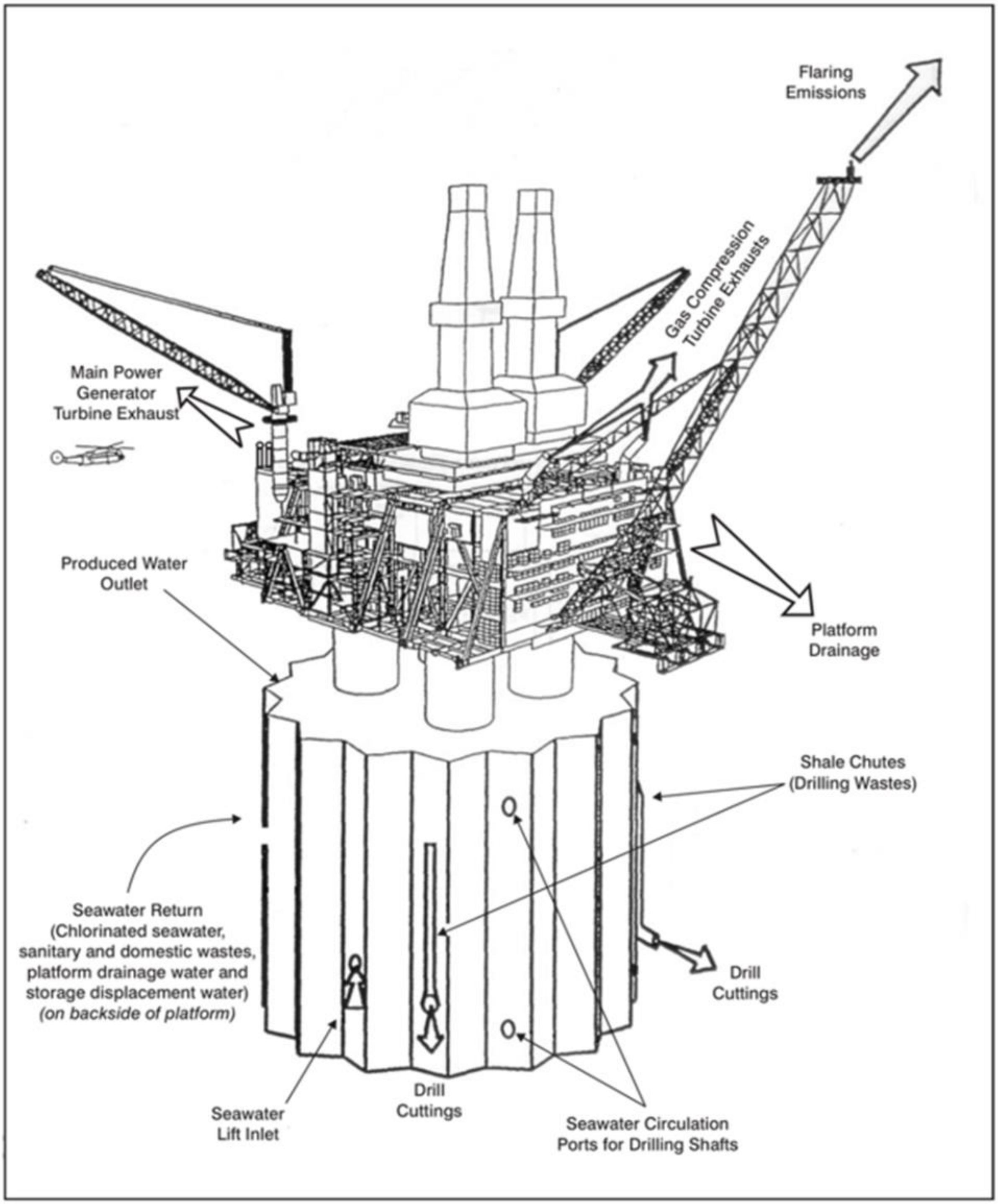


Figure 2-1: Hibernia Platform seawater and discharge locations (HMDC 2019).

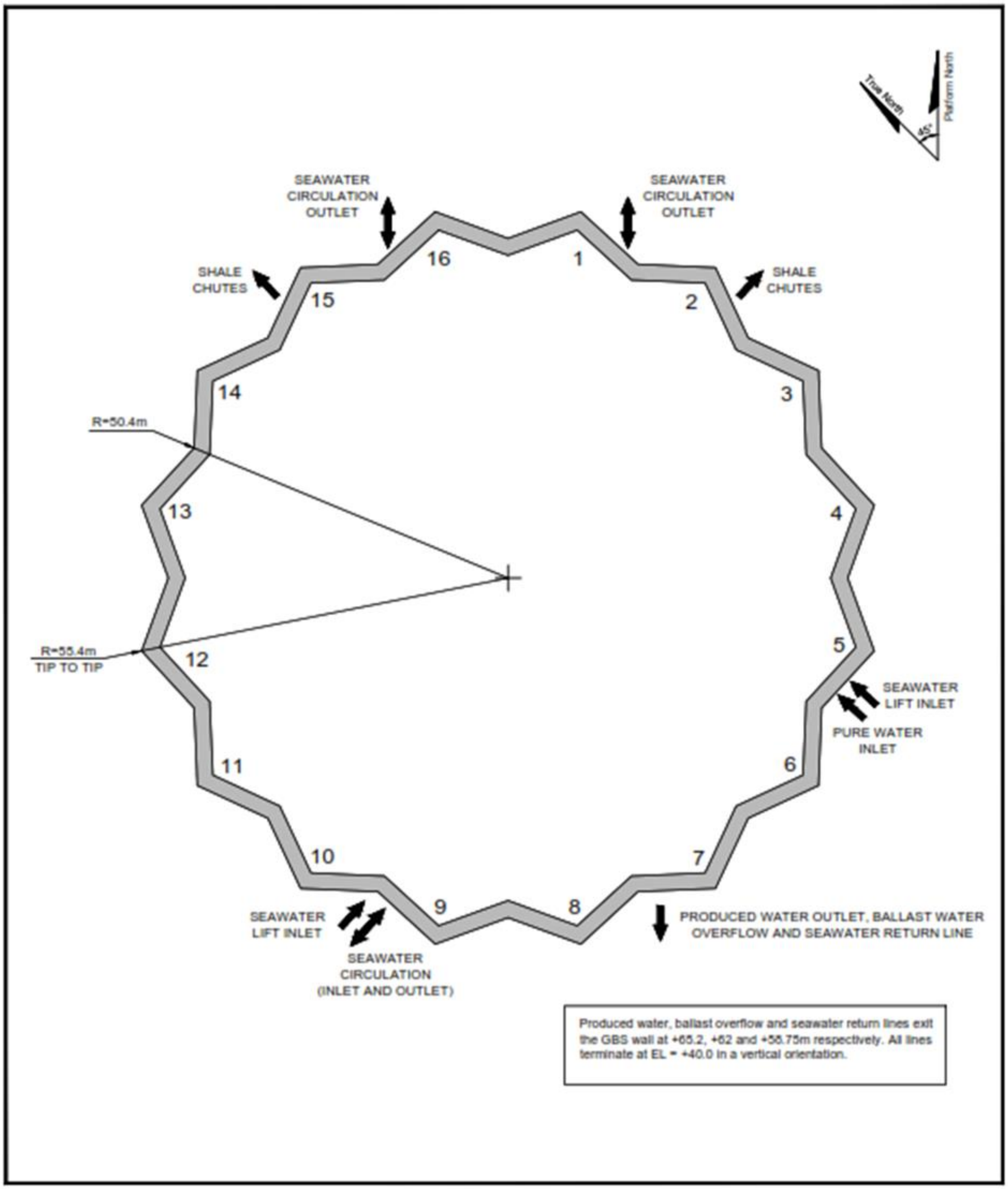


Figure 2-2: Hibernia Platform: cross sectional seawater inlet and discharge locations (modified from HMDC 2019).

2.1 Construction and Operations Activities

Key dates for construction and operation activities are identified in Table 2.1 with a focus on activities with discharges into the marine environment that have the potential to have effects identified in the EEM. Table 2-1 also highlights periods when production is shut in and there are no discharges (such as produced water) and therefore no or reduced potential for effects.

Table 2-1: Schedule of construction and operation activities.

Activity	Date	Relevant Potential Discharges
Platform Shutdown (2 Days) due to weather	2 to 3 April 2017	No produced water, drill cuttings discharges
Drilling at HSE stopped	15 Apr 2017	No cuttings discharged after this date
PMRI no production (1 Day)	19 Mar 2018	No produced water, drill cuttings discharges
Planned Platform Shutdown (35 Days)	7 Sep to 11 Oct 2018	No produced water, drill cuttings discharges
Unplanned Platform Shutdown (72 Days)	July 18 to September 27 2019	No produced water, drill cuttings discharges
No Production for One Day	10 Oct 2019	No produced water, drill cuttings discharges
Drilling Ceased	5 June 2020	No cuttings discharged after this date
Production shut in due to produced water released (15 Days)	20 Jul to 3 Aug 2020	No produced water discharges

2.2 Drilling Discharges

Drilling solids (cuttings) are the particles produced when drilling through 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 cuttings are treated prior to discharge once the drilling mud is expelled from the upper drilling riser depends on the nature of the drilling mud being used. Two general types of drilling muds are used; water based muds (WBMs); and non-aqueous fluids (NAFs) which are commonly referred to as synthetic-based muds (SBMs). WBMs are generally for the top sections (conductor and surface sections) of wells whereas NAFs are used for horizontal and deeper (intermediate and main) sections of wells because of their better performance in unstable expandable clay formations (Canadian Association of Petroleum Producers (CAPP) 2001, DeBlois et al. 2014a).

The primary constituents of WBMs are water, barium sulphate (also known as barite or $BaSO_4$) as a weighting agent, and bentonite clay as a viscosifier (Trefry et al. 2013, DeBlois et al. 2014c). 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 et al. 2014c). As WBMs are primarily water and barite, which is relatively inert, barium is the main constituent of WBM on drill cuttings (Whiteway et al. 2014).

In contrast, the primary constituents of NAFs (or SBMs) 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$^{TM/MC}$ IA-35LV (Puredrill); (HMDC 2017a), a synthetic isoalkane that is colourless, odorless readily biodegradable and non-toxic to humans and marine wildlife (Talalay and Pyne 2017). Puredrill complies with US Food and Drug Administration Regulations for pharmaceuticals while in oil-form 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 2017a). It is composed of aliphatic hydrocarbons in the fuel range ($>C_{10}$–C_{21}) and contains no aromatic hydrocarbons (DeBlois et al. 2014c). This base fluid is used at the Hibernia Platform (HMDC 2017a) as well as the Terra Nova production field (DeBlois et al. 2014c). Puredrill is also rated as a Category E product (least hazardous) in the Offshore Chemical Notification Scheme (OCNS) (DeBlois et al. 2014a).

For Hibernia Platform drilling, SBM cutting re-injection (CRI) equipment was installed and commissioned in 2001, with essentially all SBM drill cuttings and solids from the platform being reinjected into the reservoir by fourth quarter 2002 and not discharged (Table 2-2). Limited discharges of SBM cuttings was initiated in 2015 with approval from the C-NLOPB for certain situations (casing shoe tracks, cement plugs) to ensure the integrity of the CRI system. The vast majority of SBM cuttings, however, continues to be reinjected via the CRI system.

SBM cuttings were discharged to the environment according to regulatory limits for the West Aquarius MODU (HSE) drilling operation (2014-2017) and at the Hibernia Platform prior to 2002. The NAF on drilling solids (cuttings) were physically separated from NAF and treated using dryer technology for a 6.9 g/100 g oil-on-wet solids as a performance target prior to discharge (HMDC 2017b). Samples were collected every twelve hours to quantify the synthetic oil on cuttings (SOC) according to the M-I Swaco procedure LW1 041 Synthetic Oil On Cuttings: Test and Report for East Coast Canada (HMDC 2017b). Fuel range hydrocarbons ($>C_{10}$–C_{21}) and barium were the main constituents, other that rock cuttings, from the discharge of Puredrill associated drill cuttings (Whiteway et al. 2014). Table 2-2 and Table 2-3 summarize the oil-on-cuttings concentrations and discharges for SBM drill cuttings for the Hibernia Platform and HSE.

Table 2-2: Synthetic-based mud drill cuttings discharges from the Hibernia Platform (1997-2020).

Discharge Period	Average Daily SOC Concentration (g/100g)[1]	48 Hour Rolling Average SOC (g/100g)[1]	Daily Cuttings Discharged (tonnes)[2]
Nov. 1997 – Sep. 1998	16.1	0 – 33.9	10.6
Sep. 1998 – Aug. 1999	11.4	0 – 20.4	4.5
Jul. 1999 – Jul. 2000	17.7	0 – 27.3	10.4
Aug. 2000 – Jul. 2002	19.3*	0 – 22.1	4.9
Aug. 2002 – Aug. 2004	21.1	0 – 9.92	1.0
Sep. 2004 – Aug. 2007	-	-	0
Sep. 2007 - Aug. 2009	-	-	0
Sep. 2009 - Aug. 2011	-	-	0
Sep. 2011 - Aug.2014	-	-	0
Sep. 2014 - Aug. 2015	0-11.34	0-11.34	0.03
Sep. 2015 - Aug. 2016	0-18.80	0-18.80	3.3
Sep. 2016-Aug. 2017	12.8	0-12.8	<0.1

Discharge Period	Average Daily SOC Concentration (g/100g)[1]	48 Hour Rolling Average SOC (g/100g)[1]	Daily Cuttings Discharged (tonnes)[2]
Sep. 2017-Aug. 2018	11.4	0-11.4	1.3
Sep. 2018-Aug. 2019	-	-	0
Sep. 2019-Aug. 2020	7.69	0-7.69	<0.1

Notes: [1] Due to re-injection of drill cuttings, the average synthetic oil on cuttings (SOC) concentration is applicable to retained synthetic oil on the cuttings that were discharged.

[2] Daily discharge cuttings based cumulative cuttings period discharged volume (from diameter of drill bit and length of the hole) divided by number of days

Table 2-3: Synthetic-based mud drill cuttings discharges from the HSE (2014-2017).

Discharge Period	Average Daily OIC Concentration (g/100g)	48 Hour Rolling Average OIC (g/100g)	Daily Cuttings Discharged (tonnes)[1]
Jan. 2014 - Aug. 2014	1.00	6.60	3.80
Sep. 2014 - Aug. 2015	1.15	6.77	7.12
Sep. 2015 - Aug. 2016	2.17	5.60	22.27
Sep. 2016 – Apr. 2017[2]	-	-	-

Notes:

[1]Daily discharge cuttings are based cumulative cuttings period discharged volume (from diameter of drill bit and length of the hole) divided by number of days.

[2]Drilling at HSE commenced in January of 2014 and was completed in February of 2017.

2.3 Produced Water Discharges

Produced water is the by-product from the oil-water separation process during primary processing. It is comprised of formation water (water from the reservoir which contains crude oil) and injection water (water injected into the reservoir to enhance pressure and recovery). Injection water is comprised of seawater with water treatment chemicals used to remove trace oxygen (oxygen scavengers), control biological growth (biocides) and minimize corrosion (corrosion inhibitors), (HMDC 2017a). All chemical additives are screened for offshore use as per the OWTG (NEB et al. 2010). Produced water contains minor amounts of natural organic (petroleum hydrocarbons, organic acids, alkylphenols) and inorganic (heavy metals, radionuclides) components both from subsurface geological formations, as well as additives from injection water (Yeung et al. 2011). Figure 2-3 presents the produced water discharges from the Hibernia Platform since 1999. There is no produced water discharge at the HSE site as the production lines lead back to the Hibernia Platform and produced water from HSE wells is discharged from the platform produced water system. Table 2-4 presents the oil concentrations and Table 2-5 presents the more specific chemical constituents of Hibernia's produced water.

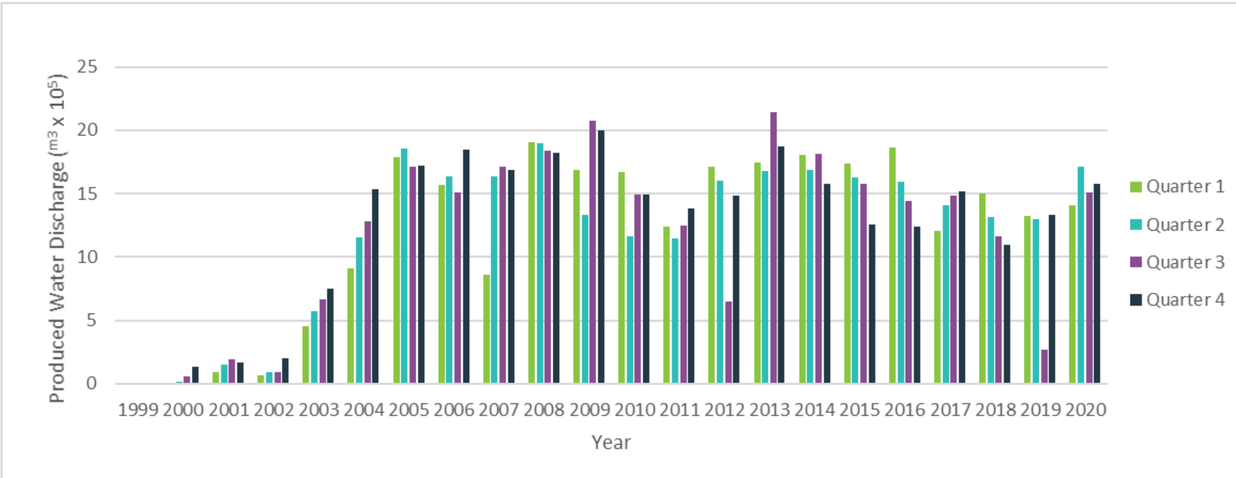


Figure 2-3: Quarterly produced water discharges.

Table 2-4: Summary of discharged oil concentrations within Hibernia's produced water (1997-2020).

Discharge Period	Daily Mean Oil Concentrations[1] (mg/L)	30-Day Average[2] (mg/L)
Nov. 1997 – Sep. 1998	NA	NA
Sep. 1998 – Aug. 1999	20.4	21.1
Jul. 1999 – Jul. 2000	24.5	31.0
Aug. 2000 – Jul. 2002	29.0	29.4
Aug. 2002 – Aug. 2004	28.8	28.6
Sep. 2004 – Aug. 2007	27.4	27.3
Sep. 2007 - Aug. 2009	20.9	21.0
Sep. 2009 - Aug. 2011	17.2	16.5
Sep. 2011 - Aug. 2014	18.8	18.9
Sep. 2014 - Aug. 2016	18.6	18.6
Sep. 2016 - Aug. 2018	17.6	17.5
Sep. 2018 - Aug. 2020	19.2	19.3

Notes:
[1] Regulatory Daily Limit is 44 mg/L
[2] Regulatory 30-day average Limit is 30 mg/L

Table 2-5: Produced water chemical constituents (2000-2020).

Constituent	North Sea Data (mg/L)	US Data (mg/L)	Hibernia Data (mg/L)[1]									
			2000	2002	2004	2007	2009	2011	2014	2016	2018	2020
Total Oil	2-220.0	2.3–359.0	11.0	28.2	27.3	22.6	16.0	26.7	11.1	2.5	17.5	0.70
Benzene	0.4-5.02 0.3-44.03	0.2–14.0	8.0	8.4	18.2	13.5	14.4	13.3	13.3	12.0	10.3	11
Toluene	0.01-2.02 4.0-14.53	0.2–8.0	4.3	4.6	9.6	7.9	8.9	7.6	7.8	6.3	6.1	6.5
Ethylbenzene	0.01-2.02 4.0-14.53	0.03–0.6	0.2	0.4	0.7	0.5	0.6	0.4	0.4	0.4	0.4	0.39
Xylene	0.1-7.02 0.83	-	1.1	1.1	3.6	2.5	2.8	2.1	2.4	2.0	2.1	1.7
Naphthalenes[4]	0.07-0.1	0.02–0.3	0.08 0.1284	0.2 0.4274	0.3	0.3	0.1	0.1	0.2	0.3	0.4	0.3
Phenol	2.0-23.0	0.2–3.4	-	-	12.0	8.0	10.4	11.3	6.8	19	0.6	-

Notes:
[1] Hibernia Data prior to 2016, North Sea and US Data compiled from HMDC (2017)
All annual Hibernia data is represented by a single sample
[2] Oil
[3] Gas
[4] Napthalenes include 1-methylnaphthalene and 2-methylnaphalene

2.4 Other Waste Discharges

2.4.1 Storage Displacement Water

Storage displacement water is chlorinated water that is pumped into and out of the GBS oil storage tanks during oil production and offloading operations to keep a somewhat consistent volume of combined crude oil and displacement water (NEB et al. 2010). During oil production, crude oil is pumped into the oil storage tanks with the same amount of displacement water pumped out. During crude oil offloading, the crude oil is pumped into the oil tanker vessel with an equal amount of displacement water pumped into the oil storage tanks.

The storage displacement water is treated seawater that contains chlorine as well as dispersed and dissolved hydrocarbons. The storage displacement water is tested to a regulatory limit of 15 mg/L residual oil concentration. The Hibernia displacement water is collected from an inlet in the GBS (tooth 7, Figure 2-2). Table 2-6 shows the oil concentration and flow rates for the Hibernia Displacement Water Discharges for 1997-2020 Discharge concentrations for the most recent sampling period averaged 0.88mg/L with daily average flow ranging from 0 to 25,604 m^3/day. There are no storage displacement water discharges at HSE.

Table 2-6: Storage displacement water discharges (1997-2020).

Discharge Period	Average Daily Mean Oil Concentrations[1] (mg/L)	Daily Average Effluent Flow (m^3/day)
Nov. 1997 – Sep. 1998	2.2	0 – 28,000
Sep. 1998 – Aug. 1999	1.5	0 – 27,965
Jul. 1999 – Jul. 2000	2.1	0 – 39,967
Aug. 2000 – Jul. 2002	1.7	0 – 39,954
Aug. 2002 – Aug. 2004	1.1	0 – 36,269
Sep. 2004 – Aug. 2007	0.7	0 – 35,108
Sep. 2007 - Aug. 2009	0.5	0 – 25,755
Sep. 2009 - Aug. 2011	0.6	0 – 31,593
Sep. 2011 - Aug. 2014	1.1	0 – 53,957
Sep. 2014 - Aug. 2016	1.2	0 – 27,695
Sep. 2016 - Aug. 2018	1.3	0 – 28,869
Sep. 2018 - Aug. 2020	0.88	0 – 25,604

Notes:
[1] Regulatory Daily Limit is 15 mg/L

2.4.2 Drainage Water

Deck drainage is defined as water that reaches the deck through precipitation, sea spray, or from routine operations such as wash-down and fire drills (NEB et al. 2010). Deck drainage discharge may contain various contaminants such as cleaning detergents and dispersants, small amounts of hydrocarbons and other chemicals such as lubricants (Yang et al. 2011). On the Hibernia Platform, deck drain effluent is segregated, collected and treated by two separate systems; the Process Area and Drilling Area drains.

The Process Area drains deals primarily with all drains on the platform not directly related to drilling. They can contain both hazardous (high-pressure systems; typically related to crude processing) and non-hazardous (lower pressurized systems) drainage. Oil, water, and solids are separated with some oil recovery. The Process Area Hazardous drains collect effluent including oily water from processing equipment, pig launchers and receiver and contaminated water from the chemical laydown area. The Process Area Non-hazardous drains include drainage from potable and service water facilities, chemical injection package water, coarse water strainers, diesel storage tanks, pipe rack area and the weather deck of the living quarters module. Recovered oil from non-hazardous drain tanks is pumped to the hazardous drain tank. Drainage from the helideck and fuel tote tank storage area are routed directly overboard to prevent jet fuel from entering the drain system (HMDC 2017a).

Drilling Area drains handle both hazardous and non-hazardous effluent. The Drilling Area hazardous drain effluent contains seawater, rain water, chemical and mud components, cuttings, weighing agents, lubricants and crude hydrocarbons (HMDC 2017a). The Drilling Area non-hazardous drain effluent consists of seawater, minimal hydrocarbons and mud components (HMDC 2017a). The daily mean oil concentrations for process and drilling area drainage water are presented in Table 2-7.

Table 2-7: Process area and drilling area drainage water discharges (1997-2020).

Discharge Period	Process Area Drainage		Drilling Area Drainage	
	Daily Mean Oil Concentrations[1] (mg/L)	Daily Effluent Flow (m^3/day)	Daily Mean Oil Concentrations1 (mg/L)	Daily Effluent Flow (m^3/day)
Nov. 1997 – Sep. 1998	9.0	79.0-214.0	152.3	5.0 – 224.0
Sep. 1998 – Aug. 1999	7.2	79.0-1,510.0	56.1	10.0 – 198.0
Jul. 1999 – Jul. 2000	6.4	92.0-443.0	19.7	12.9 – 190.0
Aug. 2000 – Jul. 2002	5.9	0-566.0	15.5	0.0 – 267.7
Aug. 2002 – Aug. 2004	5.0	3.1-235.0	9.3	1.1 – 214.0
Sep. 2004 – Aug. 2007	2.7	0-107.0	6.2	0.0 – 88.4
Sep. 2007 - Aug. 2009	4.8	0-56.2	5.8	0.0 – 60.0
Sep. 2009 - Aug. 2011	3.2	0-122.1	6.0	0.0 – 95.0
Sep. 2011 - Aug. 2014	5.7	0-122.1	6.6	0.0 – 110.0
Sep. 2014 - Aug. 2016	6.3	0.0 – 2,933.04	6.9	0.0 - 130
Sep. 2016 - Aug. 2018	5.0	0.0 – 5,565.12	4.1	0.0 - 110
Jan. 2019 – Dec. 2020	5.3	0.0-5,940	5.8	0.0-130
Notes: [1] Regulatory Daily Limit is 15 mg/L				

2.4.3 Seawater Return

Cooling water consists of seawater that has been chlorinated and pumped onto the platform and passed through heat exchanges to remove heat from processes on the installation. A portion of that water is used for other processes (storage displacement water, domestic sewage, drain effluent, seawater injection) with the rest discharged via the seawater return line (Figure 2-2). The seawater return is monitored for residual chlorine with a limit of 2.0 mg/L (HMDC 2017a). Table 2-8 presents the mean residual chlorine concentrations of the seawater return from 1997 to 2018.

Table 2-8: Seawater return discharges (1997-2020).

Discharge Period	Mean Residual Chlorine Concentration[1] (mg/L)
Nov. 1997 – Sep. 1998	1.0
Sep. 1998 – Aug. 1999	0.6
Jul. 1999 – Jul. 2000	0.5
Aug. 2000 – Jul. 2002	0.5
Aug. 2002 – Aug. 2004	0.8
Sep. 2004 – Aug. 2007	0.7
Sep. 2007 - Aug. 2009	0.5
Sep. 2009 - Aug. 2011	0.7
Sep. 2011 - Aug. 2014	0.8
Sep. 2014 - Aug. 2016	0.8
Sep. 2016 - Aug. 2018	0.9
Sep. 2018 - Aug. 2020	1.1
Notes: [1] Regulatory Limit is 2.0 mg/L	

2.4.4 Sanitary and Domestic Wastes

Sanitary and domestic wastes include human wastes and all liquids originating from domestic facilities (e.g., kitchen, showers). Sanitary and domestic wastes must be macerated to a particle size of six mm or less (NEB et al. 2010). Domestic effluents are also treated to remove grease and screened to remove plastic and metals prior to being discharged (HMDC 2017a).

2.5 Contamination vs 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 contaminant, it does not need to cause an adverse biological effect. The term pollution is given to a contaminant that results in adverse biological effects (Chapman 2007).

In order to determine whether any contaminant identified in samples might have a negative biological effect (i.e., is pollution), 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 analyte concentrations to indicate an injurious effect of a substance in the marine ecosystem (van der Oost et al. 2003). The use of biomarkers (changes in a biological response) provide insight regarding potential mechanisms of contaminant effects on an organism (van der Oost et al. 2003). The incorporation of such assays is included in the EEM design to monitor for potential adverse environmental conditions and are further described in later sections.

3.0 ENVIRONMENTAL EFFECTS MONITORING SUMMARY

The EEM program was designed to monitor critical elements of the receiving marine environment to provide timely and beneficial information to detect deleterious effects to the marine environment (HMDC 2019a). To assess the environmental effects of the projects, 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).

3.1 Program Components

The program components for the Hibernia EEM includes sediment quality, commercial fish, and water quality to meet the specific objectives outlined in Section 1.3. The methods, results, and interpretation of results are defined and presented in the proceeding sections of this report. Statistical interpretation is provided for the spatial and temporal trends that may be occurring in association with drilling and production activities. Particular emphasis is given to parameters associated with drilling and production operations, such as barium, hydrocarbons and produced water analytes (Trefry et al. 2013, Whiteway et al. 2014, DeBlois et al. 2014c)

3.2 Monitoring Hypotheses

The EEM program was designed to monitor critical elements of the receiving marine environment to provide timely and beneficial information to detect deleterious effects to the marine environment (HMDC 2019a). The program has been strengthened based on recommendations from regulatory review as well as experience gained during previous Hibernia EEM monitoring years. 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 2019a).

The monitoring hypotheses for the EEM program are consistent between the two operations (Hibernia Platform and HSE) and are stated in the *Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring Plan* (HMDC 2019a) as follows:

Hypothesis No.1:

> H_0 = Approved releases of solids and liquids from 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 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 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 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 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 Operations will result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.

For Hibernia Platform 'Operations' is defined as the Hibernia Platform's production and drilling operations. For HSE, 'Operations' is defined as HSE's drilling operations that were complete as of April 2017. The biological sampling program assessed the operations at a whole field level rather than individual sampling programs for Hibernia and HSE.

An integrative weight of evidence approach is used to assess the environmental effects of the project. 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 (H_0) for Hypothesis No. 2 would be rejected if the combined outcomes of the EEM program were to demonstrate that:

- Biological toxicity testing (including Petrotox sediment quality guideline and/or amphipod/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; and
- There is a statistically significant difference in the concentration of that analyte within the sediment compared to background or baseline conditions (HMDC 2019).

Where a biological effect beyond the predictions of the Environmental Impact Statement (EIS) 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 would include a qualitative and where possible, quantitative assessment using existing knowledge (referenced scientific studies), professional judgement and analytical tools (HMDC 2019a).

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 exceedance. 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.

3.3 Sampling Design

3.3.1 Timing

Table 3-1 lists the schedule for all the EEM cruises for the Hibernia program. Baseline surveys were conducted prior to the initiation of drilling operations in 1994 and 2011 for Hibernia and HSE respectively. Subsequent EEM surveys were conducted on an annual basis for the first three years and every two years thereafter with one exception; in 2014 the Hibernia Platform EEM survey was postponed by a year to synchronize with the HSE EEM schedule. In addition, the timing of the biological cruise shifted from December to early summer in 1999 to increase catch rates of target species.

Table 3-1: Hibernia EEM timelines.

Phase	Year	Sediment Cruise Dates[1]	Biological Cruise Dates
Baseline (Hibernia)	1994	Aug. 31-Sep. 10	Dec. 04-06
Year 1 (Hibernia)	1998[2]	Aug. 26-Sep. 01	Dec. 16-23
Year 2 (Hibernia)	1999[3]	Jul. 25-30, Sep. 01-Oct. 04	Jun. 08-10
Year 3 (Hibernia)	2000	Jul. 8-18	Jul. 05-06
Year 4 (Hibernia)	2002	Jul. 06-14	Jun. 29-01
Year 5 (Hibernia)	2004	Aug. 22-28	Jul. 13-14
Year 6(Hibernia)	2007	Aug. 17-29	Jul. 17-20
Year 7 (Hibernia))	2009	Jul. 30-Aug. 04	Jun. 30-Jul. 03
Year 8 (Hibernia) Baseline (HSE)	2011	Aug. 01-06	Jul. 07-12
Year 9 (Hibernia) Year 1 (HSE)	2014[4]	Aug. 07-17	Jun. 20-Jul. 01
Year 2 (HSE)	2015	Sep. 10-16	Jun. 28-30
Year 10 (Hibernia) Year 3 (HSE)	2016	Aug. 30-Sep. 6	Jun. 25-Jul. 04
Year 11 (Hibernia) Year 4 (HSE)	2018	Jul. 19-Jul. 30	Jun. 29-Jul. 06
Year 12 (Hibernia) Year 5 (HSE)	2020	Sept. 25-Oct. 3	Jul. 24-Jul. 29

Notes:
[1] The sediment cruise for Hibernia sampling also includes water sampling
[2] Hibernia began production in November of 1997
[3] The 1999 sediment cruise was split into two cruises due to equipment losses and manufacturing of new equipment
[4] Drilling at HSE commenced in January 2014 (HMDC 2017a) and was completed in April 2017

3.4 Stations

Samples of benthic marine sediment and water were collected from the seafloor from pre-established coordinates specified in the EEM design plan (HMDC 2019a). The field distance definitions for sediment sampling are listed in Table 3-2 and planned sediment sampling stations for the 2020 program are illustrated in Figure 3-1

(Hibernia) and Figure 3-2 (HSE). Further details of the sediment sampling stations are given in Section 4.0. The planned 2020 water sampling stations are illustrated in Figure 3-3 with further details in Section 5.0.

The biological sampling program collected commercial fish within a two-km radius of the Hibernia Platform, HSE EDC and within a reference area located 50 km northwest of the Hibernia Platform (50 km HRA) (Figure 3-4). As prescribed in the HMDC EEM Design Plan (HMDC 2019a), a minimum of seven tows were conducted at each location. The tow locations vary between years with details of the 2020 tow locations in Section 6.0.

Table 3-2: Field distance definitions.

Field distance descriptors[1]	Distance from Source[2]	2020 Hibernia Stations	2020 HSE Stations
Near-Field	≤1,000 m	250, 500, 1,000 m	250, 500, 1,000 m
Mid-Field[3]	>1,000 m to ≤4,000 m	2,000, 3,000 m	-
Far-Field[4]	>4,000 m	6,000, 16,000 m	6,000 m

Notes:
[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 1,500 – 3,000 m
[4] Far-Field prior to 2004 was defined as 4,000 – 8,000 m

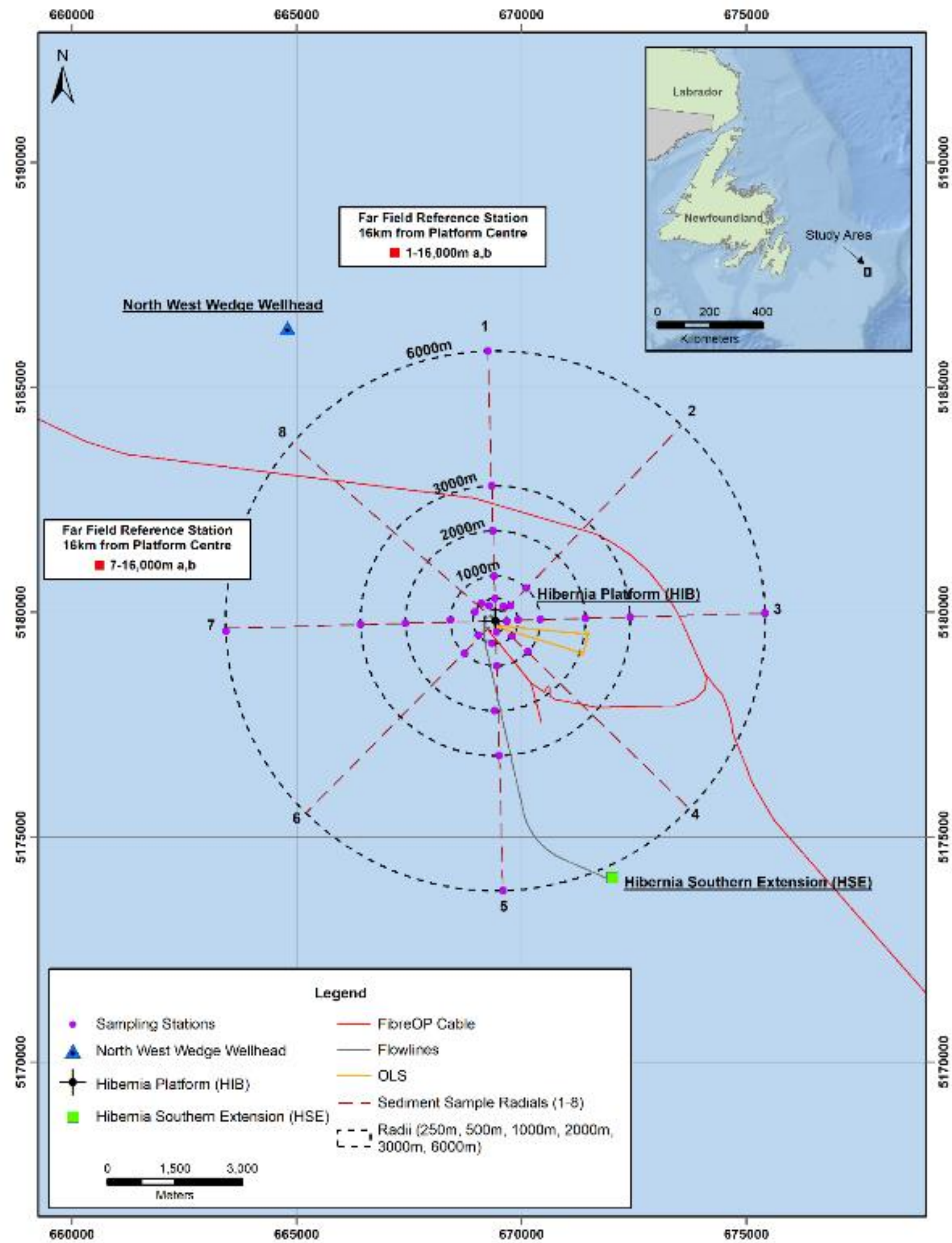


Figure 3-1: Sediment sample stations around the Hibernia Platform for the Hibernia 2020 EEM.

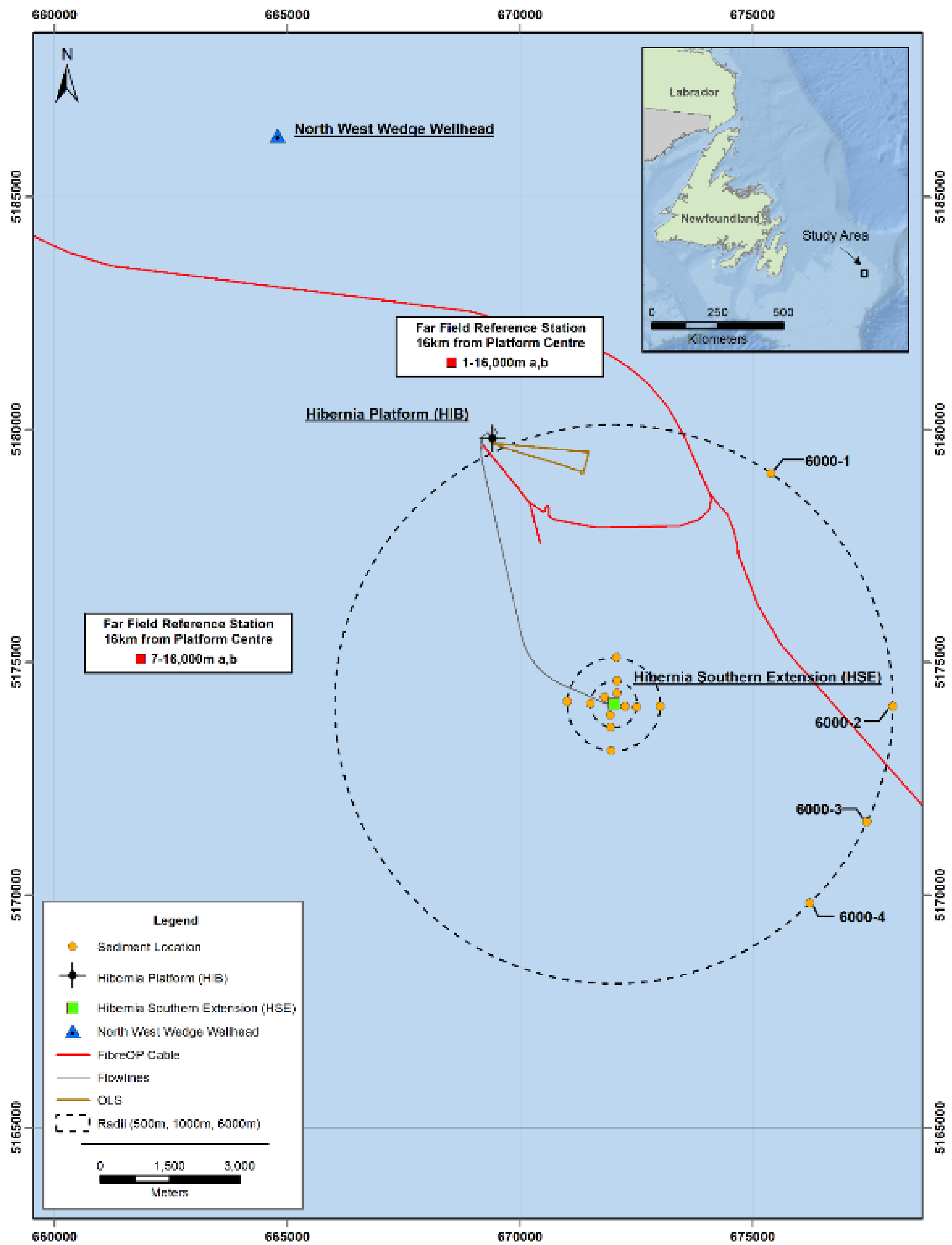


Figure 3-2: Sediment sample stations around HSE for the Hibernia 2020 EEM.

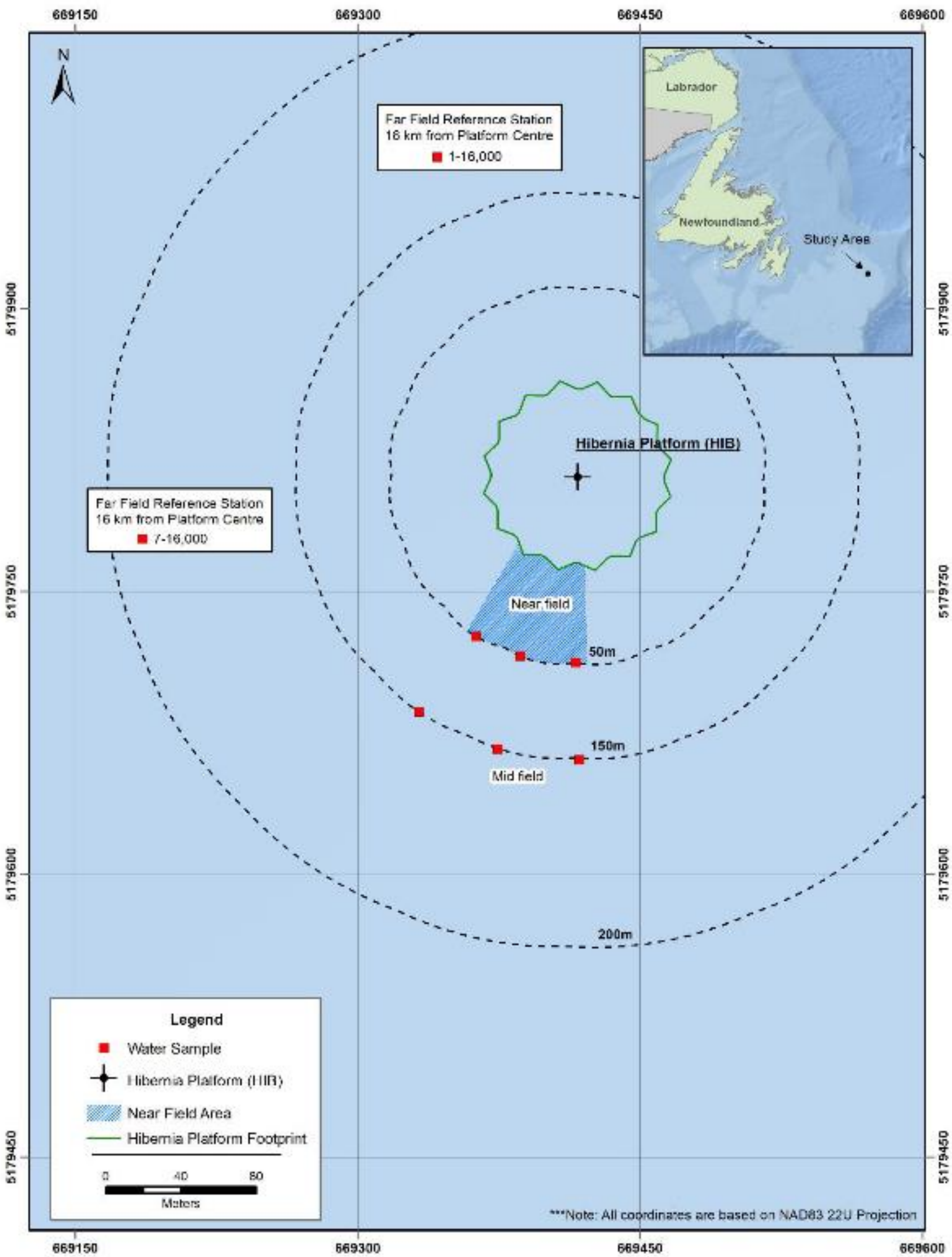


Figure 3-3: Planned water sampling stations for Hibernia 2020 EEM.

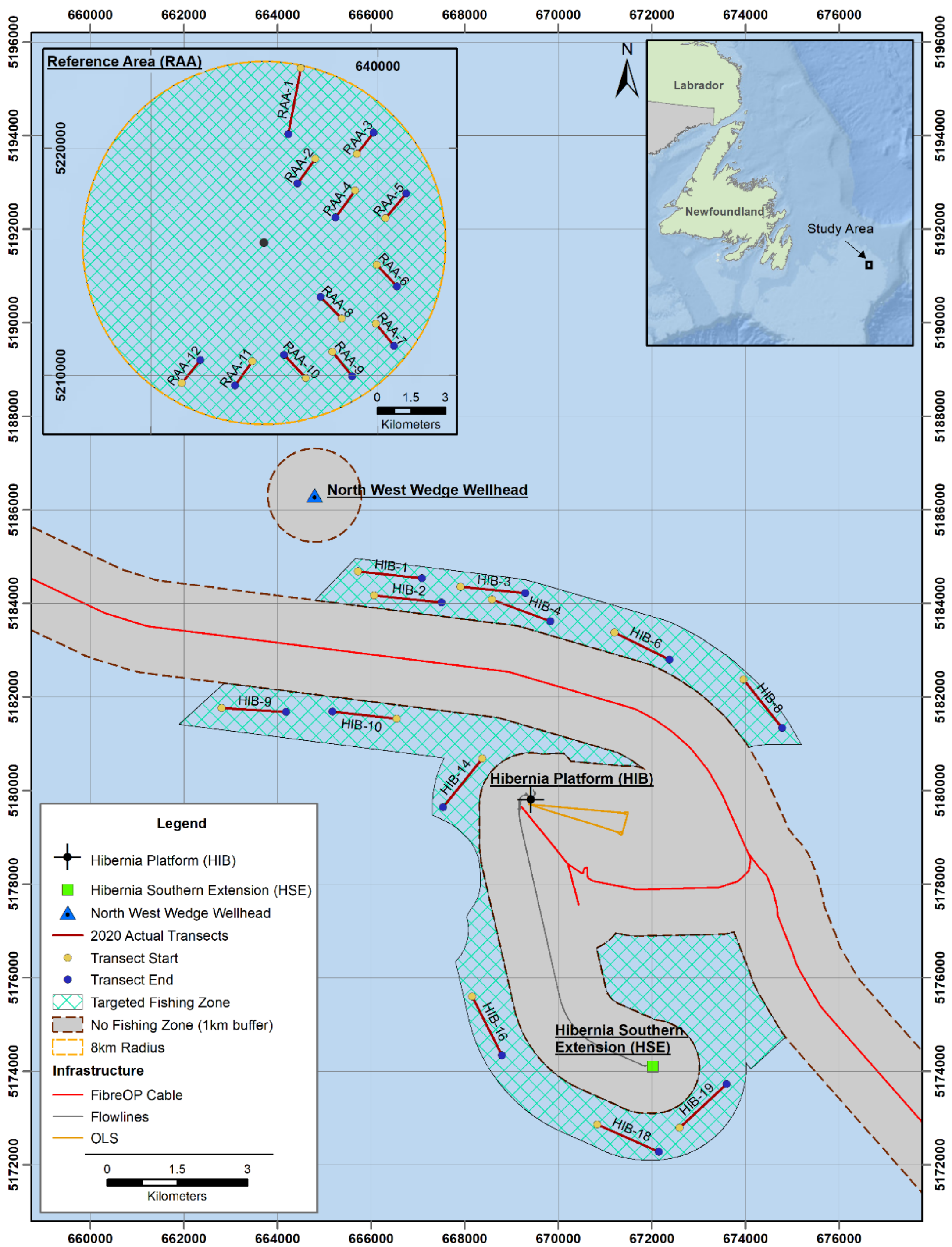


Figure 3-4: Commercial fish sampling trawls for Hibernia 2020 EEM.

3.4.1 Parameters

The EEM program consists of sampling components to assess sediment and water quality, and fish health and body burden (summarized in Table 3-3). The complete rationale for the selection of parameters as well as the various design changes are available within the EEM Design Plan (HMDC 2019a). The design plan for the Hibernia EEM was initially implemented in 2004 and amended in 2013 to include the sampling regime for HSE. The EEM program design is an iterative process which periodically undergoes review. The most recent review of the EEM program design was conducted in 2019 and resulted in the revision of the Design Plan. The revised Design Plan (HMDC 2019a) saw the removal of alkyl PAHs from the sediment and fish tissue analysis; removal of the Microtox assay for sediment toxicity assessment and replacement with a Petrotox sediment quality guideline; change in the species used for the polychaete growth and survival toxicity test; transition from an asset based (Hibernia Platform, HSE) to a field level assessment of commercial fish species; increase in separation distance between the Platform and subsea assets; reduction in the time required that archive samples are held; increase in the reference area size; and to accommodate the potential establishment of another excavated drill centre.

Table 3-3: Hibernia EEM program sediment, water, and commercial fish sampling program component parameters and analysis.

Program Component	Parameters	Analysis
Sediment Quality	Chemistry	Particle size, organic and inorganic carbon, metals, barium, hydrocarbons, ammonia and sulphide concentrations
	Toxicity	Petrotox Guideline, Amphipod survival, Polychaete growth and survival
Water Quality[1]	Chemistry	Metals, hydrocarbons, nutrients
	CTD	Dissolved oxygen, temperature, salinity, and pH profiles
Commercial Fish (American plaice)	Tissue Chemical Profiles	Body burden (metals, hydrocarbons, ammonia)
	Sensory Evaluation	Triangle test, Hedonic scaling
	Health Indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity

Notes:
[1] Water quality is associated with produced water monitoring and therefore occurs at Hibernia Platform and Reference Stations only

4.0 SEDIMENT QUALITY

The following chapter presents the sediment program analysis conducted as part of the 2020 Hibernia EEM program. This includes a description of sample collection, physical and chemical laboratory analysis, non-statistical exploratory analysis of sediment components (particle size and chemistry data), statistical analysis of sediment components, and interpretation of sediment toxicity results. Detailed descriptions of sampling methods and data reports are included in Volume II.

EEM programs have been ongoing at the Hibernia Platform (HIB) since 1994 and the HSE since 2011, therefore, this report marks the twelfth year for the Hibernia EEM program and the fifth year for the HSE EEM program. The number of sampling stations as part of the sediment component has changed since the inception of the program (Table 4-1). In 2020, 34 stations were sampled around the Hibernia Platform as part of the sediment component and 16 stations were sampled around the HSE. The HSE baseline included a total of 12 sediment stations sampled around the HSE's EDC. In 2014, four additional baseline/control stations were added at 6,000 m away from the EDC (Table 4-1). These additional stations were added to examine and quantify the potential for cumulative effects of the whole Hibernia program in EEM survey years where both production fields are surveyed (such is the case in 2020). The 2020 program was based upon the 2019 Hibernia Oil and Gas Production and Development Drilling Project EEM Plan sampling design that established a minimum buffer of 100 m from the flow lines and other subsea infrastructure therefore a few stations required adjustment to meet these buffer widths (HMDC 2019a).

Table 4-1: Number of sediment quality sampling stations at Hibernia Platform and HSE.

Year	Stations (#)		Notes/Description
	Hibernia Platform	HSE	
1994	46	-	Hibernia Baseline
1998	46	-	
1999	58	-	
2000	60	-	Additional 2 reference stations at 32 km along radials 1 and 7 (only this year)
2002	58	-	SBM Reinjection of drill cuttings fines
2004	34	-	Number of Mid- and Far-Field stations reduced
2007	34	-	
2009	34	-	
2011	34	12	HSE Baseline
2014	34	16	Additional 4 stations at 6,000 m to the east of the EDC
2015	-	16	
2016	34	16	
2018	34	16	
2020	34	16	Buffer increased to 100 m from subsea infrastructure, updated plan (HMDC, 2019).

4.1 Methods

4.1.1 Field Collection

The 2020 EEM physical survey was conducted by WSP field staff from September 25th to October 3rd aboard the supply vessel *Avalon Sea*, under contract to HMDC. The vessel arrived on location at the Hibernia field on September 26, 2020 and completed sampling on September 29, 2020. Fugro offshore surveyors (located on the bridge) were responsible for geo-positioning services including targeting proposed sampling locations and logging the actual position and time of sediment sampling.

Sediment samples were collected on a 24-hour basis when weather was suitable, and the vessel was not required for platform support. For 24-hour operations, two complete (three-person) WSP teams were required. The vessel's deckhands and the WSP team worked in a complimentary fashion with the ship's watch system. The deckhands worked 6-hour shifts; the WSP teams worked 12-hour shifts. Sampling operation protocols and duties are described as follows, each 12-hour shift was directed by the team leader and each shift started with a toolbox safety meeting. The Captain of the Avalon Sea had authority in matters of safety. The vessel crew were responsible for vessel operations, the operation of the overhead crane, and assisting the WSP team with sampling operations. Sediments were collected using a Pouliot box corer (Figure 4-2 A and B). The crane was used to deploy and retrieve the box corer. Two WSP personnel were responsible for the arming, loading, and unloading of the box corer. The positioning of box corer deployment was coordinated through the crew leader and the Fugro offshore surveyor on shift. After retrieval and the box corer was secure on deck (Figure 4-2 A and B), the third WSP team member was responsible for sub-sampling recovered box corer samples and recording field observations.

Sampling stations were arranged in a radial pattern around the Hibernia Platform and HSE (Figure 4-3). The radial pattern follows the four cardinal directions with stations occurring at distances 250 m, 275 m, 500 m, 1,000 m, 2,000 m, 3,000 m, and 6,000 m from the platform and between the cardinal directions at 250 m, 500 m, and 1,000 m. Station 8-250 was moved to a distance of 275 m from the Hibernia Platform due to the increased buffer. This was treated as if it was 250 m from the platform for all analyses. There were also two reference stations located 16,000 m from the Hibernia Platform on the north and west radii (Figure 4-1). Reference stations were collected in duplicate and designated as A and B. Additional samples were collected at stations 6-1000, 3-500, 4-500, and 7-16000A for Quality Assurance/Quality Control (QA/QC) purposes. Prior to the commencement of the EEM survey, stations 4-500, 5-500 and W-250 were moved to maintain a minimum buffer distance (100-m) from subsea infrastructure. Refer to Section 4.1.1 for the coordinates (proposed and actual) of the sediment sampling locations.

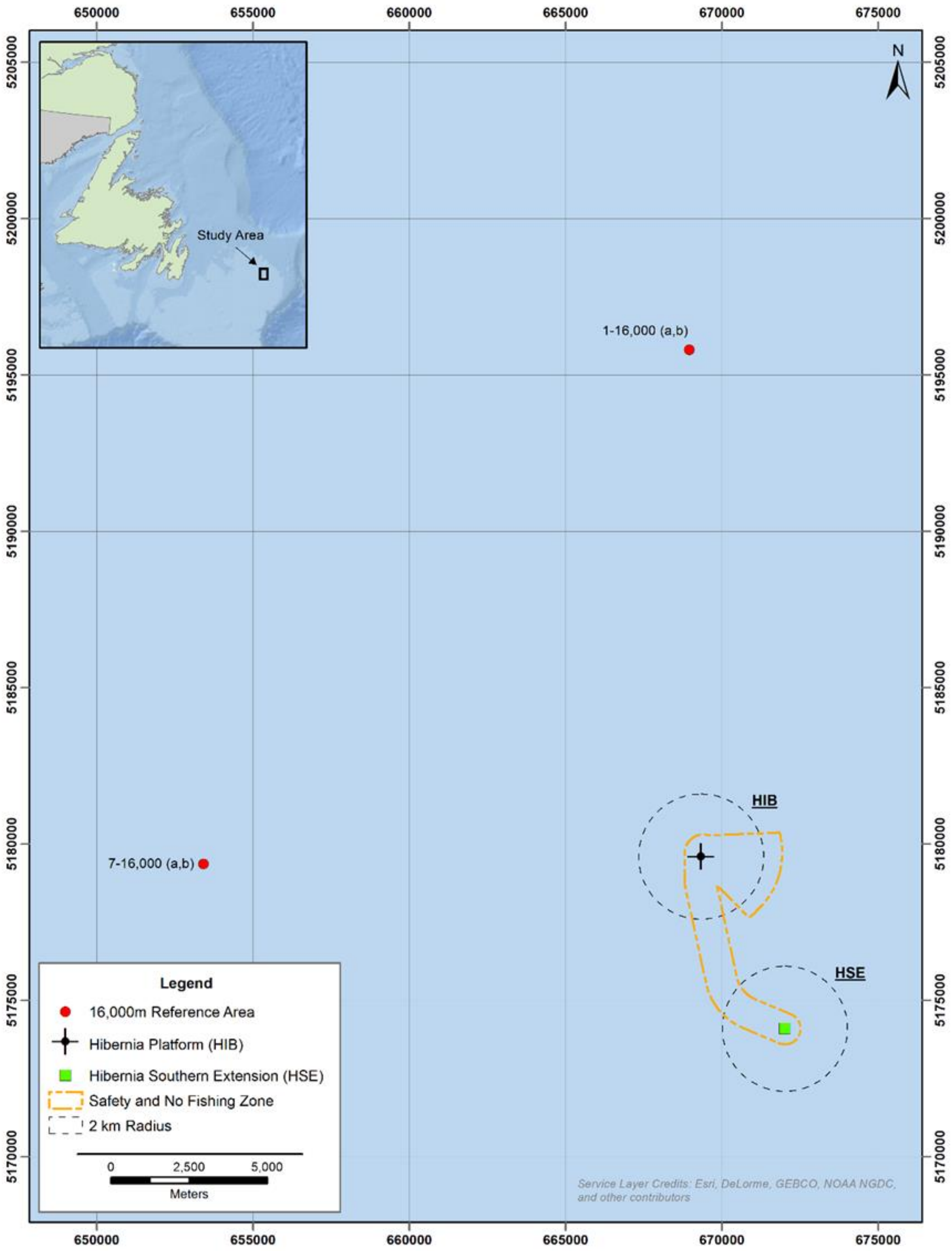


Figure 4-1: Hibernia Platform and HSE area locations with 16,000 m sediment reference sampling stations.

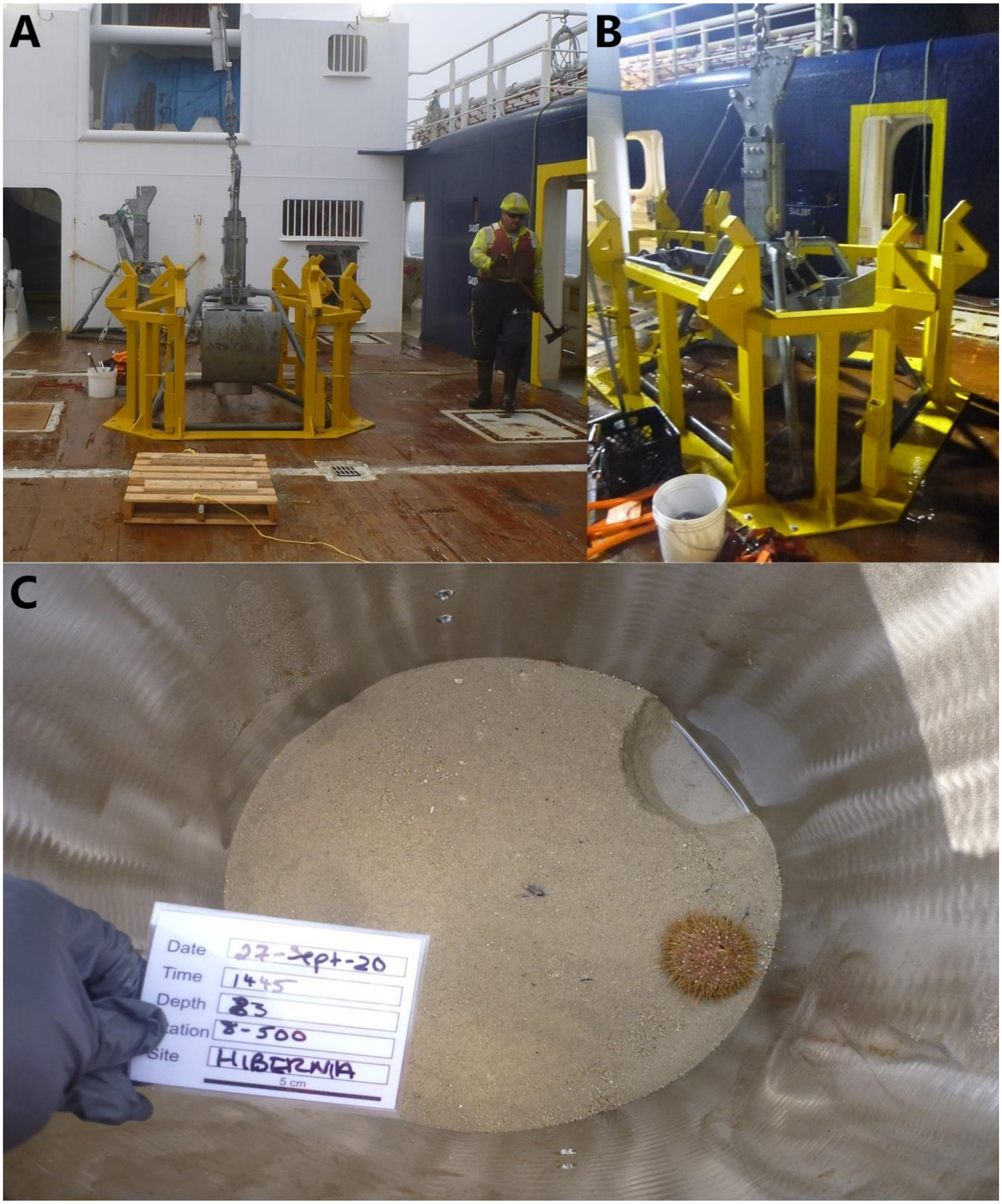


Figure 4-2: A) Deck operations of box corer in the cradle, B) Pouliot box corer closeup, C) Example photo of sediment recovered with the box corer.

4.1.1.1 Hibernia Platform

A total of 40 sediment samples (including QA/QC samples) were collected at 34 stations (including reference stations) in 2020 (Figure 4-3). One sample was collected at each station except for the QA/QC stations (where two samples were collected). Reference stations were also sampled in replicate. In the field, RAA-7-16000A was sampled for QA/QC due to sampling difficulty encountered at RAA-1-16000A. Proposed and actual coordinates are presented in Table 4-2.

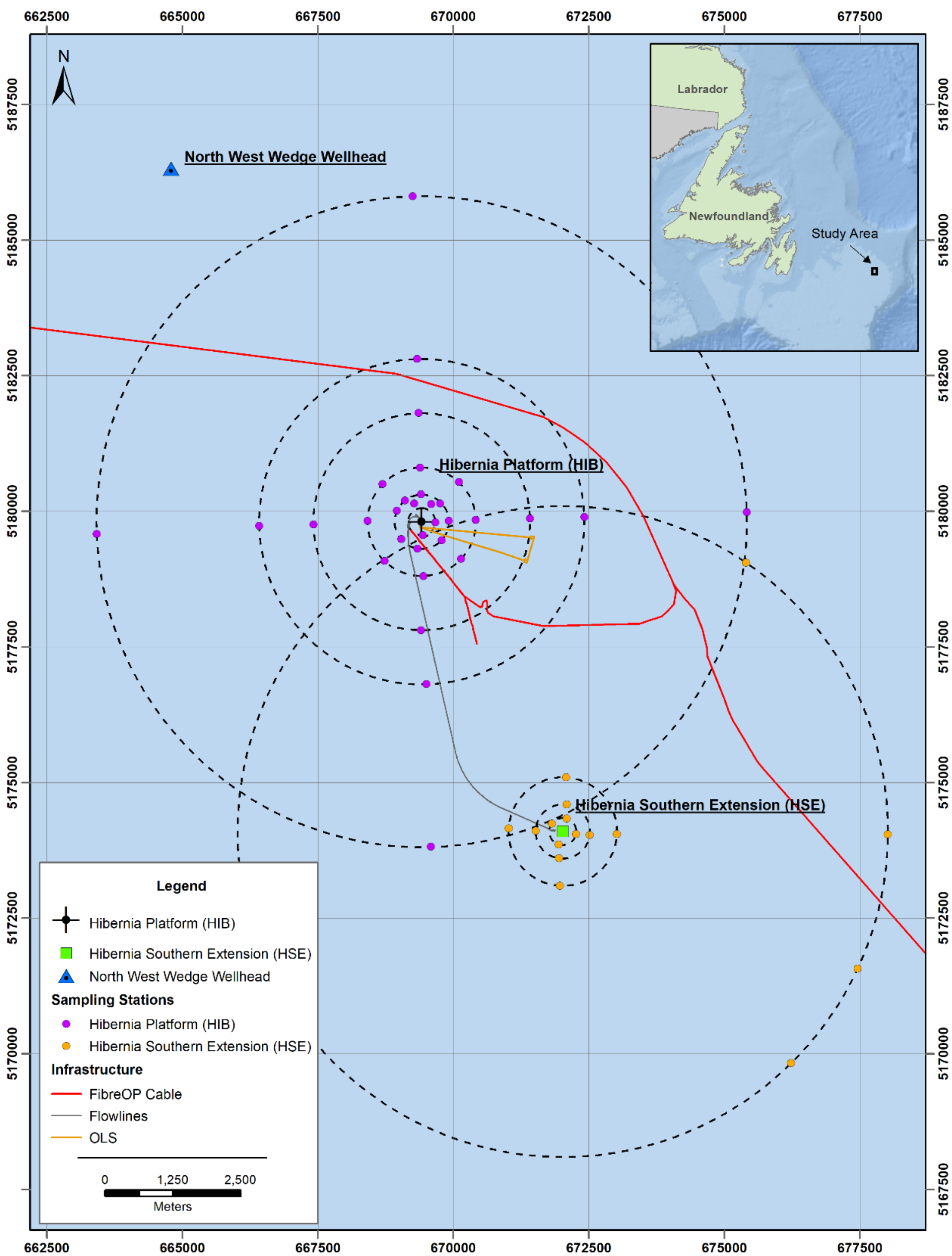


Figure 4-3: Hibernia 2020 EEM sediment quality sampling stations.

Table 4-2: Coordinates (proposed and actual) for Hibernia Platform 2020 sediment sampling locations.

Station	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
HIB-1-500	669404	5180315	19	669391.83	5180320.93
HIB-1-1000	669389	5180809	23	669393.20	5180807.43
HIB-1-2000	669361	5181814	24	669360.66	5181813.33
HIB-1-3000	669333	5182814	25	669333.58	5182814.12
HIB-1-6000	669249	5185813	26	669247.73	5185815.90
HIB-1-6000 QA	669249	5185813	27	669245.02	5185814.84
HIB-2-250	669589	5180133	20	669587.01	5180132.87
HIB-2-500	669757	5180147	21	669755.31	5180148.07
HIB-2-1000	670105	5180542	22	670105.30	5180541.62
HIB-3-500	669918	5179829	5	669922.84	5179830.65
HIB-3-500 QA	669918	5179829	6	669922.71	5179828.39
HIB-3-1000	670414	5179843	4	670421.77	5179840.82
HIB-3-2000	671417	5179872	3	671417.28	5179873.05
HIB-3-3000	672417	5179900	2	672421.23	5179898.85
HIB-3-6000	675415	5179984	1	675418.95	5179983.93
HIB-4-250	669667	5179802	7	669673.21	5179804.02
HIB-4-500 [1]	669778	5179465	8	669779.73	5179467.00
HIB-4-500 QA [1]	669778	5179465	9	669786.70	5179463.44
HIB-4-1000	670145	5179128	36	670146.87	5179125.08
HIB-5-500 [1]	669289	5179327	14	669289.70	5179324.08
HIB-5-1000	669446	5178810	11	669451.19	5178808.73
HIB-5-2000	669403	5177811	12	669406.34	5177811.14
HIB-5-3000	669502	5176817	13	669503.18	5176818.01
HIB-5-6000	669587	5173818	38	669586.48	5173818.14
HIB-6-250	669439	5179562	10	669442.55	5179559.52
HIB-6-500	669038	5179489	15	669040.97	5179485.04
HIB-6-1000	668731	5179088	35	668734.79	5179085.79
HIB-7-500	668959	5180012	16	668959.88	5180010.98
HIB-7-1000	668417	5179829	34	668418.81 [2]	5179828.00 [2]
HIB-7-2000	667419	5179759	33	667417.33	5179758.88
HIB-7-3000	666419	5179731	32	666421.54	5179731.26
HIB-7-6000	663422	5179585	31	663424.48	5179584.76
HIB-8-250	669278	5180148	18	669276.42	5180145.02
HIB-8-500	669105	5180202	17	669102.79	5180201.01
HIB-8-1000	668691	5180502	37	668692.42	5180501.22

Station	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
RAA-1-16000A	668966	5195808	39	668962.48	5195810.22
RAA-1-16000B	668966	5195808	40	668961.83	5195808.79
RAA-7-16000A	653424	5179363	28	653425.60	5179364.91
RAA-7-16000A QA[3]	653424	5179363	29	653426.12	5179363.84
RAA-7-16000B	653424	5179363	30	653423.30	5179364.27

Notes:
[1] Stations 4-500 and 5-500 were moved prior to departure to maintain minimum 100 m buffer from subsea infrastructure.
[2] Surface fix coordinates, as the USBL was disabled.
[3] QA sample was originally planned for RAA-1-16000A but changed in the field due to difficulty acquiring a sample at that location.
All coordinates are presented in UTM, Zone 22, NAD83

4.1.1.2 Hibernia Southern Extension

A total of 17 sediment samples were collected from 16 stations (including one QA/QC sample) (Table 4-3). The location of station W-250 was moved prior to the commencement of the survey to maintain the minimum buffer (100-m) from subsea infrastructure. Samples were collected along the four cardinal directions at distances 250 m, 500 m, and 1,000 m from the HSE. The four HSE specific reference stations were located 6,000 m to the west of the HSE. They are not on a specific radial. The other two reference stations were located 16,000 m from the Hibernia Platform on the north and west radii. A single box corer sample was collected at each station and an additional sample was collected at station 6000-2 for QA/QC purposes. As noted above, each reference station was collected in replicate (marked A, B).

Table 4-3: Coordinates (proposed and actual) for HSE 2020 sediment sampling locations.

Station	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
N-250	672096	5174338	4	672095.45	5174335.26
N-500	672091	5174595	3	672093.27	5174589.84
N-1000	672081	5175098	2	672080.69 [1]	5175095.47 [1]
E-250	672266	5174052	11	672264.16	5174053.80
E-500	672516	5174035	12	672513.49	5174034.91
E-1000	673019	5174052	13	673013.83	5174052.58
S-250	671945	5173861	10	671941.56	5173861.54
S-500	671952	5173605	9	671953.65	5173605.58
S-1000	671967	5173101	8	671968.20	5173098.51
W-250 [2]	671827	5174331	5	671828.80	5174330.98
W-500	671520	5174114	7	671517.44	5174113.93
W-1000	671022	5174157	6	671022.24	5174154.94
6000-1	675397	5179055	1	675382.32	5179051.30
6000-2	678018	5174048	16	678021.04	5174048.71
6000-2 QA [3]	678018	5174048	17	678023.40	5174048.73

Station	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
6000-3	677461	5171574	15	677465.89	5171573.80
6000-4	676231	5169829	14	676234.83	5169830.27

Notes:
[1] Surface fix coordinates, as the HiPAP beacon was not deployed.
[2] Station W-250 was moved prior to departure to maintain minimum 100 m buffer from subsea infrastructure.
[3] QA sample originally planned for 6000-1 but was changed in the field due to difficulty acquiring a sample at that station.
All coordinates are presented in UTM, Zone 22, NAD83

4.1.2 Field Sampling

Each recovered sediment sample was described and subsampled in the field as per the diagram in Figure 4-4. Prior to subsampling, samples were described and photographed, and temperature and redox potential measurements taken. Subsamples were collected from each box corer sample (Figure 4-4) for physical and chemical characterization, an archival sample, and toxicity bioassays (amphipod/polychaete bioassay) (Figure 4-4). Samples for QA/QC analysis were limited to physical and chemical characterization.

Subsamples were collected as follows (Figure 4-4):

- Physical, chemical, and archive samples were collected from one half of the box corer sample from the upper 5.0 cm;
- Toxicity bioassay samples were collected from the other half of the box corer sample in the upper 7.5 cm;
- All samples and measurements were collected from an undisturbed area of the sample;
- Dates and times were noted on all sample labels.

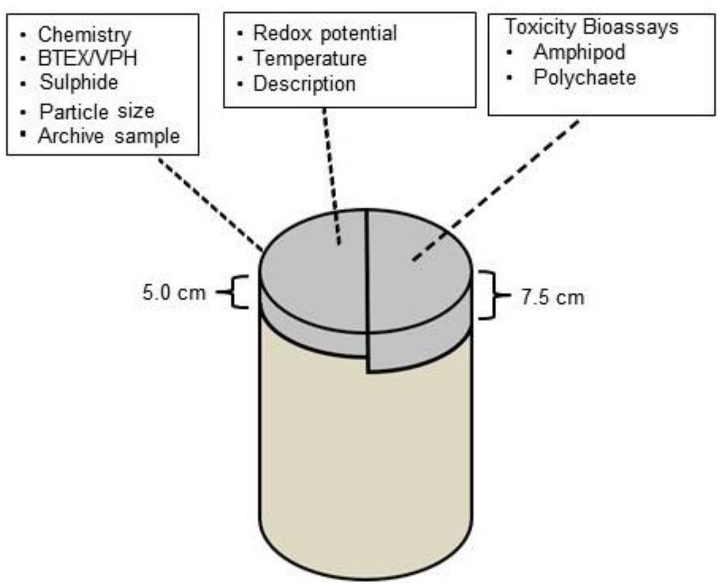


Figure 4-4: Subsample diagram for each box corer sample.

4.1.3 Laboratory and Statistical Analysis

4.1.3.1 Physical and Chemical Laboratory Analysis and Data Screening

All sediment physical and chemical analyses were carried out by Bureau Veritas (Bedford, NS). The detailed, lab supplied, analysis methodology for each analyte are included in Volume II. Physical and chemical sediment subsamples were analysed for a suite of analytes (Table 4-4) as specified in the Hibernia EEM plan (HMDC 2019a) including:

- Petroleum hydrocarbons (total petroleum hydrocarbons (TPH));
- Polycyclic aromatic hydrocarbons (PAHs);
- Total metals;
- Total barium, and weak-acid extractable (leachable) barium;
- Particle size (percent fines);
- Total organic carbon (TOC), and total inorganic carbon (TIC);
- Ammonia; and
- Sulphur/Sulphide.

While the above suite of analytes was analysed, only those that had detectable change over the course of the project (mainly barium and TPH) were screened-in for further analysis (HMDC 2019a).The laboratory data for the full suite of analytes is available in Volume II.

Table 4-4: Sediment sampling program analytical requirements.

Variable	Parameter	RDL	Units	Method of Analysis
Petroleum Hydrocarbons	Benzene	0.005	mg/kg	GC/MS
	Toluene	0.025	mg/kg	GC/MS
	Ethylbenzene	0.025	mg/kg	GC/MS
	Total Xylenes	0.01	mg/kg	GC/MS
	C_6-C_{10} (Less BTEX)	2.5	mg/kg	GC/FID
	>C_{10}-C_{21} Hydrocarbons	0.25	mg/kg	GC/FID
	>C_{21}-C_{32} Hydrocarbons	0.25	mg/kg	GC/FID
Polycyclic Aromatic Hydrocarbons[1]	1-Methylnaphthalene	0.005	mg/kg	GC/MS
	2-Methylnaphthalene	0.005	mg/kg	GC/MS
	Acenaphthene	0.005	mg/kg	GC/MS
	Acenaphthylene	0.005	mg/kg	GC/MS
	Anthracene	0.005	mg/kg	GC/MS
	Benzo(a)anthracene	0.005	mg/kg	GC/MS
	Benzo(a)pyrene equivalency	0.005	mg/kg	GC/MS
	Benzo(b)fluoranthene	0.005	mg/kg	GC/MS
	Benzo(j)fluoranthene	0.005	mg/kg	GC/MS

Variable	Parameter	RDL	Units	Method of Analysis
	Benzo(k)fluoranthene	0.005	mg/kg	GC/MS
	Benzo(g,h,i)perylene	0.005	mg/kg	GC/MS
	Chrysene	0.005	mg/kg	GC/MS
	Dibenz(a,h)anthracene	0.005	mg/kg	GC/MS
	Fluoranthene	0.005	mg/kg	GC/MS
	Fluorene	0.005	mg/kg	GC/MS
	Indeno(1,2,3-cd) pyrene	0.005	mg/kg	GC/MS
	Naphthalene	0.005	mg/kg	GC/MS
	Perylene	0.005	mg/kg	GC/MS
	Phenanthrene	0.005	mg/kg	GC/MS
	Pyrene	0.005	mg/kg	GC/MS
Metals	Aluminum (Al)	10.0	mg/kg	ICP/MS
	Antimony (Sb)	2.0	mg/kg	ICP/MS
	Arsenic (As)	2.0	mg/kg	ICP/MS
	Barium (Ba)	5.0	mg/kg	ICP/MS
	Barium (Ba) – Weak Acid Extraction	5.0	mg/kg	ICP/MS
	Beryllium (Be)	0.50	mg/kg	ICP/MS
	Cadmium (Cd)	0.05	mg/kg	ICP/MS
	Chromium (Cr)	2.0	mg/kg	ICP/MS
	Cobalt (Co)	1.0	mg/kg	ICP/MS
	Copper (Cu)	2.0	mg/kg	ICP/MS
	Iron (Fe)	50	mg/kg	ICP/MS
	Lead (Pb)	0.50	mg/kg	ICP/MS
	Lithium (Li)	2.0	mg/kg	ICP/MS
	Manganese (Mn)	2.0	mg/kg	ICP/MS
	Mercury (Hg)	0.01	mg/kg	CVAA
	Molybdenum (Mo)	2.0	mg/kg	ICP/MS
	Nickel (Ni)	2.0	mg/kg	ICP/MS
	Selenium (Se)	2.0	mg/kg	ICP/MS
	Silver (Ag)	0.50	mg/kg	ICP/MS
	Strontium (Sr)	5.0	mg/kg	ICP/MS
	Thallium (Tl)	0.10	mg/kg	ICP/MS
	Tin (Sn)	2.0	mg/kg	ICP/MS
	Uranium (U)	0.10	mg/kg	ICP/MS

Variable	Parameter	RDL	Units	Method of Analysis
	Vanadium (V)	2.0	mg/kg	ICP/MS
	Zinc (Zn)	5.0	mg/kg	ICP/MS
General Chemistry	Particle Size Analysis	0.1	%	Sieve and Pipette
	Moisture	1	%	Gravimetric
	Sulphide	0.5	µg/g	Colorimetric
	Total Carbon	0.5	g/kg	LECO® Carbon Analyzer
	Total Inorganic Carbon (TIC)	0.5	g/kg	LECO® Carbon Analyzer
	Total Organic Carbon (TOC)	0.5	g/kg	LECO® Carbon Analyzer
	Ammonia-N	0.29	mg/kg	Colorimetric

Notes:
[1] Alkylated PAHs (added in 2009) have not been detected in the sediment and were removed

The 2020 EEM sediment statistical analysis was conducted on physical and chemical analytes following data screening (HMDC 2019a). Initial data screening criterion were as follows:

- Analytes with detectable change association with drilling and production operations over the course of the project (primarily barium and TPH);
- Analytes that obviously deviate from baseline levels (or reference station levels).

An obvious deviation was defined for an analyte where more than 50% of EEM stations had concentrations greater than two standard deviations above the baseline mean. For analytes that have not been measured since baseline, the reference station sediment chemistry from 2007 to 2016 were used for comparison. Based on the above criteria, the chemical analytes screened-in for further analysis for the Hibernia Platform and HSE sediment samples are listed in Table 4-5 to Table 4-7. The reportable detection limits (RDL) for each analyte are consistent with those specified according to regulatory testing standards included in Volume II.

Table 4-5: Summary of screened-in analyte data for the Hibernia Platform sediment quality analysis.

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
TOTAL EXTRACTABLE METALS													
Barium	5	mg/kg	32	0	0	32	172.78	112.76	140	56	700	-	-
WEAK-ACID METALS													
WAM Barium	5	mg/kg	32	20	0	12	7.45	5.41	5	<RDL	33	-	-
HYDROCARBONS													
$>C_{10}$-C_{21}	0.25	mg/kg	32	1	12	19	1.11	1.41	0.55	<RDL	6.8	-	-
$>C_{21}$-C_{32}	0.25	mg/kg	32	0	3	29	0.62	0.74	0.38	<RDL	3.7	-	-
OTHER													
TIC/TOC													
Total Carbon	0.5	g/kg	32	11	0	21	4.35	8.10	0.64	<RDL	31	-	-

Notes:
[1] ISQG – Interim Sediment Quality Guidelines and PEL – Probable Effect Levels as specified in the *Canadian Environmental Quality Guidelines, CCME* (1999, updated 2001).

Table 4-6: Summary of screened-in analyte data for the HSE sediment quality analysis.

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
TOTAL EXTRACTABLE METALS													
Barium	5	mg/kg	16	0	0	16	2,246	6,887	420	84	28,000	-	-
WEAK-ACID METALS													
WAM Barium	5	mg/kg	16	5	0	11	22.09	23.98	14	<RDL	93	-	-
HYDROCARBONS													
>C_{10}-C_{21}	0.25	mg/kg	16	5	0	11	220.57	719.43	4.75	<RDL	2,890	-	-
>C_{21}-C_{32}	0.25	mg/kg	16	6	0	10	1.87	4.13	0.49	<RDL	17	-	-
PARTICLE SIZE ANALYSIS													
Clay	0.1	%	16	0	0	16	1.85	1.15	1045	0.54	4	-	-
OTHER													
TIC/TOC													
Organic Carbon	0.5	g/kg	16	4	0	12	9.72	8.14	12.5	<RDL	24	-	-

Notes:
[1]ISQG – Interim Sediment Quality Guidelines and PEL – Probable Effect Levels as specified in the *Canadian Environmental Quality Guidelines, CCME* (1999, updated 2001).

Table 4-7: Summary of screened-in analyte data for Reference Stations sediment quality analysis.

Parameter	RDL	Units	No. samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev	Median	Min	Max	ISQG[1]	PEL[1]
TOTAL EXTRACTABLE METALS													
Barium	5	mg/kg	4	0	0	4	100.25	22.10	97	77	130	-	-
WEAK-ACID METALS													
WAM Barium	5	mg/kg	4	0	4	0	<RDL	-	<RDL	<RDL	<RDL	-	-
HYDROCARBONS													
>C_{10}-C_{21}	0.25	mg/kg	4	0	0	4	<RDL	-	<RDL	<RDL	<RDL	-	-
>C_{21}-C_{32}	0.25	mg/kg	4	0	0	4	<RDL	-	<RDL	<RDL	<RDL	-	-
PARTICLE SIZE ANALYSIS													
Clay	0.1	%	4	0	0	4	0.75	0.14	0.76	0.57	0.89	-	-
OTHER													
TIC/TOC													
Total Carbon	0.2	g/kg	4	2	0	2	0.52	0.03	0.51	<RDL	0.57	-	-
Organic Carbon	0.2	g/kg	4	2	0	2	0.56	0.67	0.55	<RDL	0.63	-	-

Notes:
[1]ISQG – Interim Sediment Quality Guidelines and PEL – Probable Effect Levels as specified in the Canadian Environmental Quality Guidelines, CCME (1999, updated 2001).

4.1.3.2 Physical and Chemical Exploratory Data Analyses

Screened-in analytes were used to test for potential project related effects on the sediment environment through both non-statistical and statistical analysis. For both analyses, stations were grouped into one of three field distances from the Hibernia Platform or HSE. Table 4-8 lists the field designations with descriptions for each active centre.

Table 4-8: Hibernia Platform and HSE field distance definitions for sediment quality analyses.

Field distance descriptors[1]	Distance from Centre[2]	Hibernia Platform Stations	HSE Stations
Near-Field	≤1,000 m	250, 275, 500, 1,000 m	250, 500, 1,000 m
Mid-Field[3]	>1,000 m to ≤4000 m	2,000 – 3,000 m	-
Far-Field[4]	≥4,000 m	6,000 m	6,000 m

Notes:
[1] Whole-Field Analysis combined Near-, Mid-, and Far- for one centre with 16 km reference stations; Combined-Field Analysis is a comparison between Hibernia Platform and HSE
[2] Centre being Hibernia Platform or HSE Drill Center
[3] Mid-Field prior to 2004 was defined as 1,500-3,000 m
[4] Far-Field prior to 2004 was defined as 4,000-8,000 m

Spatial and temporal trends of screened-in analytes were described using non-statistical exploratory two-dimensional (2-D) scatter plots. The 2-D plots provide a graphical representation of trends. Plots were generated using the statistical software R (R Core Team 2020). The 'discharge point' (Hibernia Platform or HSE) is in the centre of the plot and colour denotes analyte concentration for that station. The X and Y axes represent the east-west and north-south distances (in meters), respectively from the Hibernia Platform or HSE. For Hibernia Platform, 2-D plots were generated for the Far-Field (the X and Y axes scales extend to 6,000 m) and the Near-Field (X and Y axes extend to 1,000 m). For HSE, the X and Y axes scales have been set to 1,000 m for greater resolution of the Near-Field; however, the 6,000 m stations are evaluated in the subsequent statistical exploration of the data. For visual purposes in the plots only, samples below RDL (e.g., non-detections) were set at RDL.

4.1.3.3 Physical and Chemical Statistical Analyses

The framework for statistical analysis of sediment analytes is illustrated in Figure 4-5 and is described below. As per previous Hibernia Platform and HSE EEM programs, samples below RDL (e.g., non-detections) were set at half (0.5x) the RDL value for the calculation of descriptive statistics to obtain a mean value no less than half the RDL for that analyte. The rationale for the use of half the RDL to address non-detection values (below RDL) is as described in the design plan (HMDC 2019a).

Statistical analysis was performed on screened-in analytes. The Categorical factors and associated interactions were examined via ANOVA for the Hibernia Platform and HSE. Statistical analyses are summarized in Table 4-9 and Table 4-10. In survey years that are synchronized between Hibernia Platform and HSE (such as in the 2020 EEM), a Combined-Field analysis of the Hibernia Platform and HSE was also performed in addition to the Near- and Whole-Field analyses for each surveyed area (HMDC 2019a).To test for correlation between sediment grain size and analyte concentration, Pearson correlations of the proportion of sediment grain sizes (arcsine transformed) and the analyte concentrations ($\log_{10}$ transformed) were calculated (correlations between the different sediment grain sizes were also tested). Subsequently, for analytes that did not have a large positive correlation with any sediment fraction ($r<0.5$), a two-way Analysis of Variance (ANOVA) was used for analysis (HMDC 2019a). The potential effect of a large positive correlation ($r>0.5$) between any analyte with an identified sediment type, was considered within the analysis by conducting an Analysis of Covariance (ANCOVA) to assess if the assumption of equality of slopes was met. 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, 2015). Accordingly, if the interaction between Year and either Field or Distance and the covariate was significant ($p<0.05$), the ANCOVA analysis was considered inappropriate due to violation of its assumptions; and the two-way ANOVA was interpreted instead (HMDC 2019a). A Project-related effect was indicated if the interaction term within the ANOVA was significant between Year and Field or Distance from the Hibernia Platform or HSE, respectively.

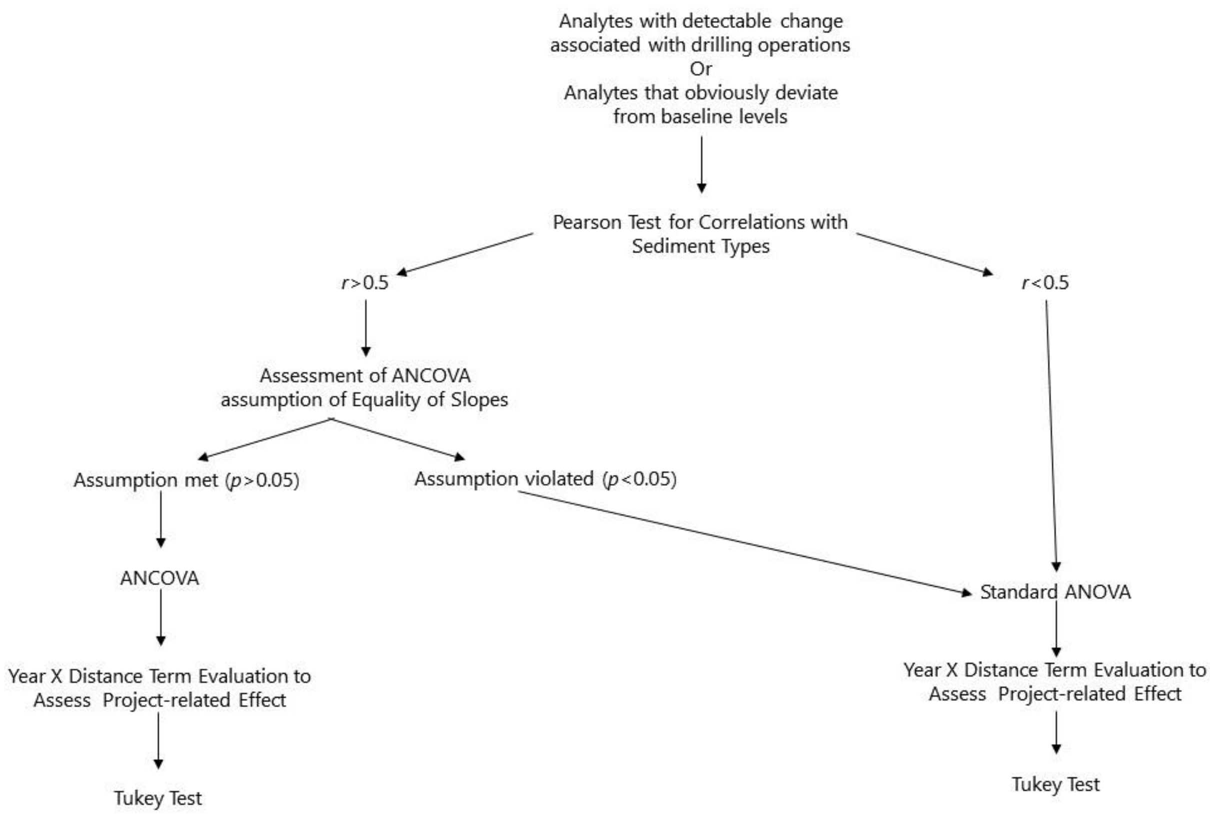


Figure 4-5: Statistical analyses framework for the Hibernia EEM.

Table 4-9: Categorical factors and associated interactions examined via ANOVA and ANCOVA for Hibernia Platform sediment quality statistical analyses.

Analysis	Factor	Levels
Near-Field Analysis	Distance	0, 100,150, 200, 250, 275, 300, 500, 750, 1,000 m
	Year	1994, 1998, 2000, 2002, 2004, 2007, 2009, 2011, 2014, 2016, 2018, 2020
	Distance x Year	-
Whole-Field Analysis	Year	1994, 1998, 2000, 2002, 2004, 2007, 2009, 2011, 2014, 2016, 2018, 2020
	Field	Near (≤1,000 m) Mid (>1,000 m - ≤3,000 m) Far (>4,000 m)
	Field x Year	-

Notes:
Degrees of freedom for Hibernia Platform analytes vary according to the years of data available and are specified in ANOVA or ANCOVA tables.

Table 4-10: Categorical factors and associated interactions examined via ANOVA and ANCOVA for the HSE sediment quality statistical analyses.

Analysis	Factor	Levels
Near-Field Analysis	Distance[1]	250, 500, 1,000, 6,000, 16,000 m
	Year	2011, 2014, 2015, 2016, 2018, 2020
	Distance x Year	-
Whole-Field Analysis	Year	2011, 2014, 2015, 2016, 2018, 2020
	Field	Near (≤1,000 m) Far (≥6,000 m)
	Field x Year	-

Notes:
[1] Distance Factor: the 6,000 m stations have been sampled since 2014.

4.1.3.4 Combined Field Statistical Analysis

Combined field analyses were performed in EEM years where the Hibernia Platform and HSE fields were both sampled. The combined field analysis consisted of two parts:

- Whole-Fields (≤6,000 m from infrastructure centre) of Hibernia Platform and HSE were combined to create the new term combined Whole-Field,
- Near-Fields (≤1,000 m from infrastructure centre) of Hibernia Platform and HSE were combined to create the new term combined Near-Field.

The combined Whole-Field analysis included data from all stations within 6,000 m from both the Hibernia Platform and the HSE (Table 4-11). The combined Near-Field analysis is conducted to assess any potential changes in the environment over time and includes stations within 1,000 m from the drill centre of each production field. The Near-Field analysis includes the terms Distance, Year, and Field as well as two-way interaction terms and a three-way interaction term (Table 4-11). The data was analysed using ANOVAs with post-hoc Tukey's pair-wise comparison test. Linear regressions were used when a statistically significant interaction term was present, and an ANOVA was not appropriate.

Use of linear regression in the combined field analyses are as follows. In the combined Whole-Field analysis, a liner regression allowed for post-hoc pair-wise comparison with a significant interaction term through the adjusted means method. This method was implemented using the R package phia (De Rosario-Martinez 2015). In the combined Near-Field analysis there was the potential for a significant three-way interaction term, thus the least-squares means (aka predicted marginal means) method was used to compare between the factors. This method was implemented using the R package lsmeans (Lenth 2016).

Table 4-11: Categorical factors used in the sediment quality combined Whole-Field analysis (2014-2020).

Variable	Levels
Field	HIB, HSE
Distance	250, 275, 500, 1,000, 6,000 m
Field x Distance	

Table 4-12: Categorical factors used in the sediment quality combined Near-Field analysis.

Variable	Levels
Field	HIB, HSE
Distance	250, 275, 500, 1,000 m
Year	2011, 2014, 2016, 2018, 2020
Field x Distance	
Field x Year	
Distance x Year	
Field x Distance x Year	

4.1.3.5 Sediment Toxicity Analyses

Standardized toxicity tests (e.g., bioassays) on sediment samples improve the capability of an EEM program to ascertain whether contaminants may be influencing living organisms (Martinez-Haro et al. 2015). This series of monitoring tools are 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 (Martinez-Haro et al. 2015). Sediment toxicity analyses using bioassays have been conducted as part of the Hibernia EEM program since baseline. Up to two sediment toxicity bioassays are conducted depending on Petrotox screening of sediment hydrocarbon levels. All toxicity tests were conducted by Avalon Laboratories (Paradise, NL). All laboratory reports are included in Volume II of this report.

In 2019, the Hibernia EEM Design Plan was changed to update the toxicity test approach (HMDC 2019a). This included replacement of the Microtox testing and screening with the Petrotox screening guideline for all sampling stations and replacement of the polychaete *Neanthes arenaceodenta* with the Atlantic species *Polydora* *cornuta*. This plan was implemented for the first time during the 2020 Hibernia EEM program, however, the Atlantic species *Polydora cornuta* was not available.

Table 4-13: Sediment quality toxicity testing sampling design differences between the 1998 to 2018 Hibernia EEM and current methodologies.

1998-2018 Hibernia EEMs	2020 Hibernia EEM
Use Microtox as trigger for further Amphipod Toxicity and Juvenile Polychaete Growth toxicity testing for stations >500m from Hibernia GBS or HSE	Use Petrotox as screening tool for Amphipod Toxicity and Juvenile Polychaete Growth and Toxicity testing for all sediment stations in the Hibernia field excluding baseline survey in which all stations will be subject to both toxicity tests.
Toxicity sampling includes Microtox, Amphipod Toxicity, and Juvenile Polychaete Growth	Toxicity sampling, Amphipod Toxicity, and Juvenile Polychaete Growth
Pacific species, *Neanthes arenaceodentata,* used for Juvenile Polychaete Growth testing.	Atlantic species, *Polydora cornuta*, used for Juvenile Polychaete Growth testing.

The toxicity test screening and two bioassays performed as part of the 2020 EEM program is:

- Petrotox Test is a no-effects threshold screening tool (150 mg/kg >C_{10}-C_{21});
- Juvenile Polychaete Survival and Growth Test: Measurement of juvenile polychaete (*Polydora cornuta*) growth and survival when cultured in test sediment (EC 2001) and;
- Amphipod bioassay Test: Measurement of cultured amphipod (*Rhepoxynius abronius*) survival on test sediment (EC 1992, 1998).

The first part of the toxicity bioassays was a screening test to determine which samples to screen-in for further toxicity testing. The Petrotox model is a method to predict the aquatic toxicity of petroleum substance composition (Redman et al. 2012). PureDrill IA 35-LV is the drilling mud base fluid used at Hibernia and other drilling platforms on the Grand Banks of Newfoundland (HMDC 2017a). HMDC undertook a risk assessment of PureDrill IA 35-LV in the environment using the Petrotox model (Stantec 2013). From the risk assessment, the Petrotox model found a no-effects concentration threshold of 150 mg/kg for PureDrill IA 35-LV. The hydrocarbons in the >C_{10}-C_{21} range were used as a marker for PureDrill 1A 35-LV (HMDC 2017a). All samples equal to or above the no-effects threshold of 150 mg/kg hydrocarbons >C_{10}-C_{21} hydrocarbons were screened-in for toxicity testing.

The juvenile polychaete growth test is an assay to evaluate the effect of a sediment sample on the growth and mortality of juvenile polychaetes (PSEP 1995, EC 2001). As described in the Hibernia EEM Design Plan (HMDC 2019a), this test has been performed by culturing juvenile polychaetes on sediment collected from each sampling station. The polychaete test organism, *Neanthes arenaceodenta* is a Pacific species that has been used for the program since 1998. It was switched with *Polydora cornuta*, which is a species found naturally in Canadian (Atlantic) coastal waters (EC 2001) based on recommendations from Environment Canada and Climate Change (ECCC) (HMDC 2019a). However, for the 2020 EEM program, *Polydora cornuta* polychaetes were unable to be collected and therefore *Neanthes arenaceodenta* was used for polychaete toxicity test.

A sediment sample is considered toxic if there is a 20% reduction in polychaete survival between the sediment sample and reference sample which is statistically significant. The reference sediment sample is considered toxic if there is a 30% reduction in survival which is statistically significant between the reference station sample and laboratory control. A summary of the procedure is as follows: five juvenile individuals (three-weeks old) are co-cultured in replicates of five sampling containers for each sediment station sample. The organisms are fed and the water in each replicate container was changed at regular intervals during the 20-day cultivation period (HMDC 2019a). The number of survivors and weight of the juvenile polychaetes was measured at the end of the assay period and statistically (t-test) compared to the response rates observed in reference station samples to determine toxic versus non-toxic responses (HMDC 2019a).

Amphipod bioassays examines the survival rate of organisms cultured in test sediments according to conditions outlined in the Biological Test Method: Acute test for sediment toxicity using marine or estuarine amphipods (EPS 1/RM/26, 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, 1998) (EC 1992, 1998). However, the process of extracting pore water can result in inaccurate sulphide readings. As per ECCC recommendations, pore water chemistry was replaced with sediment sulphide, ammonia, and redox analyses. A toxic response would be a 20% reduction in survival based on comparison of samples to reference area station samples or a 30% reduction based on a comparison of reference samples to laboratory controls. A brief description of the amphipod bioassay procedure is as follows: each sediment sample is divided into five replicate containers with 20 amphipods (*Rhepoxynius abronius*) each. The amphipods are exposed for ten days, after which the percent survival is examined between the test and control samples. Survival rates compared to control sediment were analysed using Dunnett's t-test. Sediment sulphide, ammonia and redox potential concentrations for each sample were compared to a control sample.

4.1.3.6 Sediment Toxicity Statistical Analyses

For toxicity data, 2-D plots provided an indication of the general spatial trend in concentrations among years (e.g., 1994–2018 for the Hibernia Platform and 2011, 2014, 2015, 2016, and 2018 for HSE). Statistical evaluation of the quantified results among years is conducted as outlined in the Hibernia EEM and the 2014 EEM Program (HMDC 2017b, 2019a)with the addition of multivariate analysis to examine multiple variables simultaneously.

Patterns and trends in relation to time and distance were assessed using Euclidean distance and Non-metric multidimensional scaling (nMDS) visualizations. An nMDS graphically represents the data in a way that best maintains the relative similarity distances to all other points in the analysis. Points with observations more similar to each other will group closer to each other. Each axis (x, y, z) represents a dimension of similarity. Hypotheses were tested using a permutation-based multivariate analogue of ANOVA (PERMANOVA) (Anderson et al. 2008). The analyses were carried out in Primer PRIMER-e software using the Permanova+ add-on (Clarke and Warwick 2001, Anderson et al. 2008).

4.2 Results

4.2.1 Physical and Chemical Exploratory Data Analyses

4.2.1.1 Sediment Fractions

The following descriptions of sediments surrounding the Hibernia Platform and HSE are based on physical and chemical analysis of sediment samples (as opposed to analysis of the minerology) (HMDC 2017b). No Hibernia

Platform station sediment fractions were screened-in for further analysis based on the screening criteria as >50% of stations had concentrations greater than two standard deviations above the baseline mean. Sediment around the Hibernia Platform was primarily sand (mean=93%) with secondary substrates (e.g., gravel, clay, and silt).

For the HSE, sand was the primary particle size at all survey stations (mean=80.5%) followed by gravel (mean=16%), clay (mean=1.85%), and silt (mean=0.85%). Of the four particle sizes, clay was the only particle size screened-in for further analysis as >50% of stations had concentrations greater than two standard deviations above the baseline mean. Spatial and temporal patterns of clay concentrations in the Near-Field (≤1,000 m) are presented below (Figure 4-6). Clay concentrations were relatively higher towards the north and east of the HSE; however, the highest reported concentration occurred at station S-250 (4%). In 2020, concentrations ranged between 0.54% and 4%. Baseline concentrations for clay were between 0.32% and 1.42% with concentrations at station S-250 at 0.83%. Clay concentrations at stations S-500 and E-250 are lower than concentrations reported in 2018, 2016, and 2015.

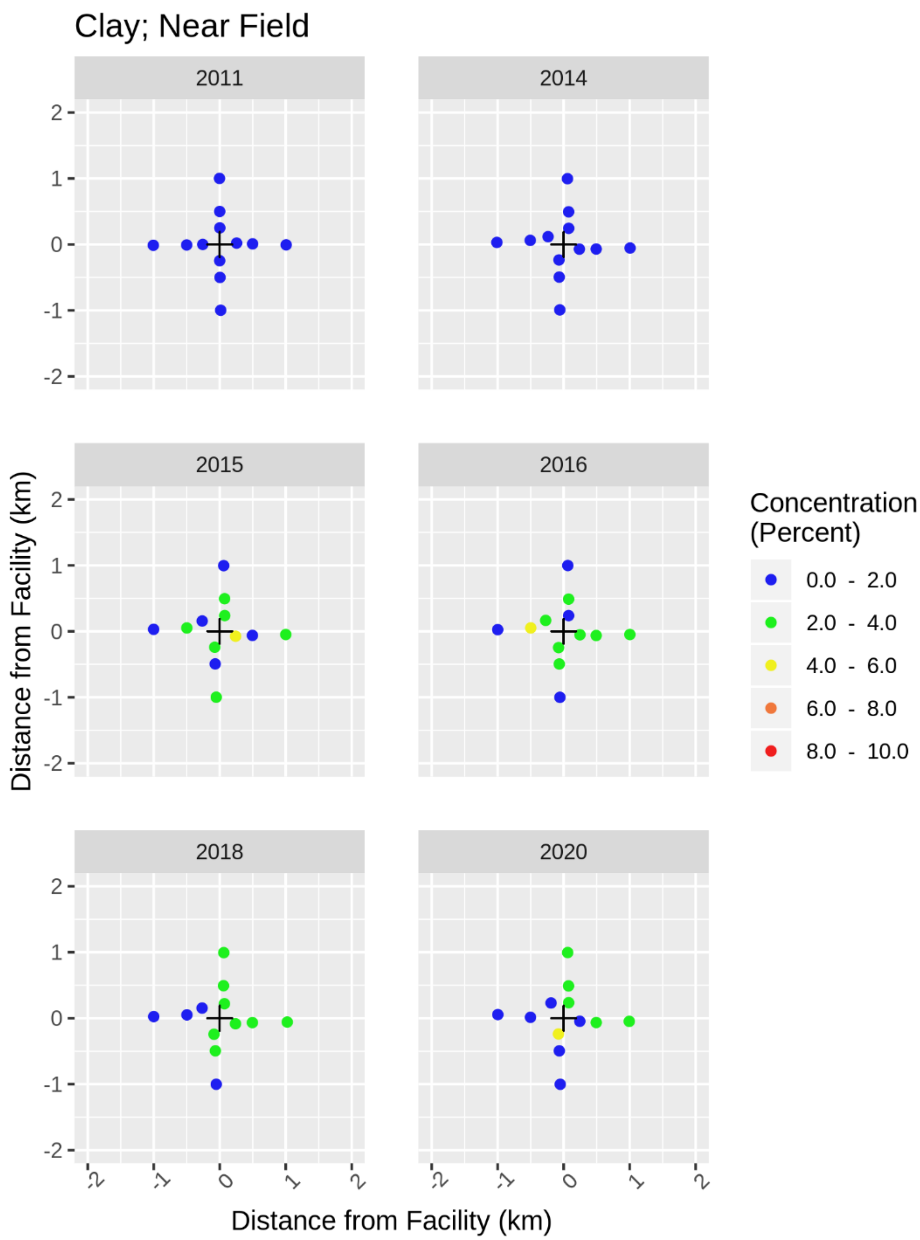


Figure 4-6: Spatial and temporal pattern of clay concentration (%) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020).

4.2.1.2 Barium

Barium sulphate (barite or $BaSO_4$) is one of the main and least toxic components of both water-based drilling mud (WBM) and synthetic-based drilling muds (SBM). Due to its low solubility, barium concentrations in barite are used as a marker for drilling mud in sediment (Neff 2008, Bakhtyar and Gagnon 2012, Trefry et al. 2013, DeBlois et al. 2014a). Concentrations of barium (from strong-acid extraction methods) have been reported in every survey since baseline. In 2001-2002, SBM cuttings began being reinjected which substantially reduced the amount of material being released at sea. Other releases which also contain barium, such as WBMs and cuttings, continue to be discharged. To quantify the total barium in sediment samples weak acid extraction analysis has also been utilized. Weak-acid extractable barium (WAM barium) has been reported in every survey since 1999.

Spatial and temporal trends for total barium concentrations around the Hibernia Platform are presented for the Whole-Field (including reference stations) (Figure 4-7) and the Near-Field (<1,000 m from the platform) (Figure 4-8). Barium concentrations ranged between 56 mg/kg and 700 mg/kg in 2020. The highest concentration occurred at station 7-3000 which is to the west of the platform (Figure 4-7). In previous EEM years and baseline, the highest concentrations of barium have occurred within 250 m of the platform and ranged between 450 mg/kg and 3,100 mg/kg (Figure 4-8). Overall barium concentrations have declined from concentration highs reported in 1999 to 2002.

WAM barium spatial and temporal trends are presented for both the Whole-Field (Figure 4-9) and the Near-Field (Figure 4-10). WAM barium concentrations were between <5 mg/kg and 33 mg/kg. The highest concentrations of WAM barium have occurred within 250 m of the platform since it was first reported in 1999 and concentrations have been decreasing since 2007 (Figure 4-10).

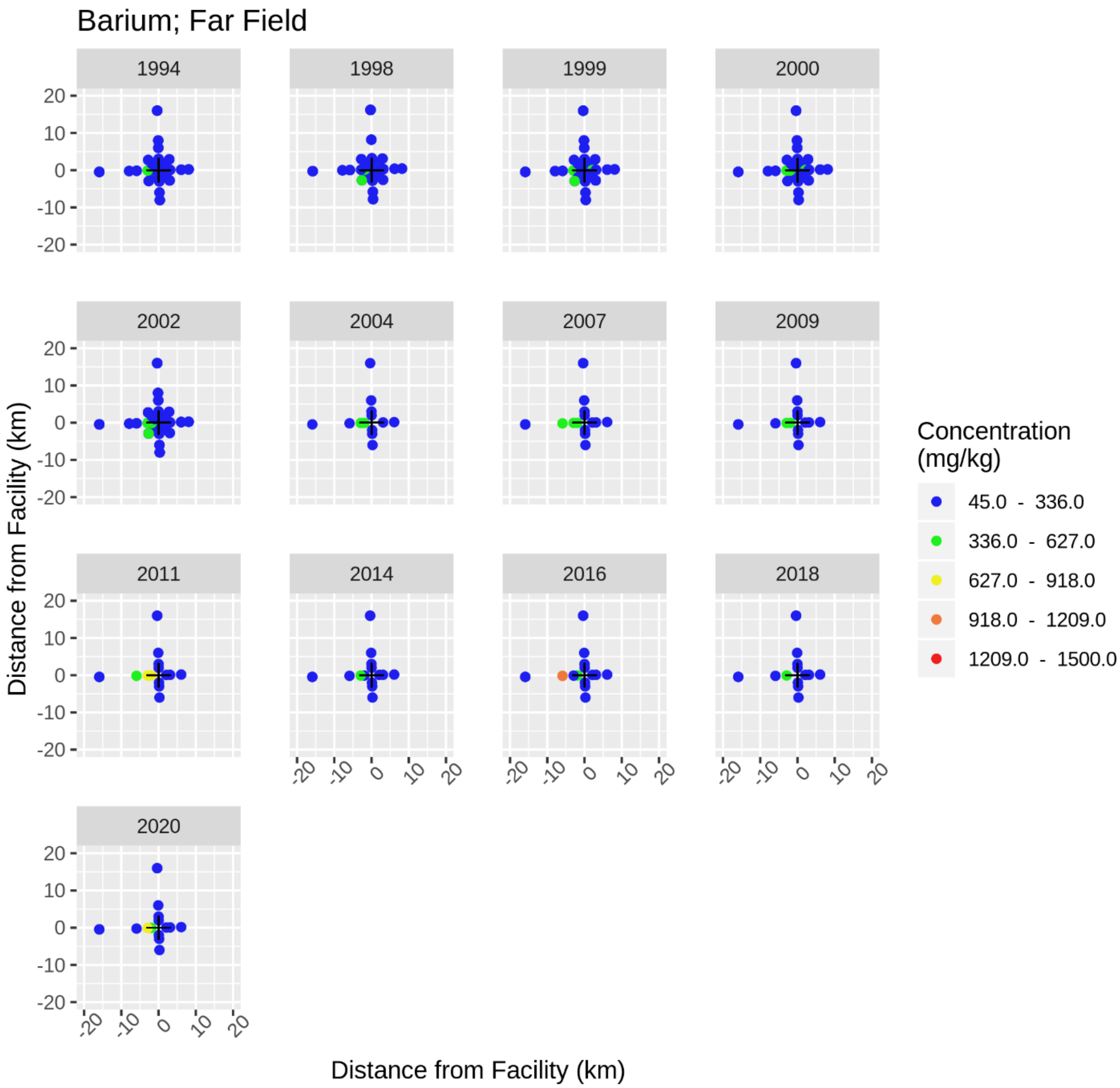


Figure 4-7: Spatial and temporal pattern of barium concentration (mg/kg) in Hibernia Platform sediment samples within 6,000 m of the platform in Baseline (1994), and EEM programs (1998-2020).

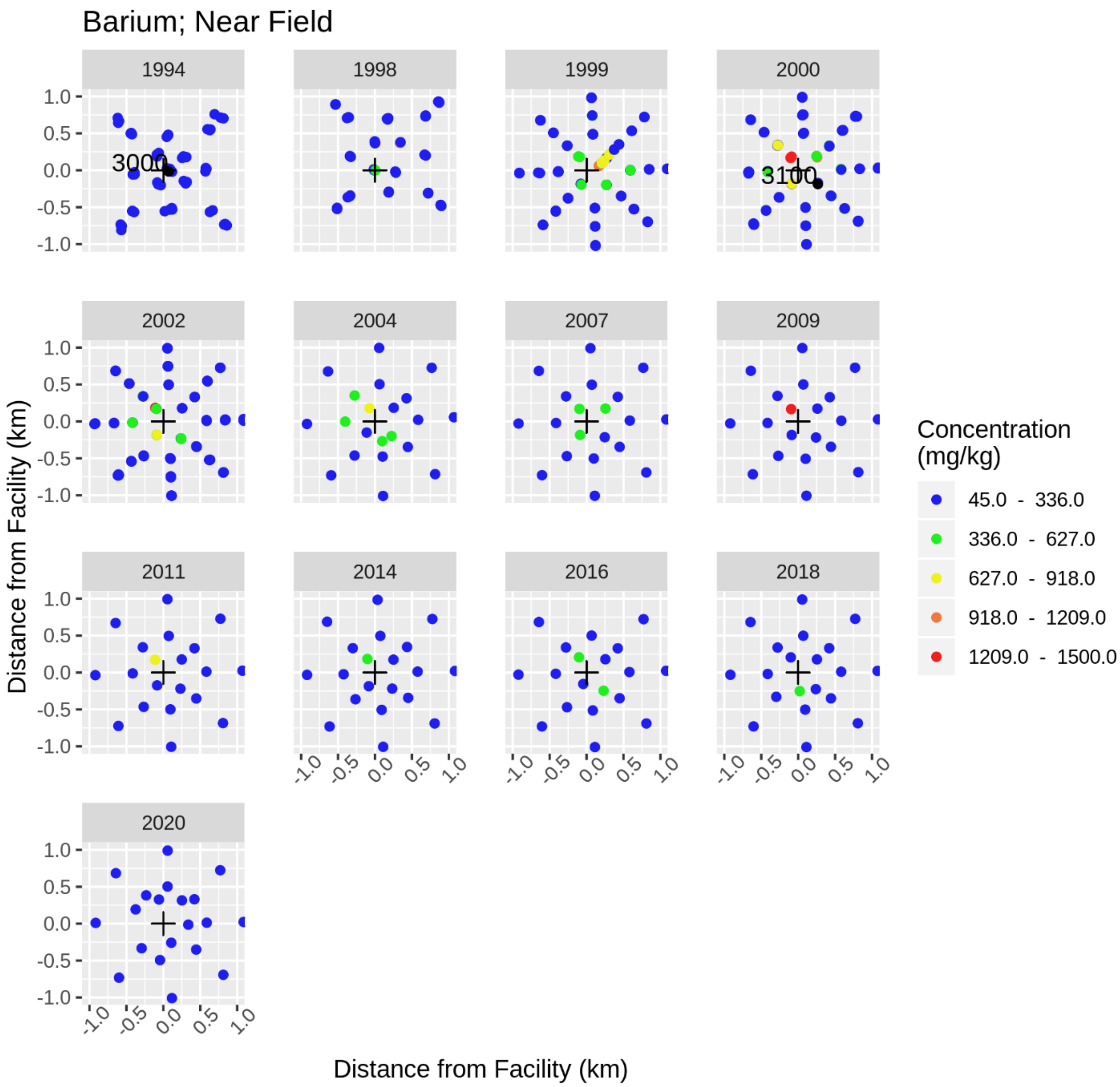


Figure 4-8: Spatial and temporal pattern of barium concentration (mg/kg) in Hibernia Platform sediment samples within 1,000 m of the platform for Baseline (1994) and EEM programs (1998-2020).

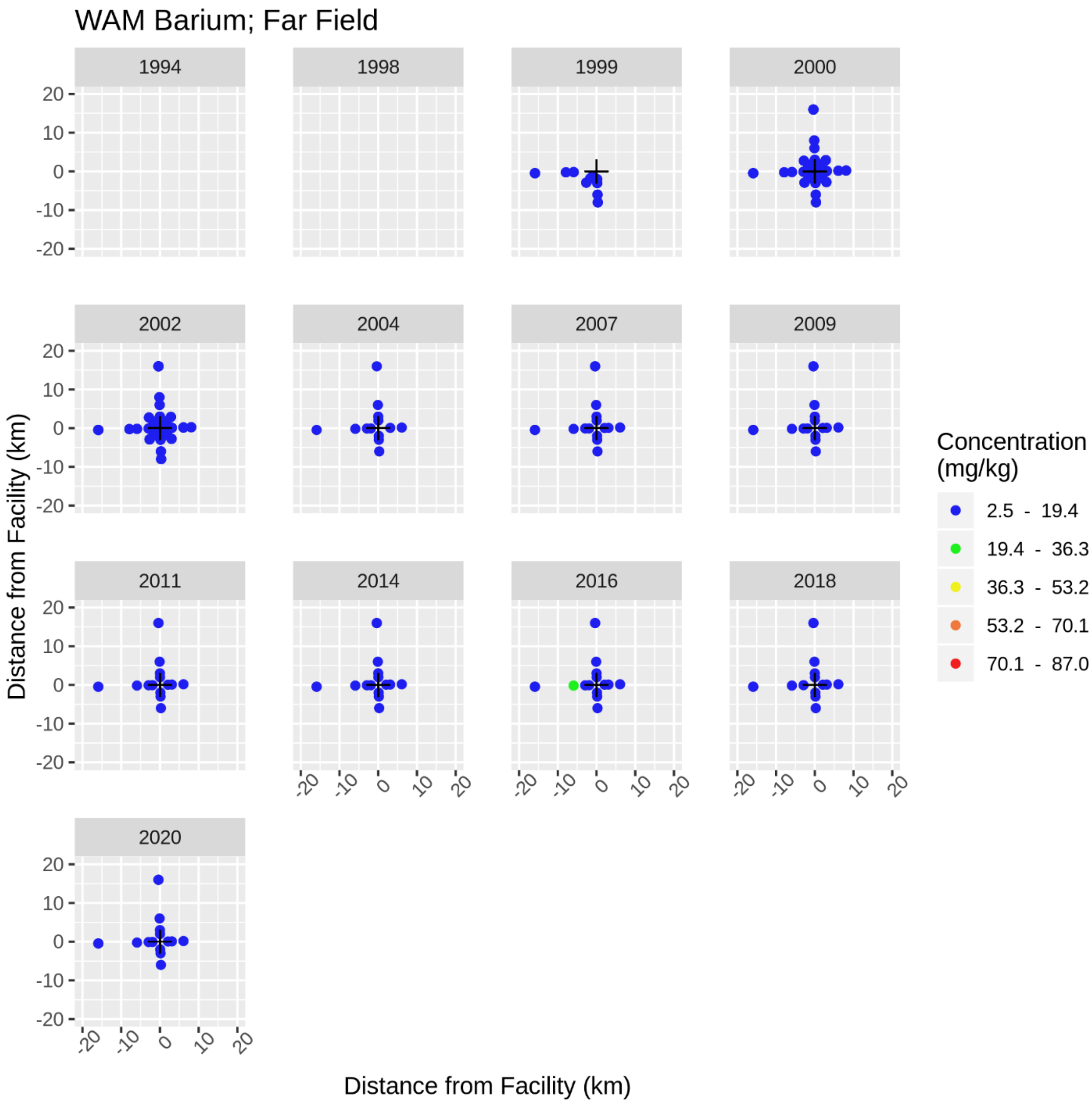


Figure 4-9: Spatial and temporal pattern of weak-acid metal barium concentration (mg/kg) in Hibernia Platform sediment samples within 6,000 m of the platform in EEM programs (1999-2020), analyte not tested for in Baseline (1994).

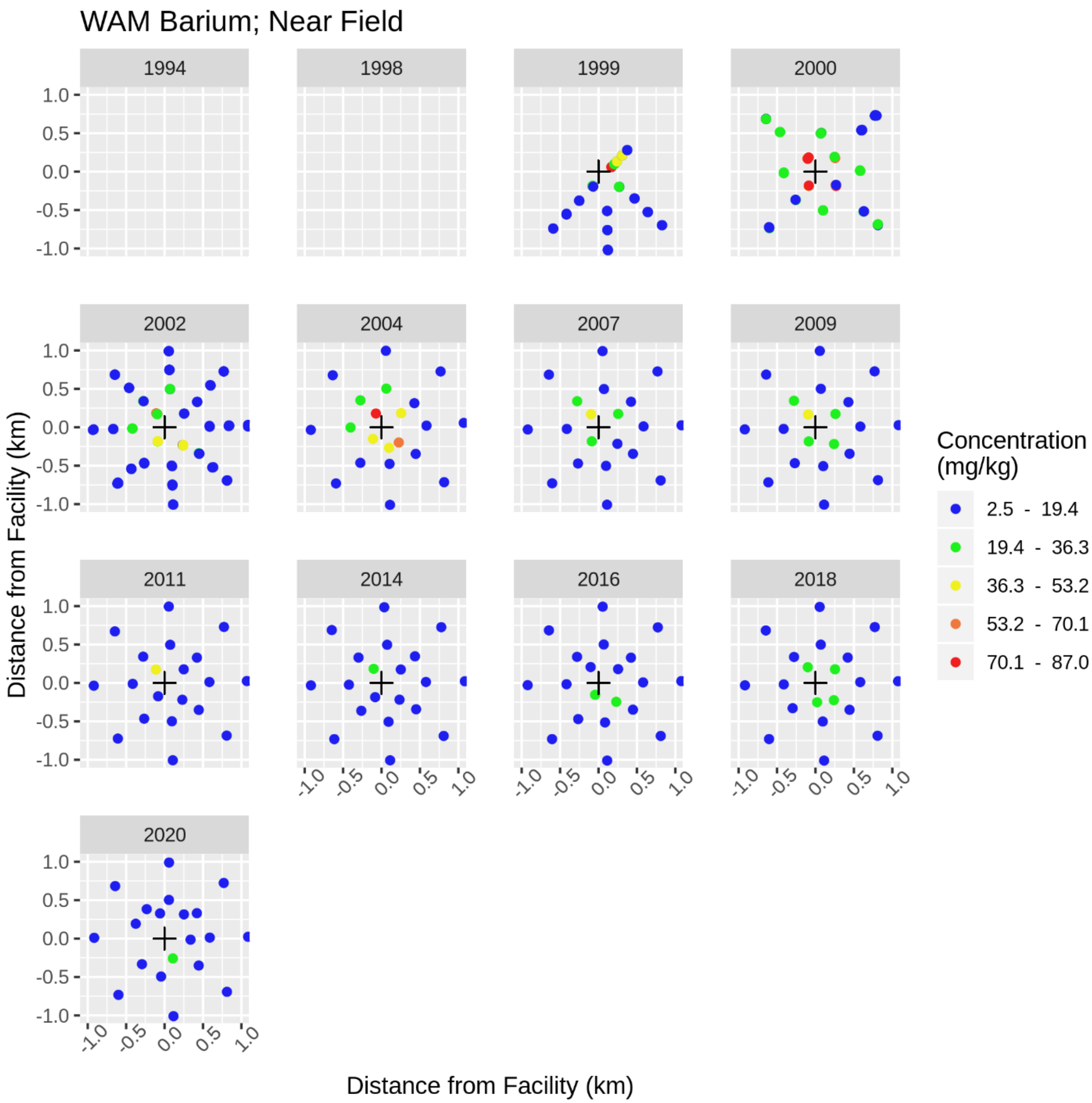


Figure 4-10: Spatial and temporal pattern of weak-acid metal barium concentration (mg/kg) in Hibernia Platform sediment samples within 1,000 m of the platform in EEM programs (1999-2020), analyte not tested for in Baseline (1994).

The following 2-D plots illustrate the spatial and temporal trends for total barium concentrations within the Near-Field of the HSE (Figure 4-11). In 2020, sediment barium concentrations ranged between 84 mg/kg and 28,000 mg/kg within 6,000 m of the EDC (Table 4-6). The highest barium concentration in 2020 was reported at S-250 (Figure 4-11). Barium concentrations began increasing from baseline levels in 2014 with the highest concentrations of barium occurring within 500 m of the HSE. Barium concentrations peaked in 2018 where concentrations within 500 m of the HSE ranged between 2,000 mg/kg and 16,000 mg/kg compared to concentrations between 200 mg/kg and 6,200 mg/kg reported in 2016. However, in 2020, concentrations have considerably decreased from 2018 levels to between 400 mg/kg and 1,700 mg/kg (excluding S-250).

For concentrations of WAM barium, the spatial and temporal trends are presented in Figure 4-12. WAM barium concentrations had an upward trend in the (particularly in the 500 m of the HSE) starting in 2014 until 2018. In 2020, concentrations ranged between <5 (RDL) mg/kg and 93 mg/kg. Overall concentrations within 500 m in 2020 (16 mg/kg and 93 mg/kg) have decreased from 2018 levels (34 mg/kg and 99 mg/kg). Station S-250 had the highest reported concentrations of both barium and WAM barium however, stations with the highest of either analyte have differed in past EEMs.

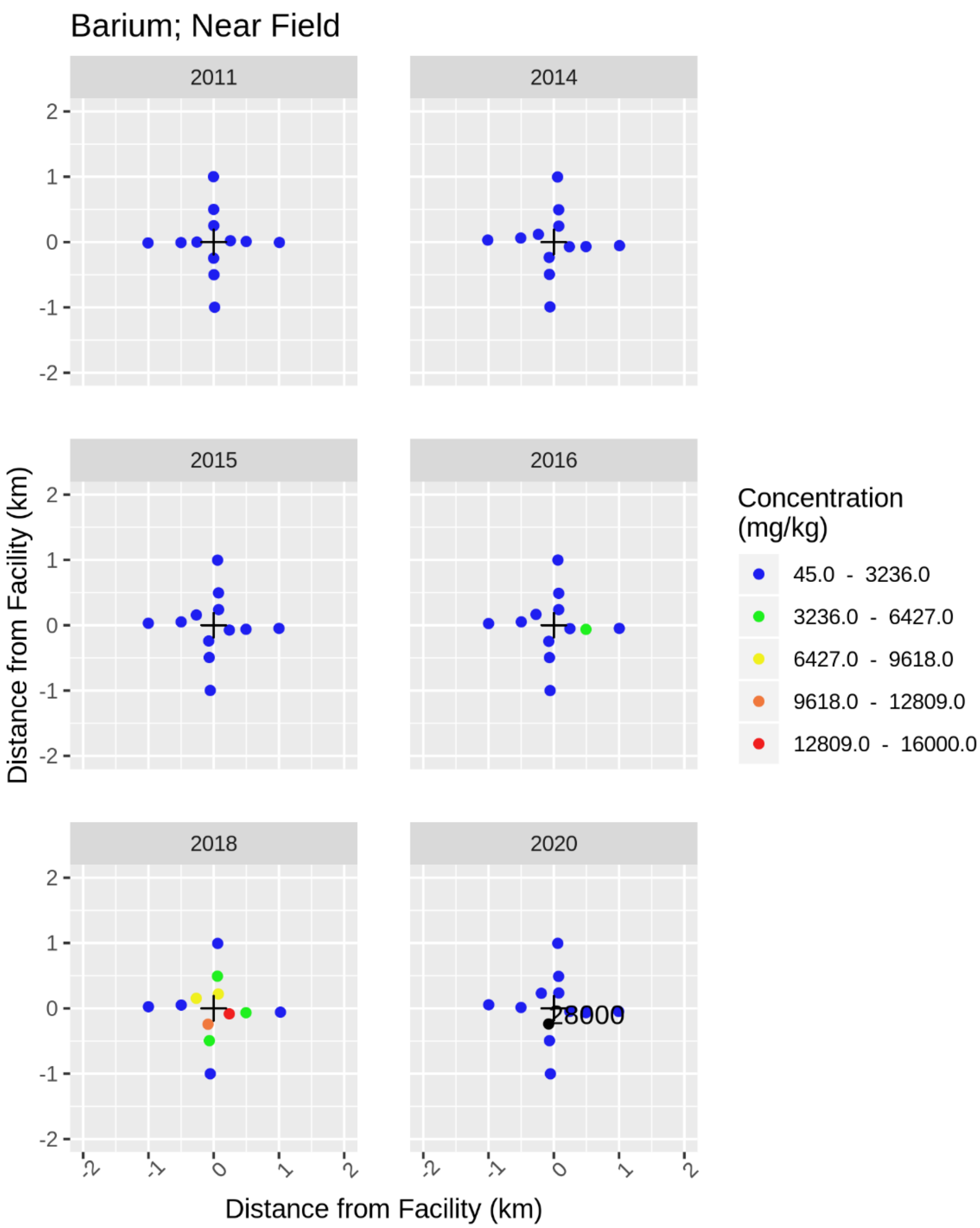


Figure 4-11: Spatial and temporal pattern of barium concentration (mg/kg) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020). Note that value for the black dot (28,000 mg/kg) is listed on the graph and indicates a value outside the concentration range presented.

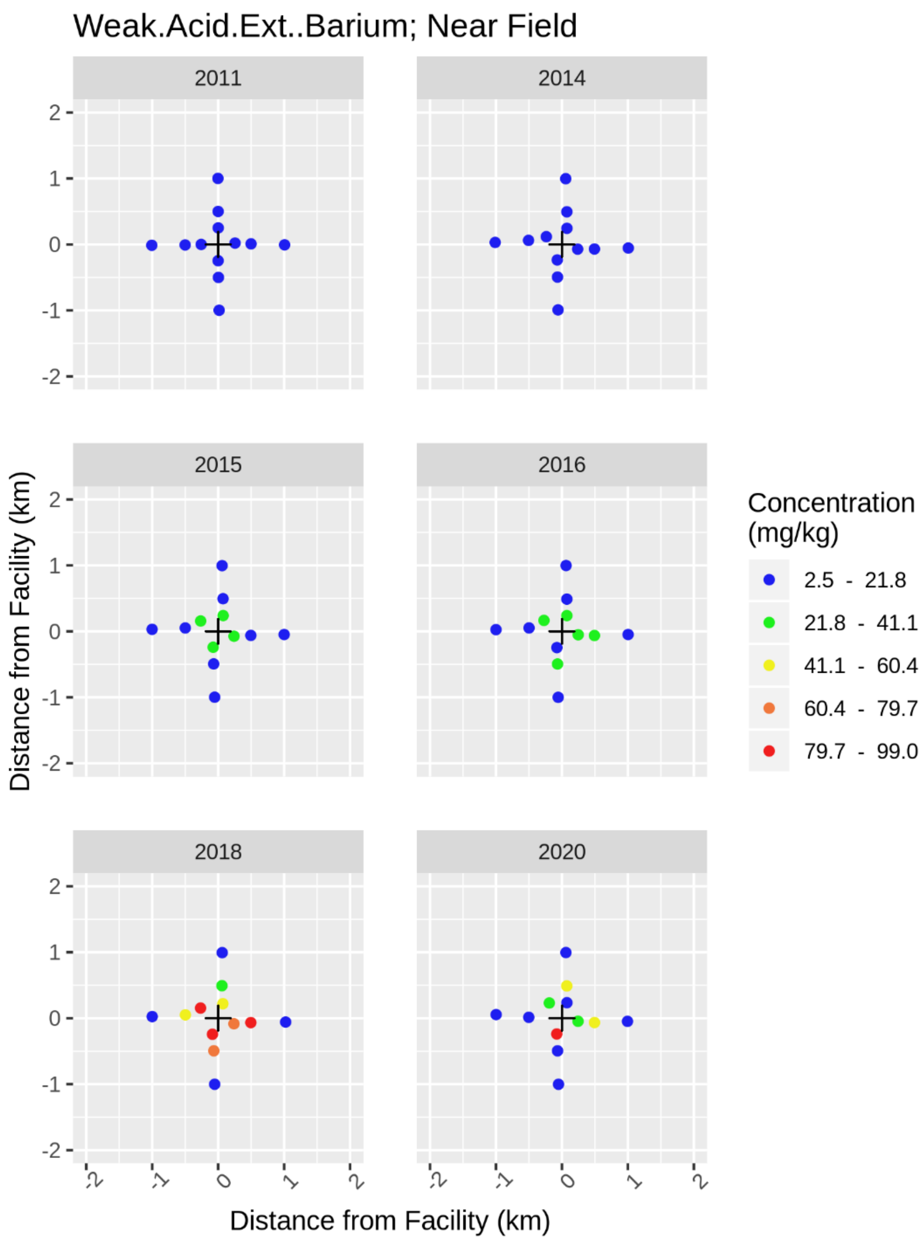


Figure 4-12: Spatial and temporal pattern of weak-acid metal barium concentration (mg/kg) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020).

4.2.1.3 Hydrocarbons

The 2-D plots presenting the spatial and temporal trends for fuel and lube range hydrocarbons for stations sampled around the Hibernia Platform are presented in Figure 4-13 to Figure 4-16. Fuel range hydrocarbon ($>C_{10}$-C_{21}) concentrations in 2020 ranged between <0.25 (RDL) mg/kg and 6.8 mg/kg. This is a substantial decrease from 1999 levels (0.33 mg/kg and 10500 mg/kg). Drilling at the Hibernia platform ceased on May 14, 2020.

These trends are similarly observed in lube range hydrocarbons ($>C_{21}$-C_{32}). Concentrations of lube range hydrocarbons in 2020 were between <0.25 mg/kg (RDL) and 3.7 mg/kg and overall concentrations have decreased since 1999 levels (<0.25 mg/kg (RDL)-181 mg/kg).

Laboratory detection limits for both fuel and lube range hydrocarbons have changed over the course of Hibernia Platform operations (1994: <10 mg/kg, 1998-2004: <0.25 mg/kg, 2007-2011: <0.3 mg/kg, 2014-2020: <0.25 mg/kg) and thus only general comparisons to baseline levels can be made. The mean concentration for both fuel and lube range hydrocarbons in 2020 were below the detection limit used during baseline (1.1 mg/kg and 0.62 mg/kg, respectively).

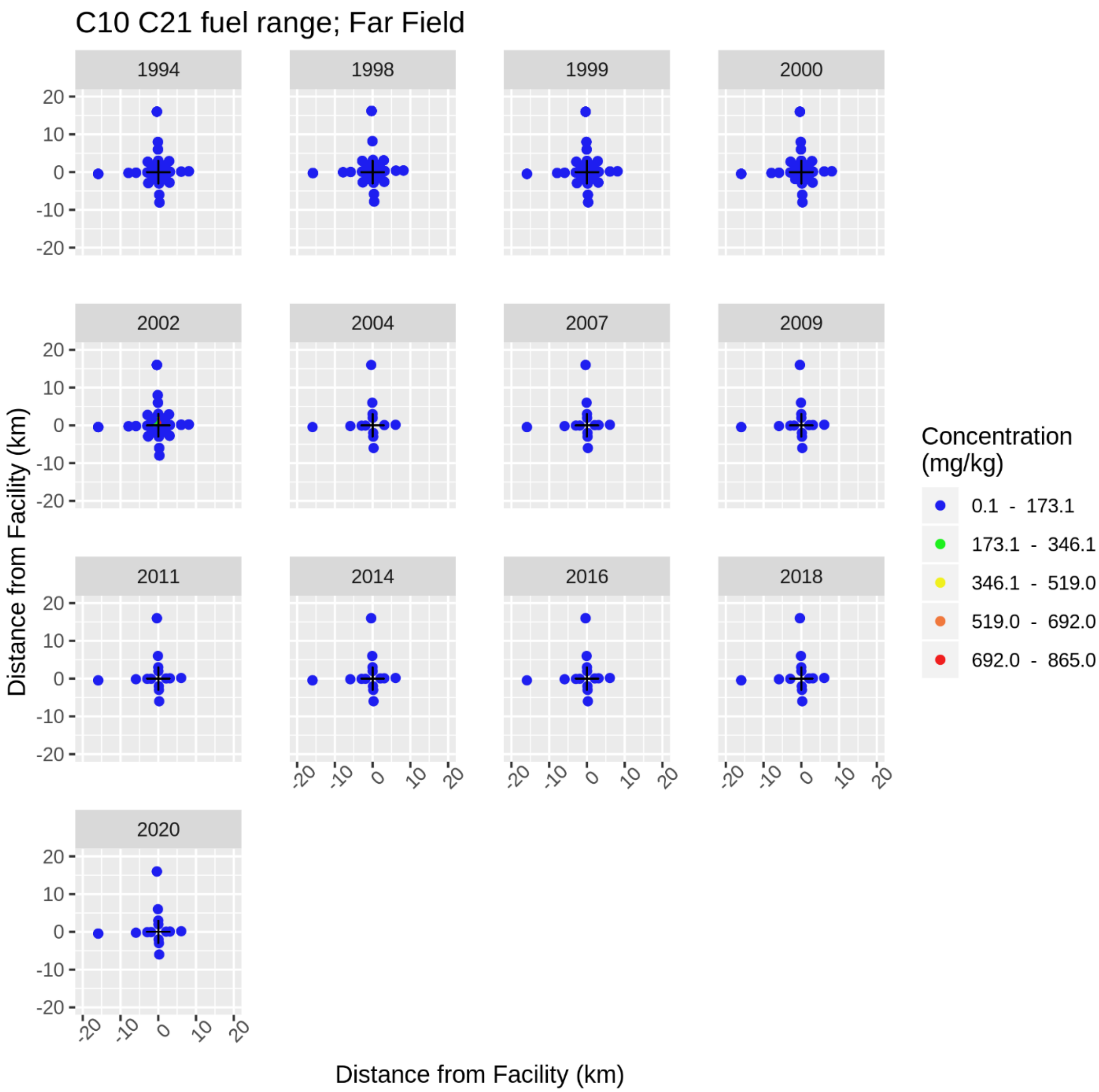


Figure 4-13: Spatial and temporal pattern of >C_{10}-C_{21} concentration (mg/kg) in Hibernia Platform sediment samples within 6,000 m of the platform for Baseline (1994) and EEM programs (1998-2020).

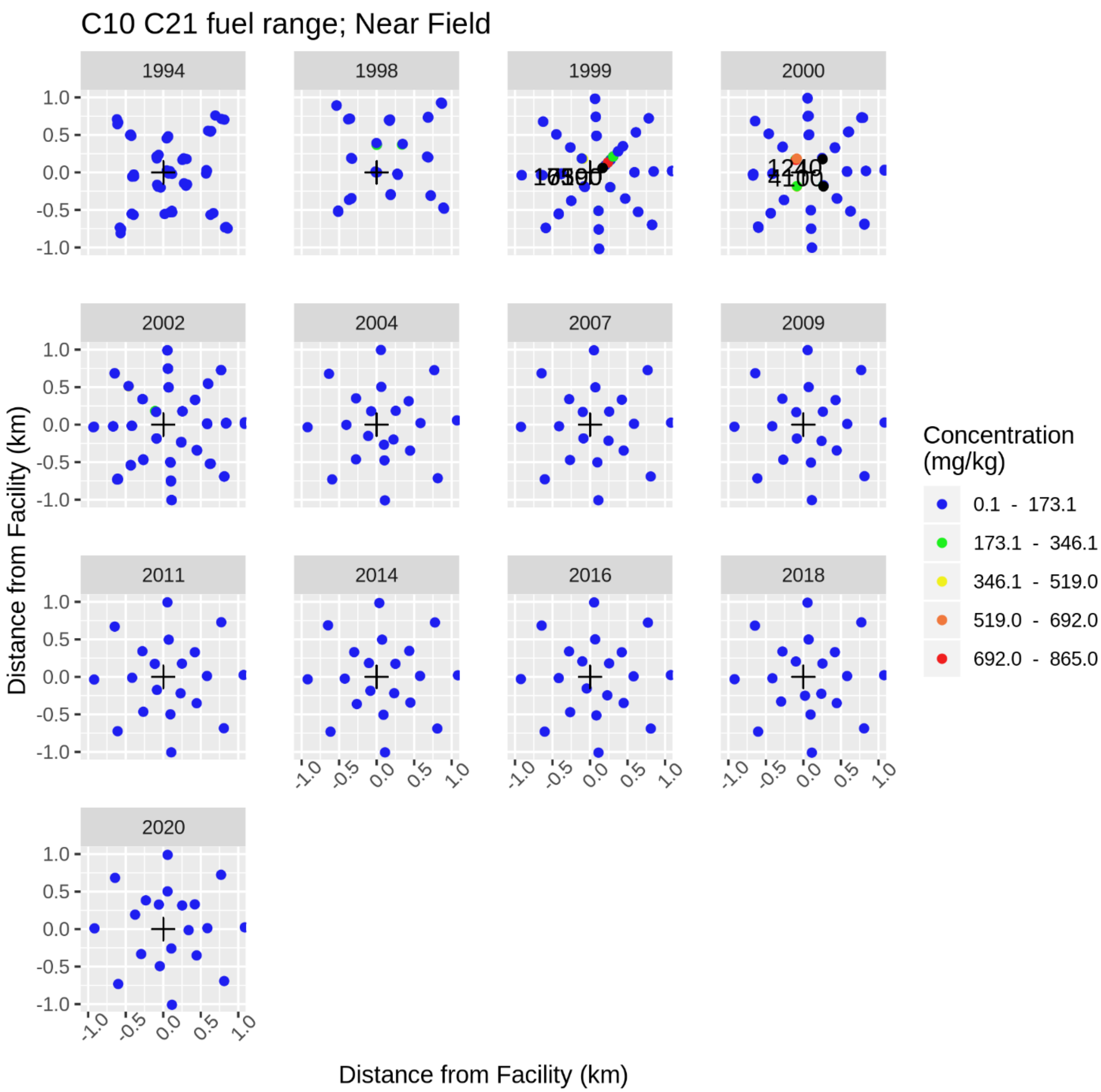


Figure 4-14: Spatial and temporal pattern of >C_{10}-C_{21} concentration (mg/kg) in Hibernia Platform sediment samples within 1,000 m of the platform for Baseline (1994) and EEM programs (1998-2020).

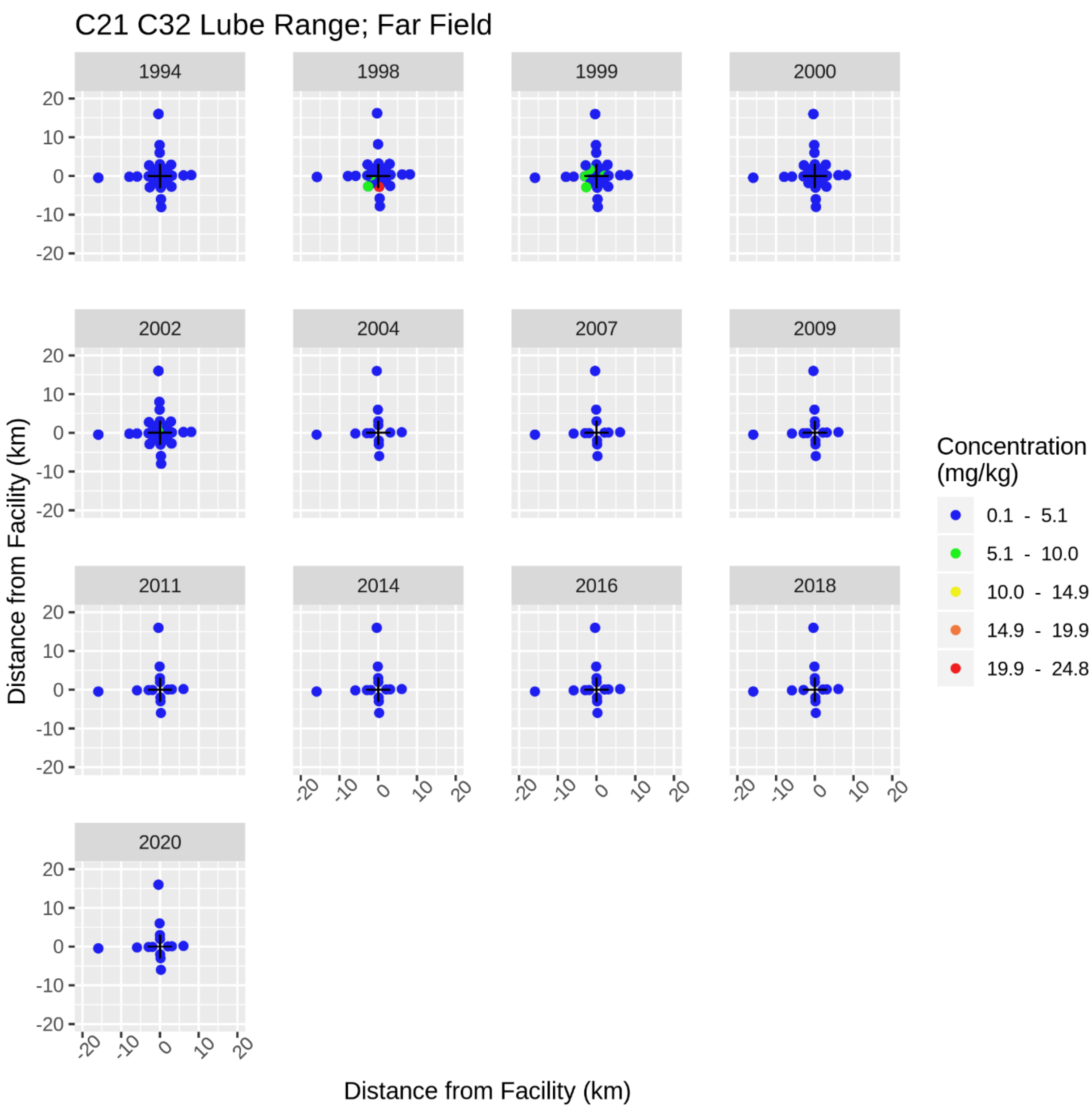


Figure 4-15: Spatial and temporal pattern of >C_{21}-C_{32} concentration (mg/kg) in Hibernia Platform sediment samples within 6,000 m of the platform for Baseline (1994) and EEM programs (1998-2020).

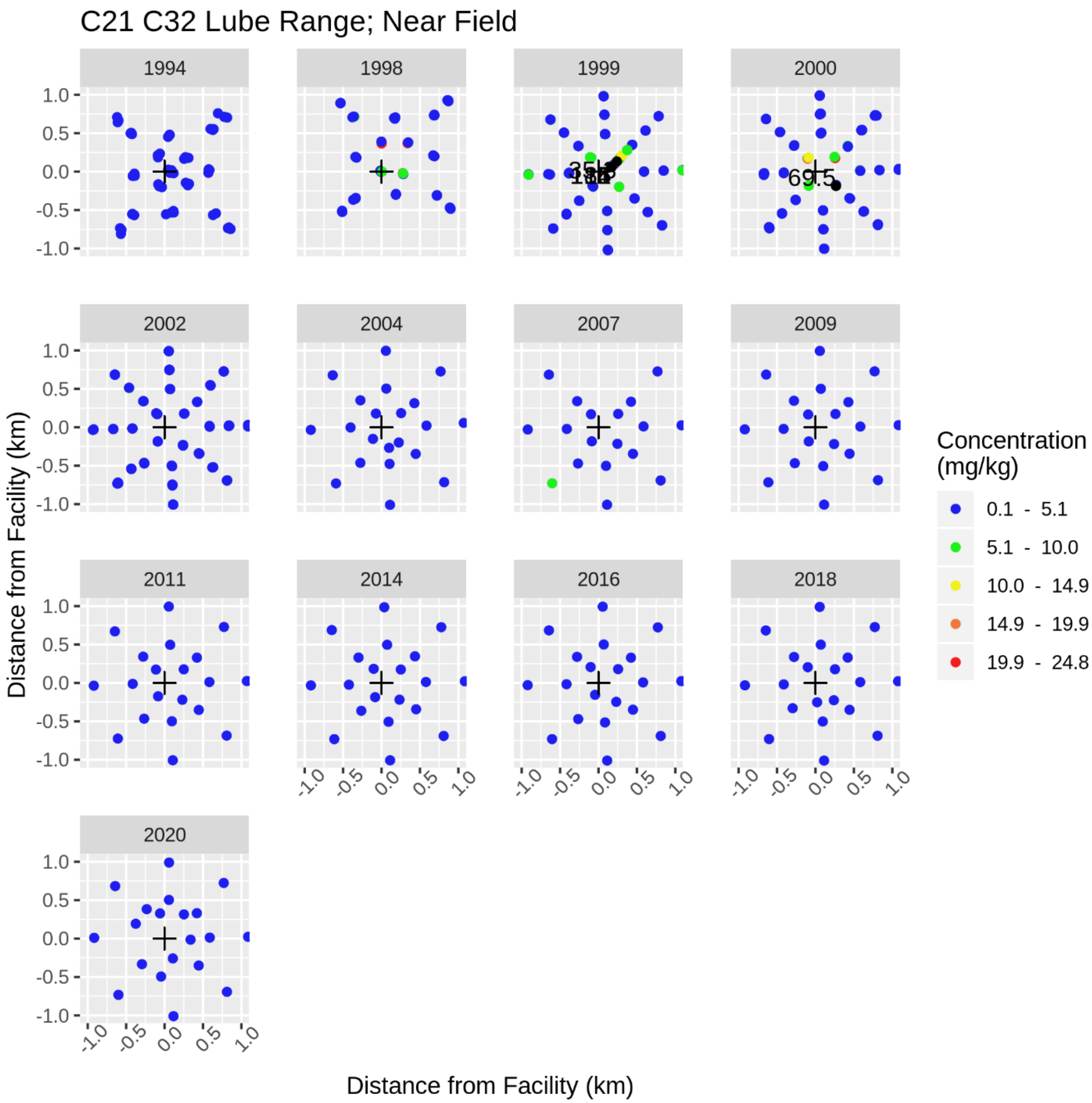


Figure 4-16: Spatial and temporal pattern of >C_{21}-C_{32} concentration (mg/kg) in Hibernia Platform sediment samples within 1,000 m of the platform for Baseline (1994) and EEM programs (1998-2020).

Spatial and temporal trends for both fuel and lube range hydrocarbon concentrations around the HSE are presented below in 2-D plots (Figure 4-17 and Figure 4-18). In 2020 the ranges of fuel and lube range hydrocarbons were <0.25 mg/kg (RDL) to 2890 mg/kg and <0.25 mg/kg (RDL) to 17 mg/kg, respectively. For both hydrocarbon ranges, station S-250 had the highest reported concentrations. Fuel range hydrocarbon concentrations have increased since from baseline levels and substantially increased in 2018 (<0.25 mg/kg-5,200 mg/kg). However, concentrations in 2020 (for $>C_{10}$-C_{21}) have decreased at all stations within 500 m from the EDC from 2018 levels (Figure 4-17). Notably, station E-250 reported a considerable decrease from 5,200 mg/kg (2018) to 420 mg/kg and station S-250 also reported a decrease in concentrations from 5,100 mg/kg (2018) to 2,890 mg/kg.

These spatial and temporal trends are similarly observed in lube range hydrocarbons (Figure 4-18). Lube range hydrocarbon concentrations within 500 m of the EDC had increased from baseline levels in both 2016 (<0.25 mg/kg and 11 mg/kg) and substantially in 2018 (between <0.25 mg/kg and 54 mg/kg). These concentrations have decreased in 2020 from 2018 highs, most notably at stations E-250 (from 54 mg/kg to 3.3 mg/kg) and S-250 (from 41 mg/kg to 17 mg/kg). Additionally, four stations to the west and north of the EDC have returned to, or below, baseline levels (W-250, W-500, N-500, and N-250).

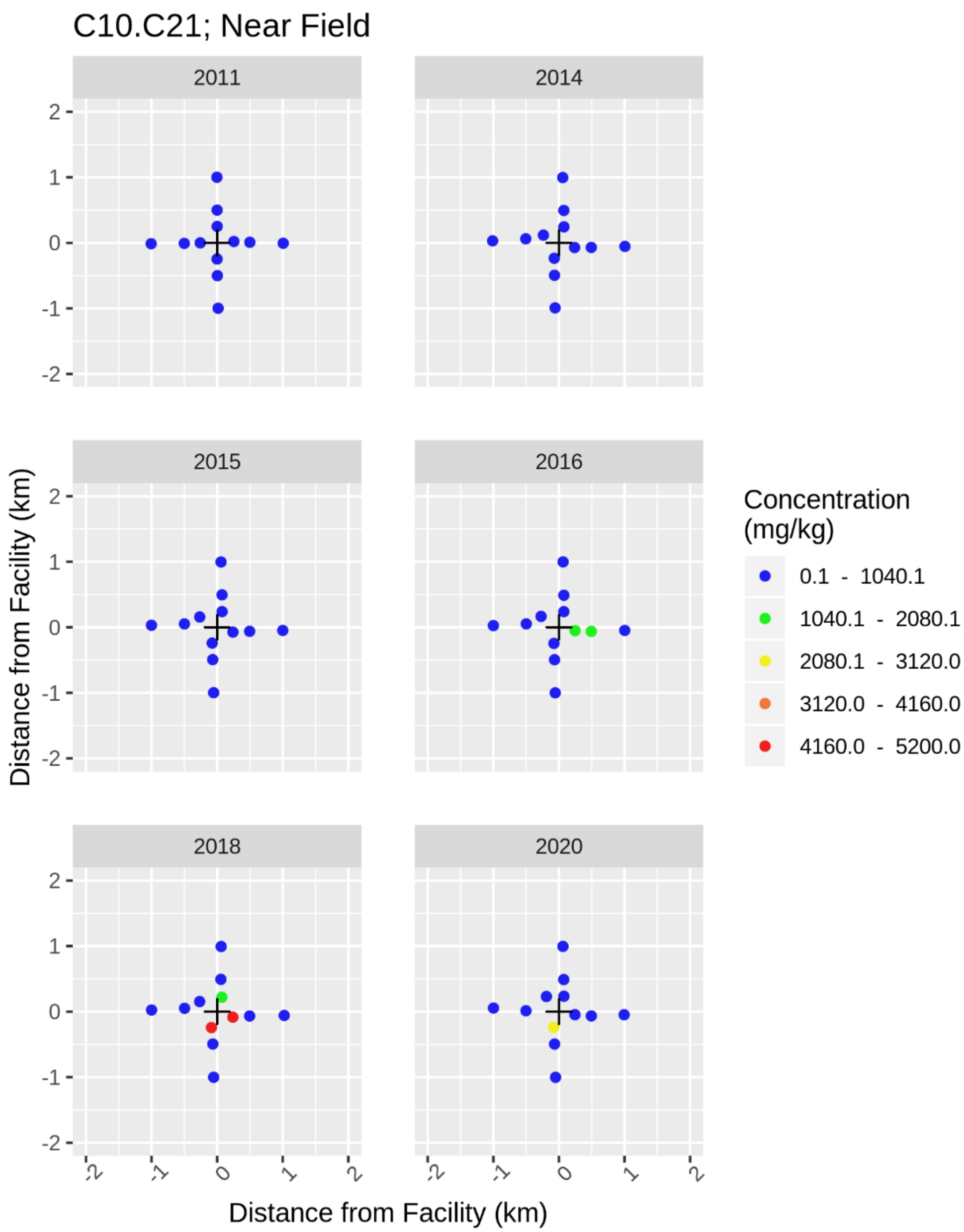


Figure 4-17: Spatial and temporal pattern of >C_{10}-C_{21} concentration (mg/kg) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020).

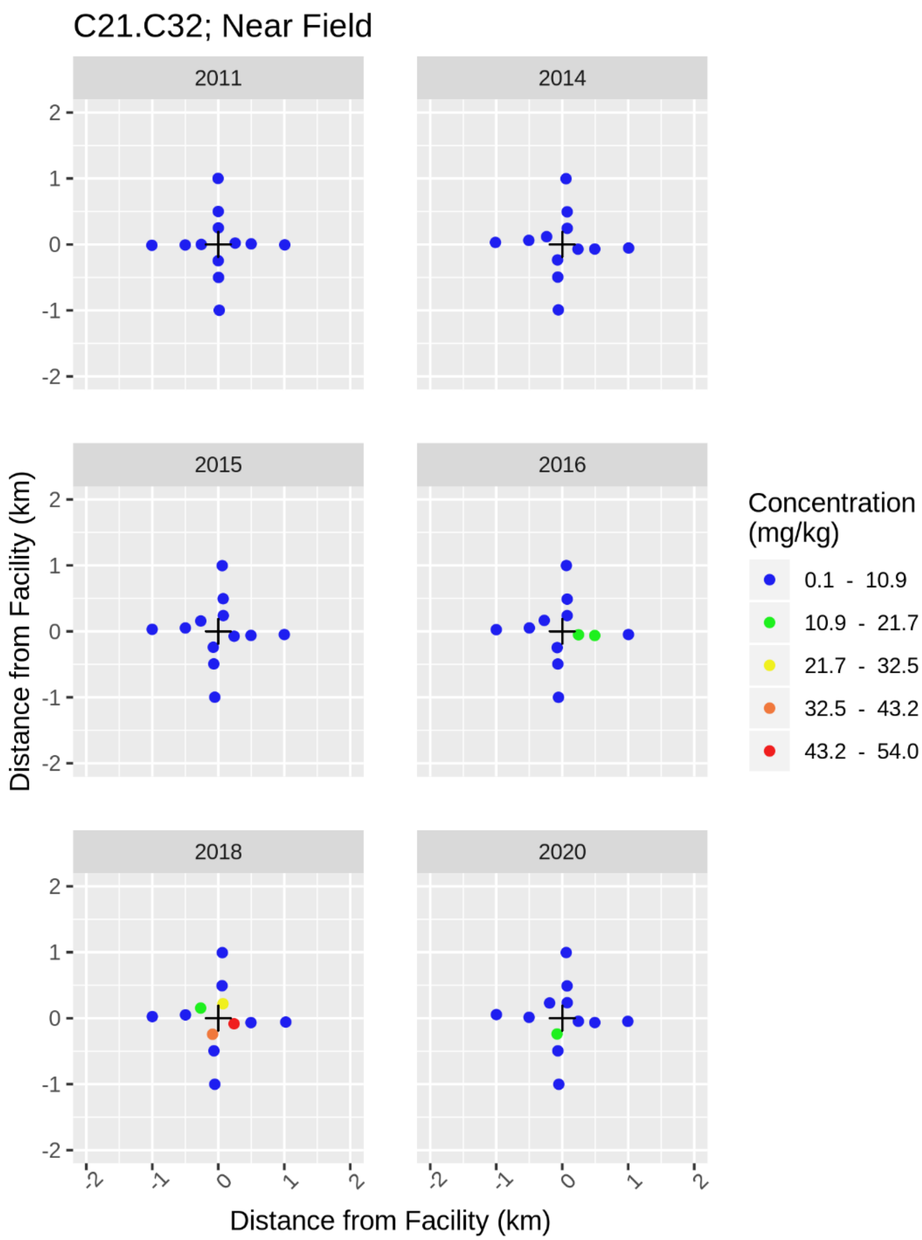


Figure 4-18: Spatial and temporal pattern of >C_{21}-C_{32} concentration (mg/kg) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020).

4.2.1.4 Other Bio-Geochemical Parameters

The hydrocarbons described above are a source of organic matter and are metabolized by the biota in the sediment (Gray and Elliott 2009). Physiochemical parameters such as organic carbon, sulphide and nitrogen (among others) can be associated with the breakdown of hydrocarbons in marine sediment (Steichen et al. 1996). Of these analytes, total carbon and TOC were screened-in for further analysis for Hibernia and HSE sediments, respectively. The distributions of total carbon around the Hibernia Platform and TOC around the HSE are discussed below.

4.2.1.5 Total Carbon

At Hibernia, the analyte total carbon was screened-in for further analysis based on comparisons to concentrations reported in reference station sediments from 2007-2016. Total carbon was first reported in 2000 and concentrations have been consistently higher towards the west of the platform compared to other sampling radials in the Far-Field (Figure 4-19). In 2020, total carbon concentrations ranged between 0.5 g/kg (RDL) and 31 g/kg. The highest concentration was reported at 7-3000. In the Near-Field, concentrations are mainly at RDL (Figure 4-20).

The bio-geochemical analyte screened-in at HSE was TOC (Figure 4-21). From 2011 to 2016, concentrations in Near-Field stations were relatively similar. TOC concentrations peaked in 2018 with a mean of 16.4 g/kg which is an increase from the 2016 EEM and baseline surveys (mean=10.3 and 7.9 g/kg, respectively). The mean TOC concentration in 2020 was 9.72 g/kg and a reported range of <RDL and 24 g/kg. Stations to the north, east, and south had relatively higher concentrations (at all distances) compared to those in the west. The highest concentration of TOC was reported at station N-500; however, most of the stations to the east reported higher TOC concentrations than previous EEM years. The stations 6,000 m from the EDC are also located to the east. Three of the four stations 6,000 m from the EDC (not pictured) were below RDL with one reporting a concentration of 1.3 g/kg. This is lower than concentrations reported in 2016 or 2018 (6.9 g/kg and 4.5 g/kg respectively).

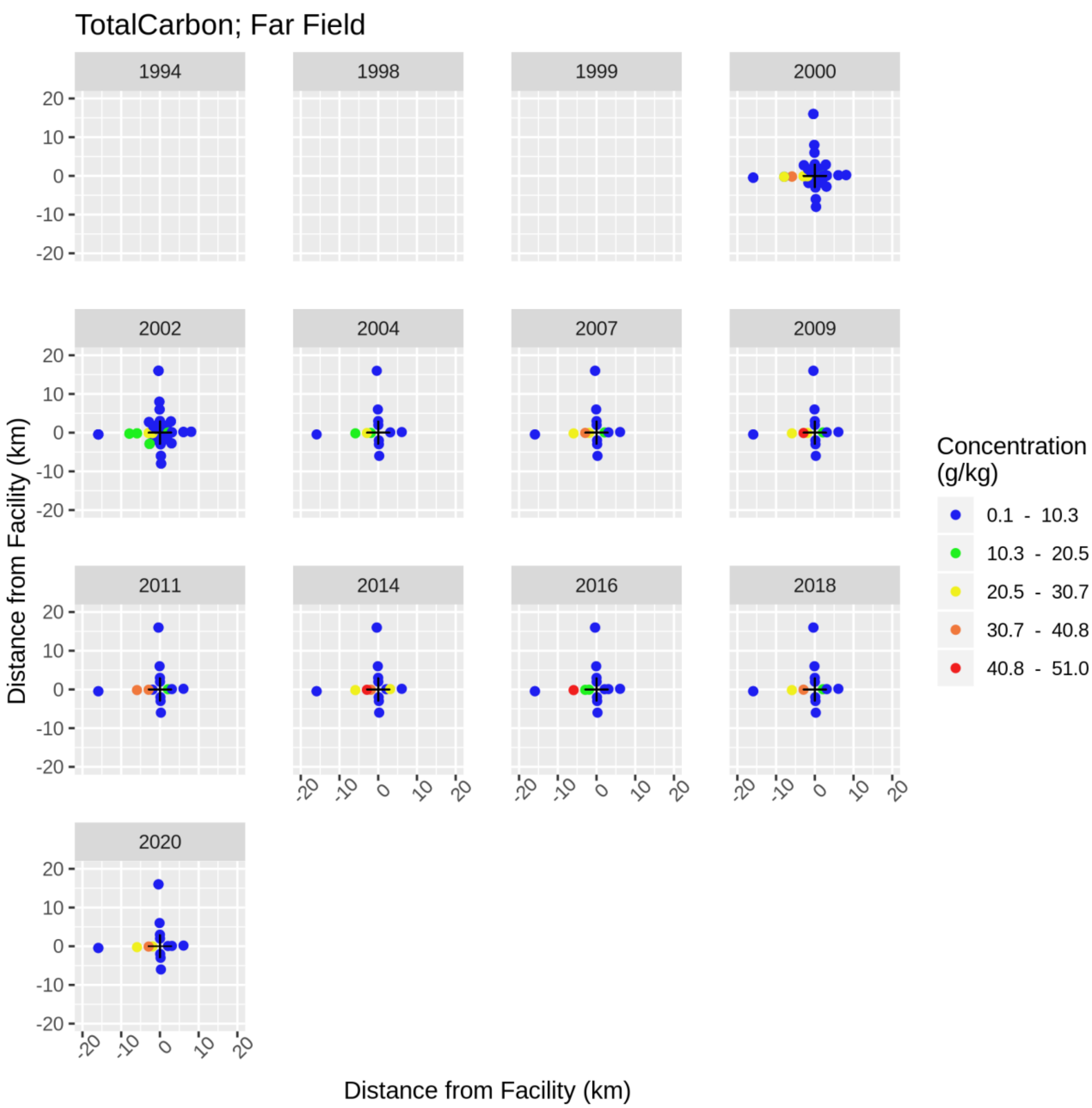


Figure 4-19: Spatial and temporal pattern of total carbon concentrations (g/kg) in Hibernia Platform sediment samples within 16,000 m of the platform for EEM programs (2000-2020), analyte not tested for in Baseline (1994).

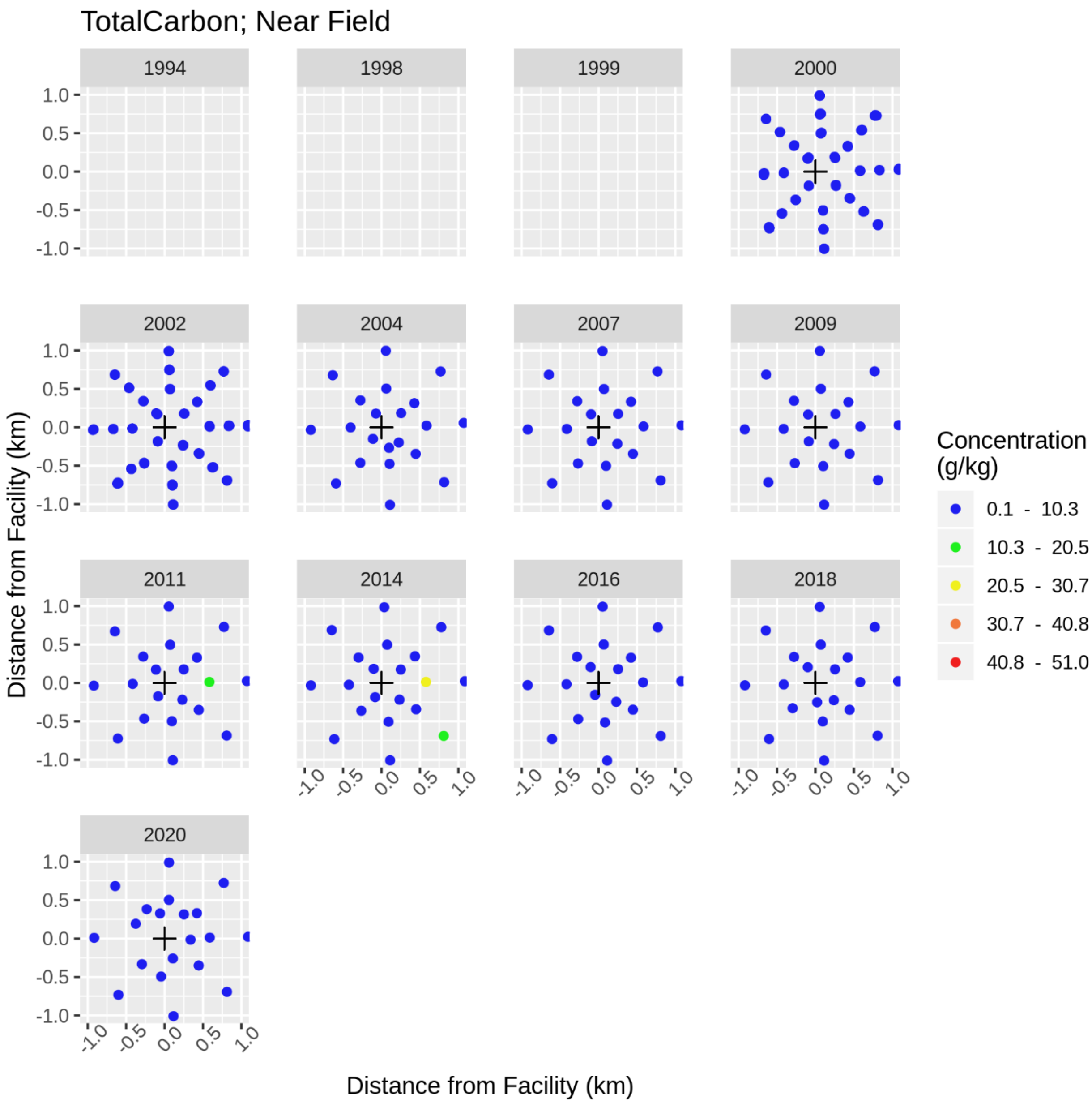


Figure 4-20: Spatial and temporal pattern of total carbon concentrations (g/kg) in Hibernia Platform sediment samples within 1,000 m of the platform for EEM programs (2000-2020), analyte not tested for in Baseline (1994).

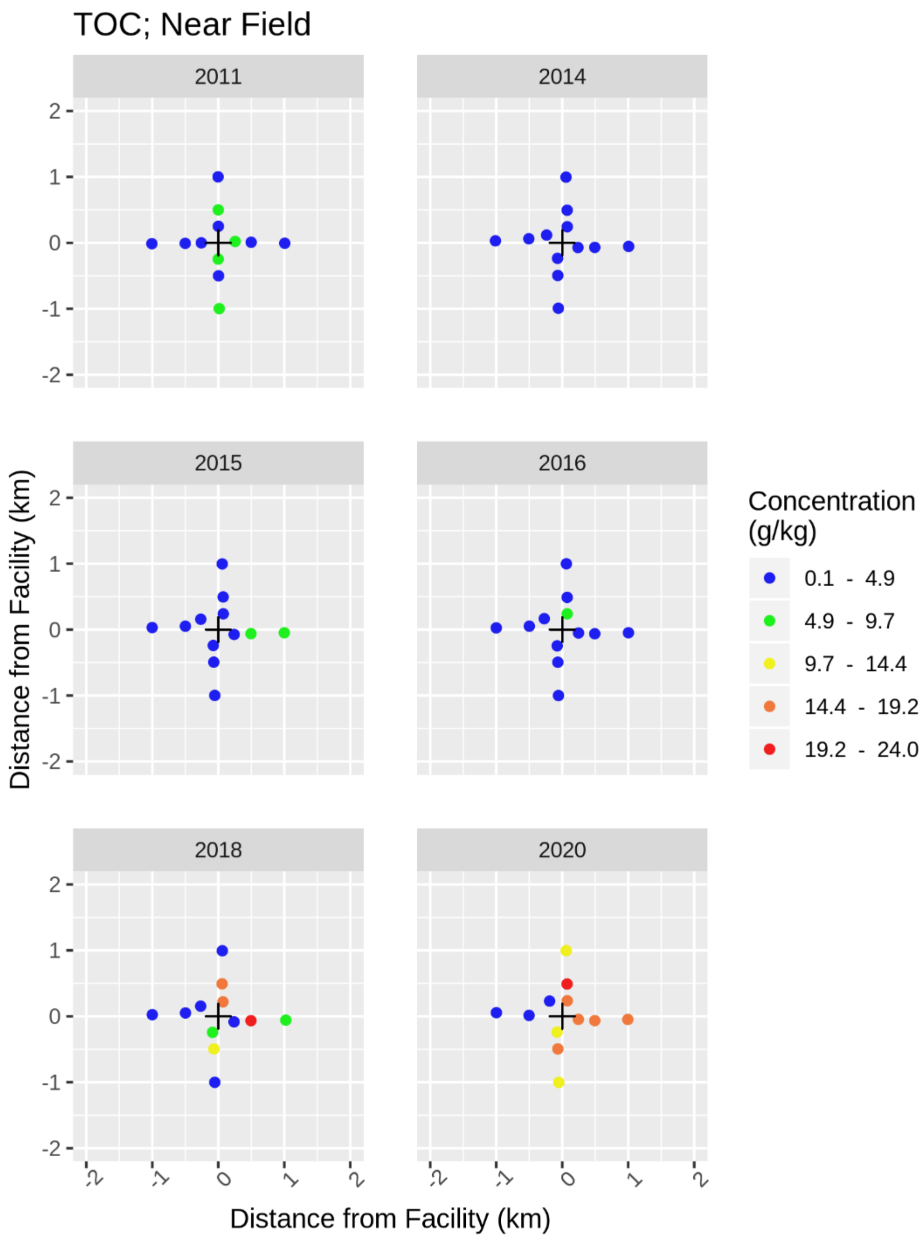


Figure 4-21: Spatial and temporal pattern of TOC concentration (g/kg) in HSE sediment samples within 1,000 m of the EDC in Baseline (2011) and EEM programs (2014-2020).

4.2.2 Physical and Chemical Statistical Analyses

The following section discusses the results of the statistical analyses for screened-in sediment types and analytes for the 2020 EEM survey.

4.2.2.1 Sediment Fractions

Percent clay in HSE sediments was not strongly correlated to either sand or gravel (r=-0.318 and r=0.255, respectively) but was correlated to silt (r=0.507). An ANCOVA analysis was conducted for analyses with this covariate however, the Field x Silt interaction term was significant (p<0.001) in the Whole-Field analysis, indicating ANCOVA was not appropriate due to co-linearity and an ANOVA was preformed instead (Table 4-14). In both the Whole- and Near-Field analyses, Year x Field interaction terms were not statistically significant and do not indicate a Project-related effect. However, in both the Whole- and Near-Field analyse the term Year was statistically significant (p<0.01). The median clay concentrations peaked in 2015 (Figure 4-22) and have been trending mainly downward since. In 2020, clay concentrations were mainly lower than those reported in 2018, specifically at stations within 250 m, 500 m, and 6,000 m from the HSE but higher at 1,000 m. At all distances, clay concentrations are still higher than levels reported in 2011.

Table 4-14: Two-factor ANOVA table for percent clay at the HSE (arcsine transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	0.023	0.006	4.409	**<0.01**
Field	2	0.026	0.013	9.972	**<0.001**
Year x Field	3	0.002	0.001	0.410	0.747
Residuals	70	0.090	0.001		
Near-Field (2011-2020)					
Year	5	0.052	0.010	12.014	**<0.001**
Field	2	0.005	0.003	2.979	0.059
Year x Field	10	0.009	0.001	1.091	0.385
Residuals	54	0.046	0.001		
Notes: Bolded p-value denotes a significant result (p<0.05)					

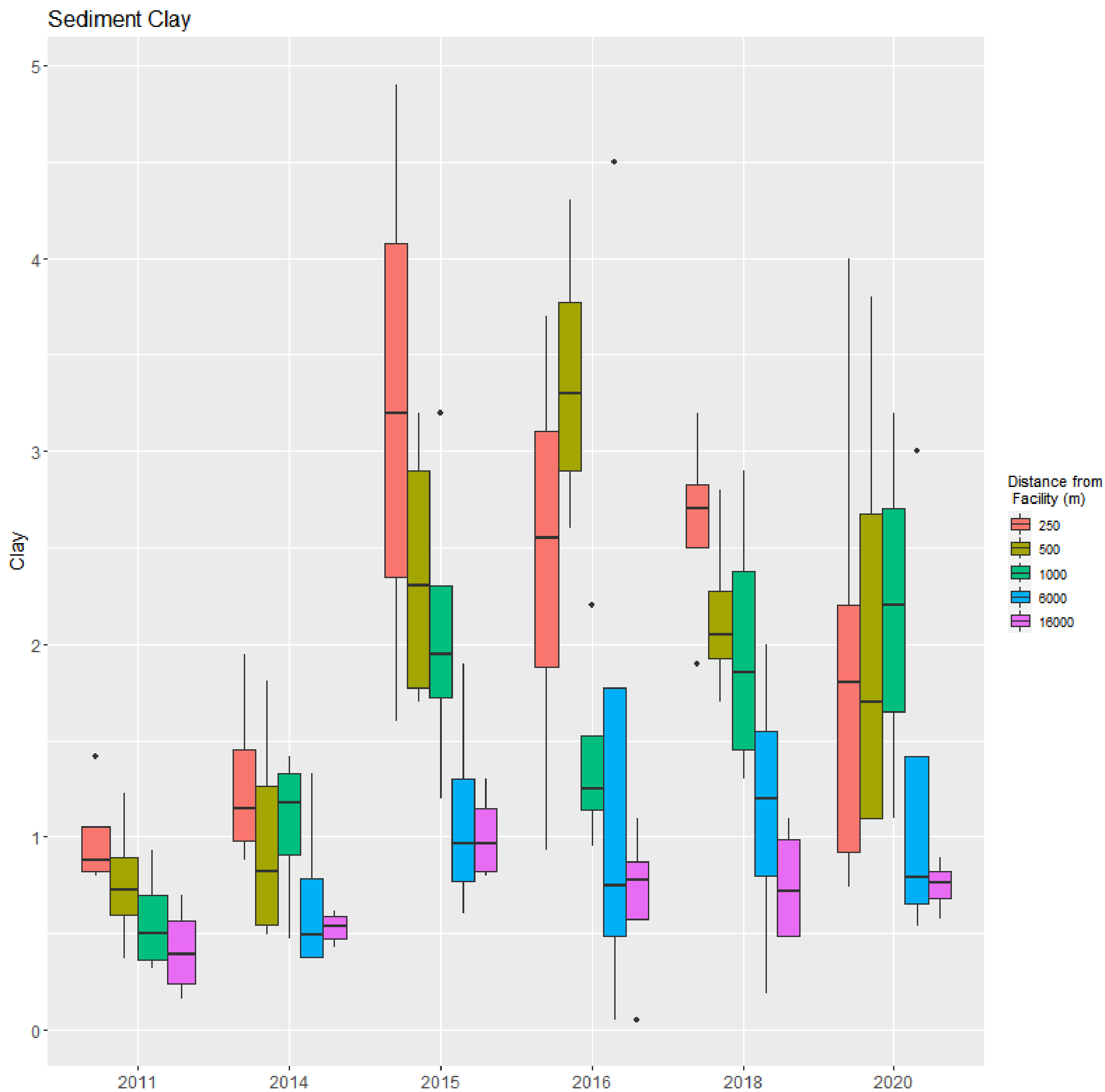


Figure 4-22: Boxplot of clay (%) in sediment samples by Distance for each EEM Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

4.2.2.2 Correlation Analysis

Potential correlations between sediment particle size and analyte concentration (across all distances) were assessed. The sediment particle sizes considered as potential covariates (r>0.5) are summarized in Table 4-15 for the Hibernia Platform and the HSE. The interpretation for each analyte is discussed separately below according to the analysis framework summarized in Figure 4-5. Results for each analyte are presented below.

Table 4-15: Summary of 2020 analytes with Hibernia Platform and HSE sediment covariate types.

Analyte	Covariate Sediment Type (r > 0.5)[1]			
	Clay	Silt	Sand	Gravel
Hibernia				
Barium	0.274	0.447	-0.174	0.130
WAM barium	0.040	0.297	0.036	-0.059
>C_{10}-C_{21} (Fuel range hydrocarbons)	-0.032	0.190	0.071	-0.082
>C_{21}-C_{32} (Lube range hydrocarbons)	0.125	0.206	-0.063	0.043
Total Carbon	0.284	**0.598**	-0.732	**0.705**
HSE				
Barium	**0.666**	**0.693***	-0.534	0.483
WAM barium	**0.628***	**0.557**	-0.498	0.455
>C_{10}-C_{21} (Fuel range hydrocarbons)	**0.699**	**0.660**	-0.613	**0.569**
>C_{21}-C_{32} (Lube range hydrocarbons)	**0.600**	**0.706***	-0.474	0.446
Organic Carbon (TOC)	**0.537***	0.424	-0.625	0.602

Notes:
Bolded value denotes r>0.5.
[1] HMDC (2013)
* Indicates sediment that was used as a covariate within ANCOVA analyses

4.2.2.3 Barium

For Hibernia sediments, barium was not correlated (r>0.5) to any of the sediment types (clay: r=0.274, silt: r=0.447, sand: r=-0.174, gravel: r=0.130; (Table 4-15) and an ANOVA analysis was deemed appropriate. From the ANOVA analyses in both the Whole- and Near-Fields, the variables Year, Field/Distance, and Year x Field/Distance were all statistically significant (p<0.01). The statistically significant Year x Field/Distance values may be an indication of a Project-related change (Table 4-16). This is similar to findings from the 2016 and 2018 EEM results.

Median concentrations of barium have been decreasing at all stations since the highest detectable levels reported in 2000 (Figure 4-23). The 2020 barium concentration levels continue the downward trend with levels within 500 m of the Hibernia Platform below 1999 levels. Barium concentrations reported in the 2020 EEM are not statistically different from those reported in 2018, 2016 or Baseline (1994).

Table 4-16: Two-factor ANOVA table for barium at Hibernia Platform (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (1994-2020)					
Year	12	1.97	0.164	3.406	**<0.001**
Field	2	8.80	4.399	91.148	**<0.001**
Year x Field	24	2.30	0.096	1.983	**<0.01**
Residuals	1129	54.49	0.048		
Near-Field (1994-2020)					
Year	12	3.631	0.303	11.94	**<0.001**
Distance	9	13.894	1.544	60.89	**<0.001**
Year x Distance	28	2.172	0.078	3.06	**<0.001**
Residuals	497	12.600	0.025		
Notes: Bolded p-value denotes a significant result ($p<0.05$)					

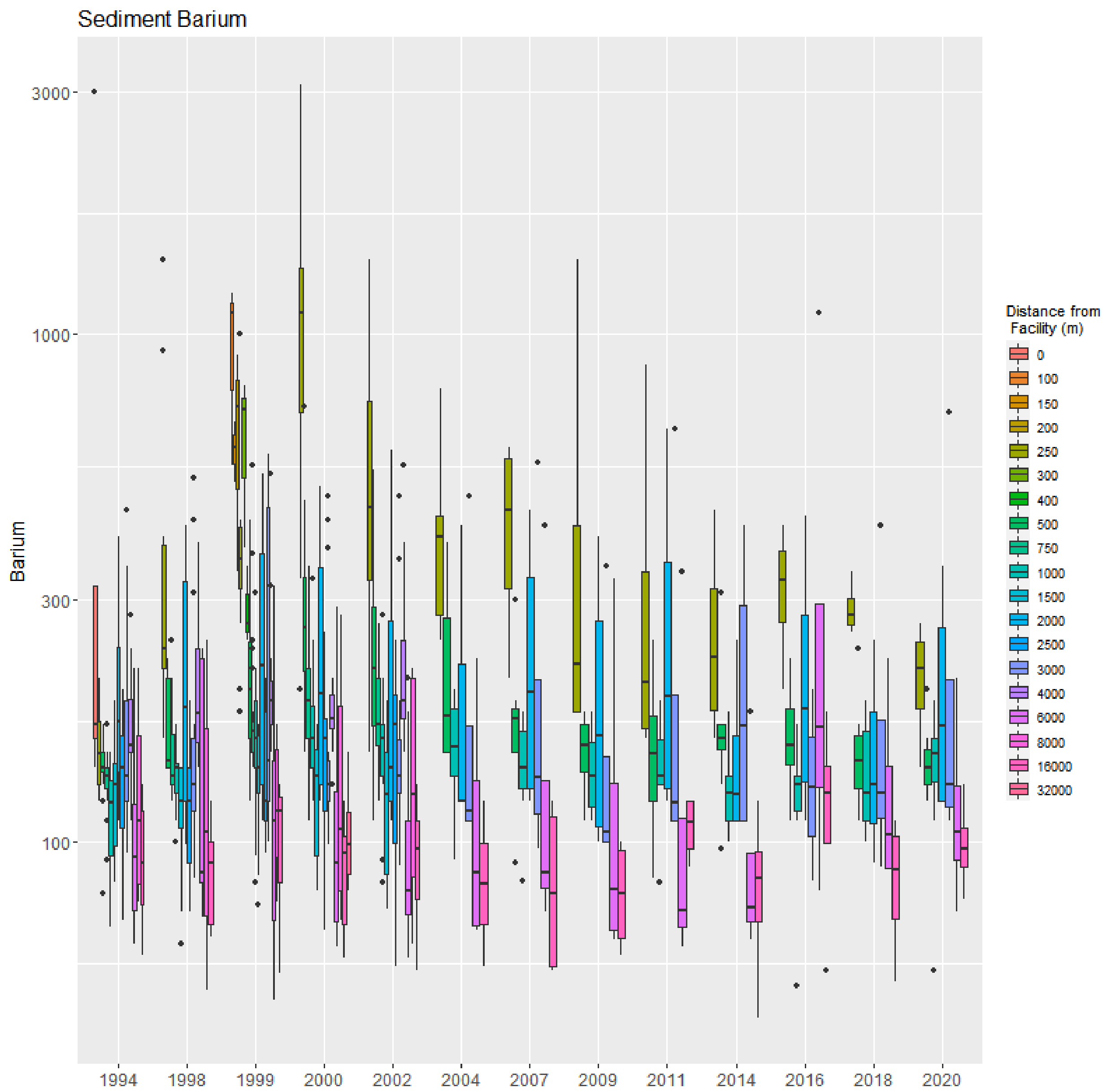


Figure 4-23: Boxplot of barium (mg/kg) (log_{10} scale) in sediment by Distance and Year at the Hibernia Platform. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

At the HSE, barium was correlated to the smaller particle sizes clay and silt (r=0.666 and r=0.693, respectively; Table 4-15). An ANCOVA was performed for the highest correlated sediment type, silt. The interaction terms between the covariate silt and the Field/Distance term were not statistically significant in either the Whole- or Near-Field analyses and the ANCOVA model was deemed appropriate (Table 4-17). The Year x Field/Distance term in the Whole-Field and Near-Field analysis were statistically significant (p=0.036 and p<0.01 respectively) which could indicate a Project-related effect.

The terms Year and Field/Distance were also statistically significant (p<0.001) in both the Whole- and Near-Field analyses. Median barium concentrations decreased in the 2020 EEM from 2018 concentrations (Figure 4-24). Specifically, barium concentrations within 500 m of the HSE have decreased from 2018 concentrations which were the highest recorded levels of any previous sampling year.

Table 4-17: Two-factor ANCOVA table for barium at HSE (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	5.596	1.399	11.836	**<0.001**
Field	2	6.144	3.072	25.988	**<0.001**
Year x Field	3	1.080	0.360	3.044	**0.036**
Field x Silt	2	0.028	0.014	0.120	0.887
Residuals	60	7.092	0.118		
Near-Field (2011-2020)					
Year	5	10.775	2.155	30.016	**<0.001**
Distance	2	6.605	3.303	46.001	**<0.001**
Year x Distance	10	2.171	0.217	3.023	**<0.01**
Distance x Silt	2	0.115	0.057	0.799	0.457
Residuals	36	2.585			
Notes: Bolded p-value denotes a significant result (p<0.05)					

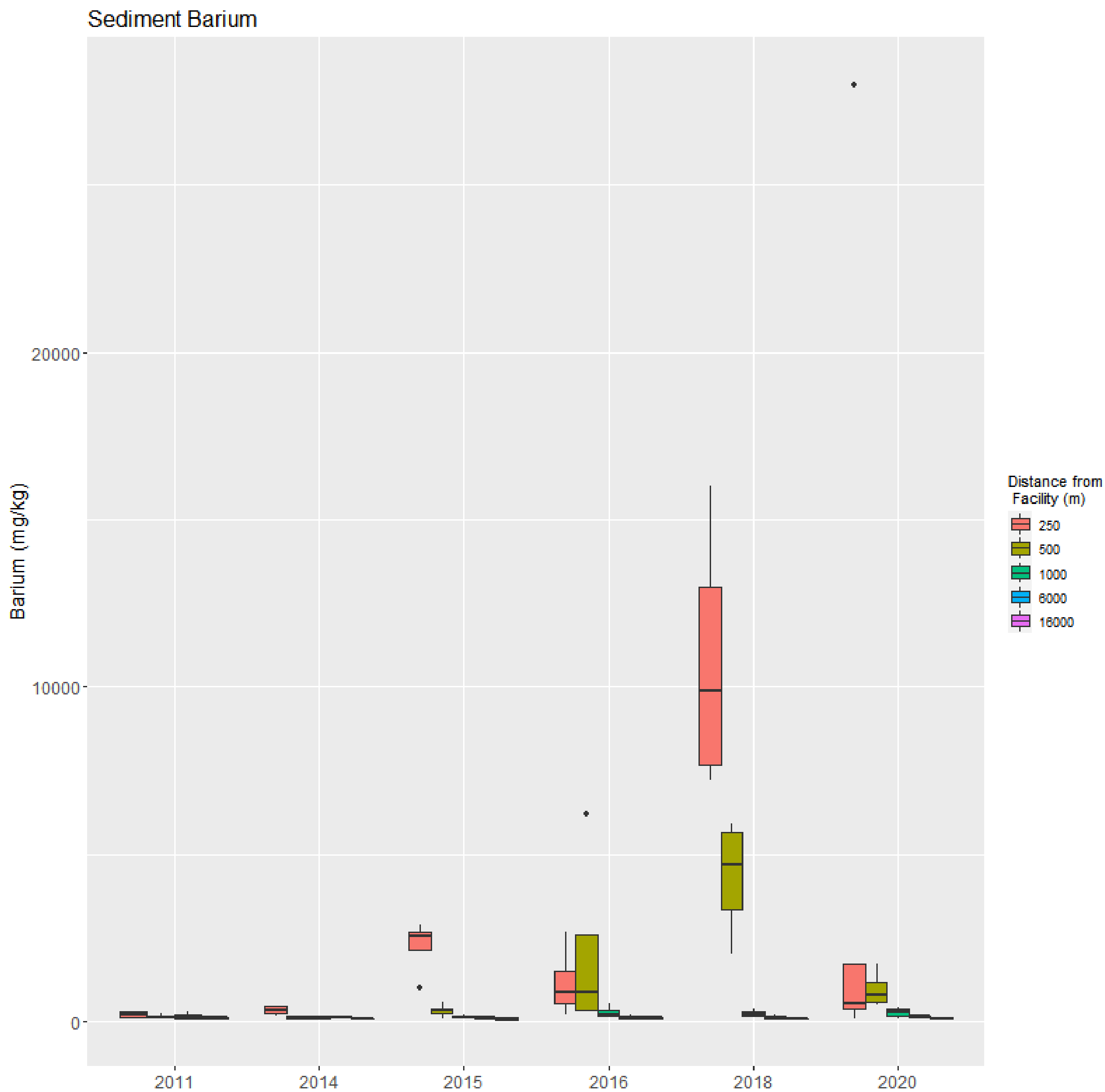


Figure 4-24: Boxplot of barium (mg/kg) (log_{10} scale) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

WAM Barium

At the Hibernia Platform, WAM barium was not correlated to any of the sediment types ($r<0.5$) thus an ANOVA analysis was deemed appropriate (Table 4-18). In the Whole-Field and Near-Field analyses, all variables were significant ($p<0.01$). A statistically significant Year x Field value could indicate a Project-related effect (Table 4-18).

The median WAM barium concentration decreased in the Near-Field from 2018 concentrations but increased slightly at stations in the Mid-Field (Figure 4-25). WAM barium concentrations measured in 2020 were not statistically different from concentrations reported in either the 2016 or 2018 EEM results.

Table 4-18: Two-factor ANOVA table for WAM barium at Hibernia Platform (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (1999-2020)					
Year	10	1.776	0.178	11.23	**<0.001**
Field	2	5.210	2.605	164.72	**<0.001**
Year x Field	20	1.623	0.081	5.13	**<0.001**
Residuals	668	10.564	0.016		
Near-Field (1999-2020)					
Year	10	3.321	0.332	31.617	**<0.001**
Distance	8	7.807	0.976	92.906	**<0.001**
Year x Distance	22	0.574	0.026	2.484	**<0.001**
Residuals	309	3.246	0.011		
Notes: Bolded p-value denotes a significant result (p<0.05) WAM barium testing introduced in 1999					

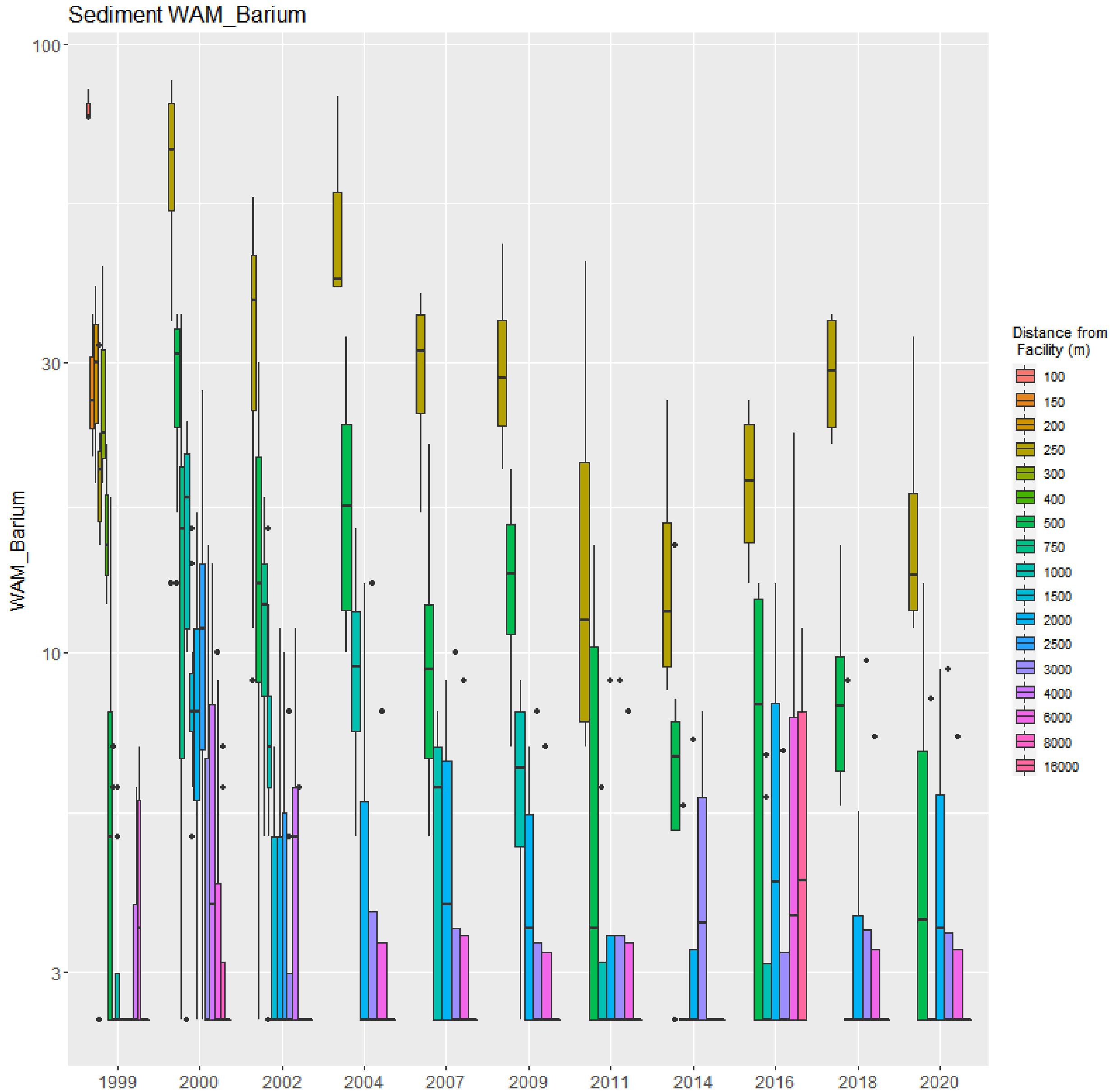


Figure 4-25: Boxplot of WAM barium (mg/kg) (log_{10} scale) in sediment by Distance and Year at the Hibernia Platform. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

WAM barium concentrations in HSE sediments was correlated to clay and silt (r=0.628 and r=0.557, respectively; Table 4-15) and an ANCOVA was performed with clay as the covariate. The covariate x interaction term (Field x Clay) was not statistically significant and the ANCOVA was deemed appropriate (Table 4-19). In both the Whole- and Near-Field analysis, all terms were statistically significant (except for the covariate term as previously stated above). The Year x Field term in the Whole-Field and Year x Distance term in the Near-Field were both statistically significant ($p<0.01$) and could indicate a Project-related change.

Median WAM barium concentrations had an upward trend at stations within 250 m of the HSE since 2014 and 500 m since 2015 (Figure 4-26). This trend reversed in the 2020 EEM. Median WAM barium concentrations in 2020 are lower than those reported in 2018. The concentrations reported in 2018 were the highest recorded levels of any previous sampling year. Median concentrations reported from stations at 1,000 m and 6,000 m are similar to those reported in 2016 and 2018.

Table 4-19: Two-factor ANCOVA table for WAM barium at HSE (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	5.584	1.396	18.617	**<0.001**
Field	2	8.514	4.257	56.773	**<0.001**
Year x Field	3	1.579	0.747	9.956	**<0.01**
Field x Clay	2	0.313	0.157	2.090	0.133
Residuals	60	4.499	0.075		
Near-Field (2011-2020)					
Year	5	11.85	2.367	64.210	**<0.001**
Distance	2	2.020	1.010	27.394	**<0.001**
Year x Distance	1	1.316	0.132	3.570	**<0.01**
Distance x Clay	2	0.014	0.007	0.184	0.833
Residuals	36	1.327	0.037		
Notes: Bolded p-value denotes a significant result ($p<0.05$)					

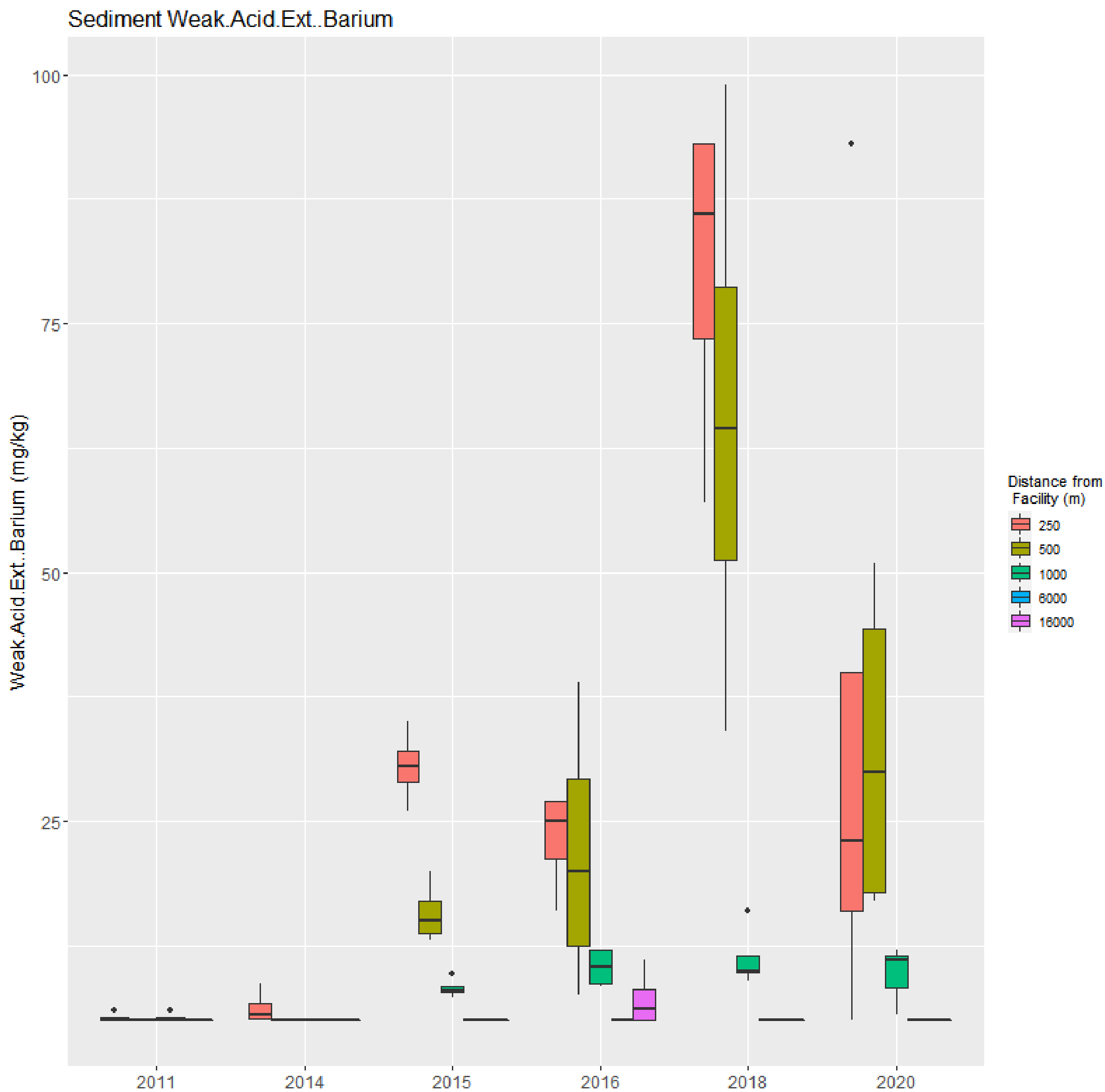


Figure 4-26: Boxplot of WAM barium (mg/kg) (log_{10} scale) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

4.2.2.4 Hydrocarbons and Other Bio-geochemical Parameters

Fuel Range Hydrocarbons (>C_{10}-C_{21})

In Hibernia platform sediments, fuel range hydrocarbons (>C_{10}-C_{21}) were not correlated to any of the sediment types (r<0.5; Table 4-15) and an ANOVA was performed. In both the Whole- and Near-Fields, all variables were statistically significant ($p<0.001$) (Table 4-20). The statistically significant Year x Field/Distance interaction could indicate a Project-related effect.

Examining the >C_{10}-C_{21} median concentrations at all distances, the downward trend that began in 2004 continues in the 2020 EEM (Figure 4-27). The downward trend begins after peak concentrations were observed in 1999 and 2000 and after cuttings reinjection commenced.

Table 4-20: Two-factor ANOVA table for >C_{10}-C_{21} at Hibernia Platform (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (1994-2020)					
Year	12	233.1	19.42	64.58	**<0.001**
Field	2	141.3	70.64	234.88	**<0.001**
Year x Field	24	77.0	3.21	10.67	**<0.001**
Residuals	1126	338.7	0.30		
Near-Field (1994-2020)					
Year	12	269.51	22.459	80.027	**<0.001**
Distance	9	48.83	5.426	19.334	**<0.001**
Year x Distance	28	28.10	1.003	3.576	**<0.001**
Residuals	498	139.76	0.281		
Notes: Bolded p-value denotes a significant result ($p<0.05$)					

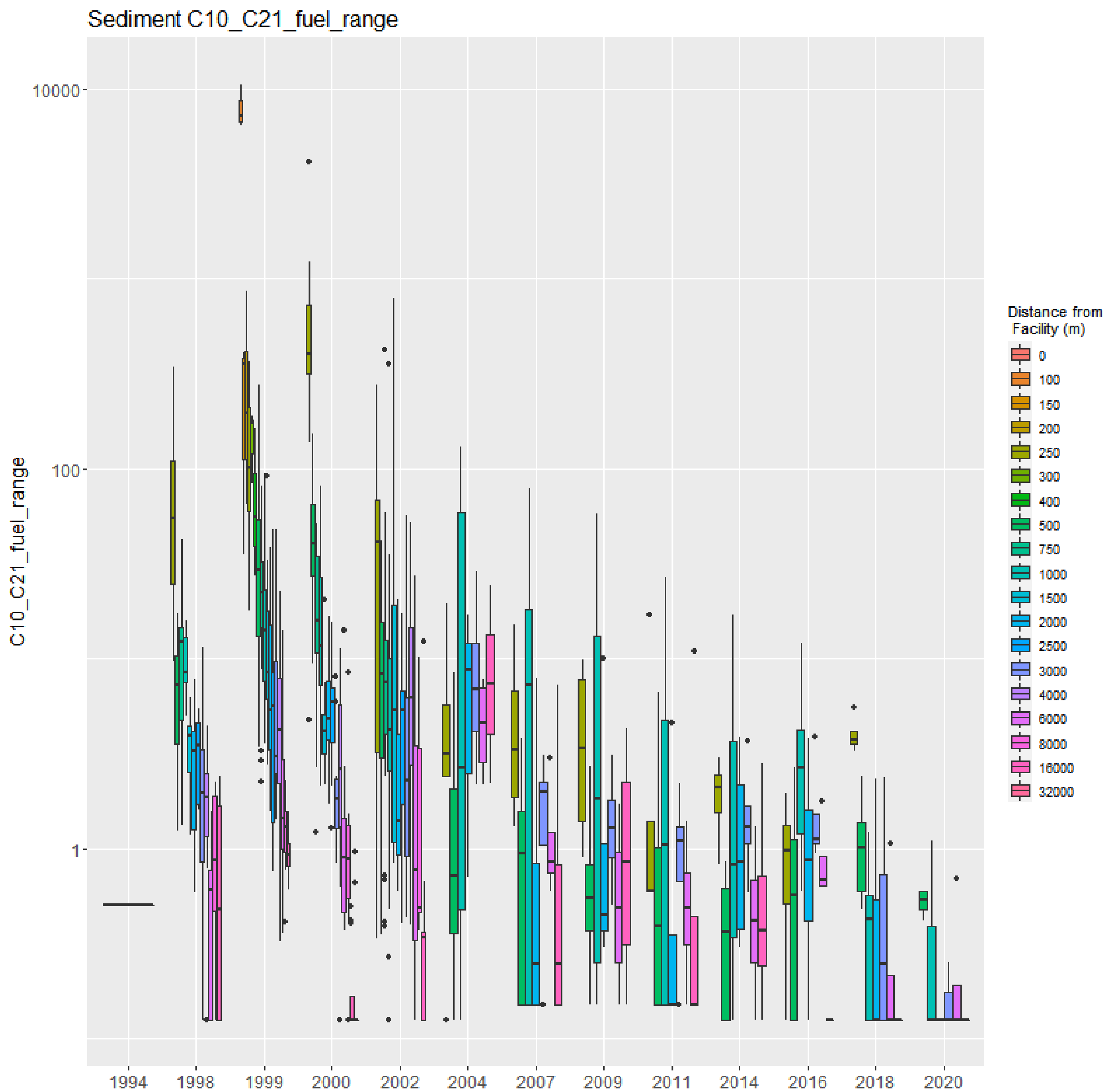


Figure 4-27 Boxplot of >C_{10}-C_{21} (mg/kg) ($\log_{10}$ scale) in sediment by Distance and Year at the Hibernia Platform. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

At the HSE, fuel range hydrocarbons were correlated to clay, silt, and gravel (r=0.699, 0.66, and 0.569 respectively; Table 4-15) and an ANCOVA was selected for analysis with clay as a covariate. The interaction terms Distance x Clay, Distance x Silt, and Distance x Gravel in the Near-Field analysis were statistically significant (p=0.037, p=0.038, and p=0.04, respectively) and an ANCOVA was deemed inappropriate, and an ANOVA was performed (Table 4-21). In the Whole-Field and Near-Field analyses, the Year x Field/Distance interaction terms were not statistically significant and does not indicate a Project-related change.

The Year, Field, and Distance terms were individually statistically significant ($p<0.01$). The median $>C_{10}$-C_{21} hydrocarbon concentrations within 500 m from the HSE were on an upward trend since 2015 with the 2018 levels being the highest recorded (Figure 4-30). In 2020, the median concentrations are on a downward trend and more similar to 2015 EEM concentrations. Beyond >1,000 m from the HSE, $>C_{10}$-C_{21} concentrations remain at similar levels to those at baseline and previous sampling years.

Table 4-21: Two-factor ANOVA table for $>C_{10}$-C_{21} at HSE (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	15.35	3.838	4.899	**<0.01**
Field	2	52.58	26.292	33.564	**<0.001**
Year x Field	3	4.94	1.647	2.102	0.108
Residuals	70	54.83	0.783		
Near-Field (2011-2020)					
Year	5	41.39	8.278	18.351	**<0.001**
Distance	2	23.90	11.951	26.493	**<0.001**
Year x Distance	10	8.24	0.824	1.826	0.078
Residuals	54	24.36	0.451		
Notes: Bolded p-value denotes a significant result (p<0.05)					

Lube Range Hydrocarbons ($>C_{21}$-C_{32})

At the Hibernia Platform, lube range hydrocarbon ($>C_{21}$-C_{32}) concentrations were not correlated to any sediment fraction (Table 4-15). An ANOVA analysis was performed (Table 4-22). The Year x Field interaction term was statistically significant in both the Whole-Field analysis ($p<0.001$) and in the Near-Field analysis ($p<0.001$) which may be indicative of a Project-related change.

In both the Whole- and Near-Field analysis, the terms Year and Field/Distance were statistically significant ($p<0.001$). Median $>C_{21}$-C_{32} concentrations continue a mainly downward trend that began in 2009 EEM (Figure 4-28). In the Near-Field, median concentrations have decreased from 2018 levels.

Table 4-22: Two-factor ANOVA table for >C_{21}-C_{32} at Hibernia Platform (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	12	79.54	6.628	43.995	**<0.001**
Field	2	12.01	6.006	39.865	**<0.001**
Year x Field	24	13.26	0.553	3.668	**<0.001**
Residuals	1122	169.03	0.151		
Near-Field (2011-2020)					
Year	12	80.59	6.716	71.695	**<0.001**
Distance	9	20.39	2.266	24.187	**<0.001**
Year x Distance	28	15.00	0.536	5.721	**<0.001**
Residuals	496	46.46	0.094		
Notes: Bolded p-value denotes a significant result ($p<0.05$)					

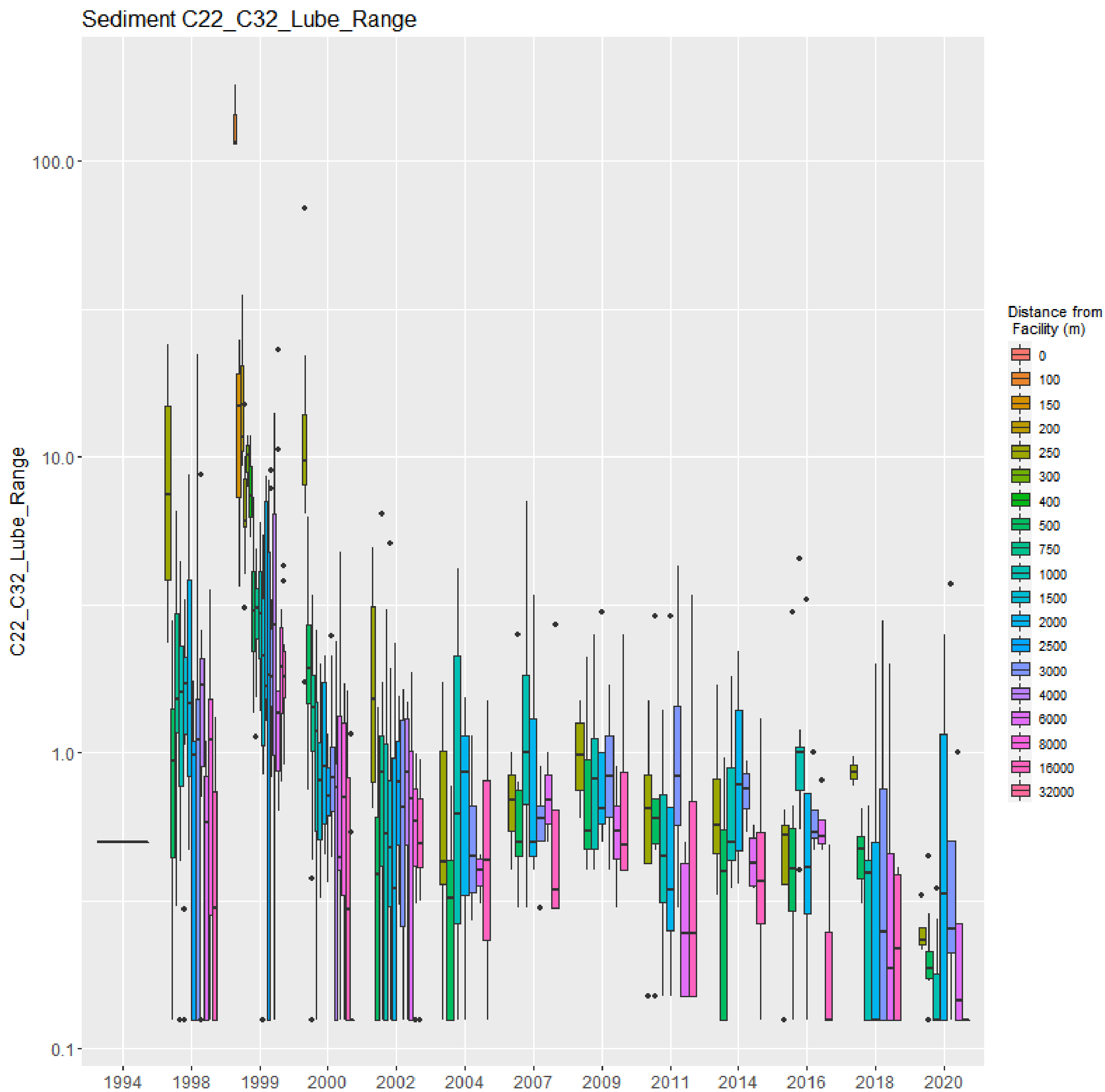


Figure 4-28: Boxplot of >C_{21}-C_{32} (mg/kg) (log_{10} scale) in sediment by Distance and Year at the Hibernia Platform. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

At the HSE, lube range hydrocarbons were correlated to clay, and silt (r=0.600, and 0.706, respectively; Table 4-15) and an ANCOVA was selected for analysis. Neither of the interaction terms (Field x Silt nor Distance x Silt) were statistically significant (Table 4-21). In both the Whole- and Near-Field analysis the interaction terms (Year x Field and Year x Distance respectively) were not statistically significant and do not indicate a Project-related change.

The Year, Field, and Distance terms were statistically significant ($p<0.001$). The $>C_{21}$-C_{32} hydrocarbon median concentrations within 500 m from the HSE had been on an upward trend since 2015 with the 2018 levels being the highest recorded (Figure 4-30); however, 2020 marks a downward trend. Median concentrations in 2020 were below 2016 EEM concentrations.

Table 4-23: Two-factor ANCOVA table for $>C_{21}$-C_{32} at HSE (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	7.477	1.869	17.291	**<0.001**
Field	2	5.878	2.939	27.186	**<0.001**
Year x Field	3	0.489	0.163	1.509	0.221
Field x Silt	2	0.054	0.027	0.250	0.779
Residuals	60	6.487	0.108		
Near-Field (2011-2020)					
Year	5	8.850	1.770	17.000	**<0.001**
Distance	2	3.551	1.776	17.054	**<0.001**
Year x Distance	10	0.995	0.099	0.955	0.497
Distance x Silt	2	0.528	0.264	2.534	0.093
Residuals	36	3.748	0.104		
Notes: Bolded p-value denotes a significant result (p<0.05)					

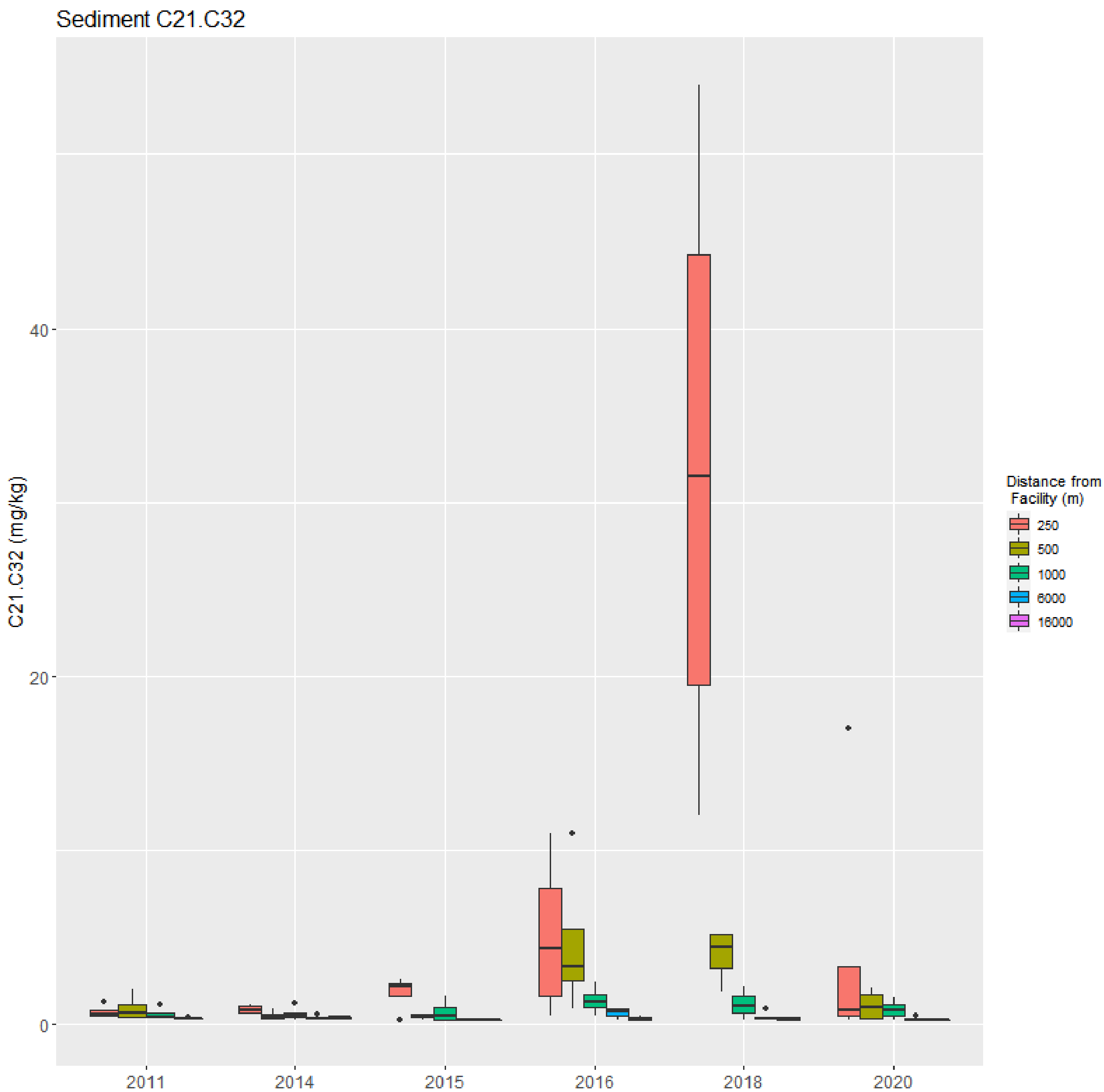


Figure 4-29: Boxplot of >C_{21}-C_{32} (mg/kg) (log_{10} scale) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

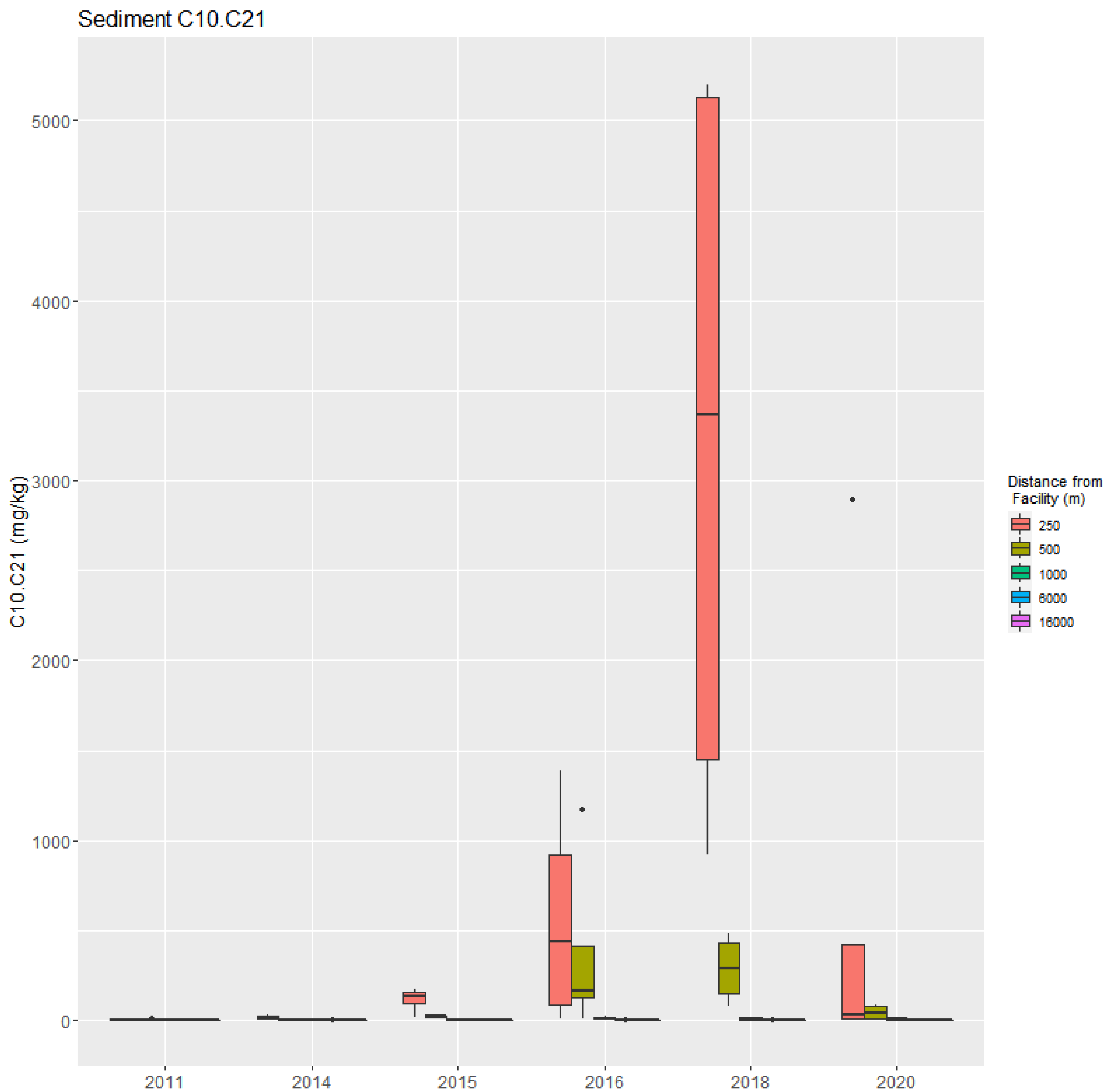


Figure 4-30: Boxplot of >C_{10}-C_{21} (mg/kg) (log_{10} scale) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

Total Carbon

At the Hibernia Platform, total carbon concentrations were correlated to silt (*r*=0.598), and gravel (*r*=0.705) (Table 4-15). An ANCOVA analysis was performed, however the Distance x Gravel interaction term was statistically significant and violated the assumptions, thus an ANCOVA was deemed inappropriate, and an ANOVA was performed (Table 4-22). The Year x Field interaction term was not statistically significant in the Whole-Field analysis (p=0.766) or the Year x Distance term in the Near-Field analysis (p=0.812) and do not indicate a Project-related change.

In the Whole-Field analysis, Year was statistically significant (p<0.001). Median total carbon concentrations have increased in the Far-Field in 2020 from 2018 levels (Figure 4-28). In the Near-Field, concentrations have been on an upward trend. Total carbon has only been reported since the 2000 EEM.

Table 4-24: Two-factor ANOVA table for Total Carbon at Hibernia (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	9	0.087	0.01	0.559	0.831
Field	2	1.370	0.685	39.422	**<0.001**
Year x Field	18	0.233	0.013	0.744	0.766
Residuals	653	11.348	0.017		
Near-Field (2011-2020)					
Year	9	0.046	0.005	1.628	0.106
Distance	3	0.018	0.006	1.883	0.132
Year x Distance	19	0.042	0.002	0.707	0.812
Residuals	308	0.962	0.003		
Notes: Bolded p-value denotes a significant result (p<0.05)					

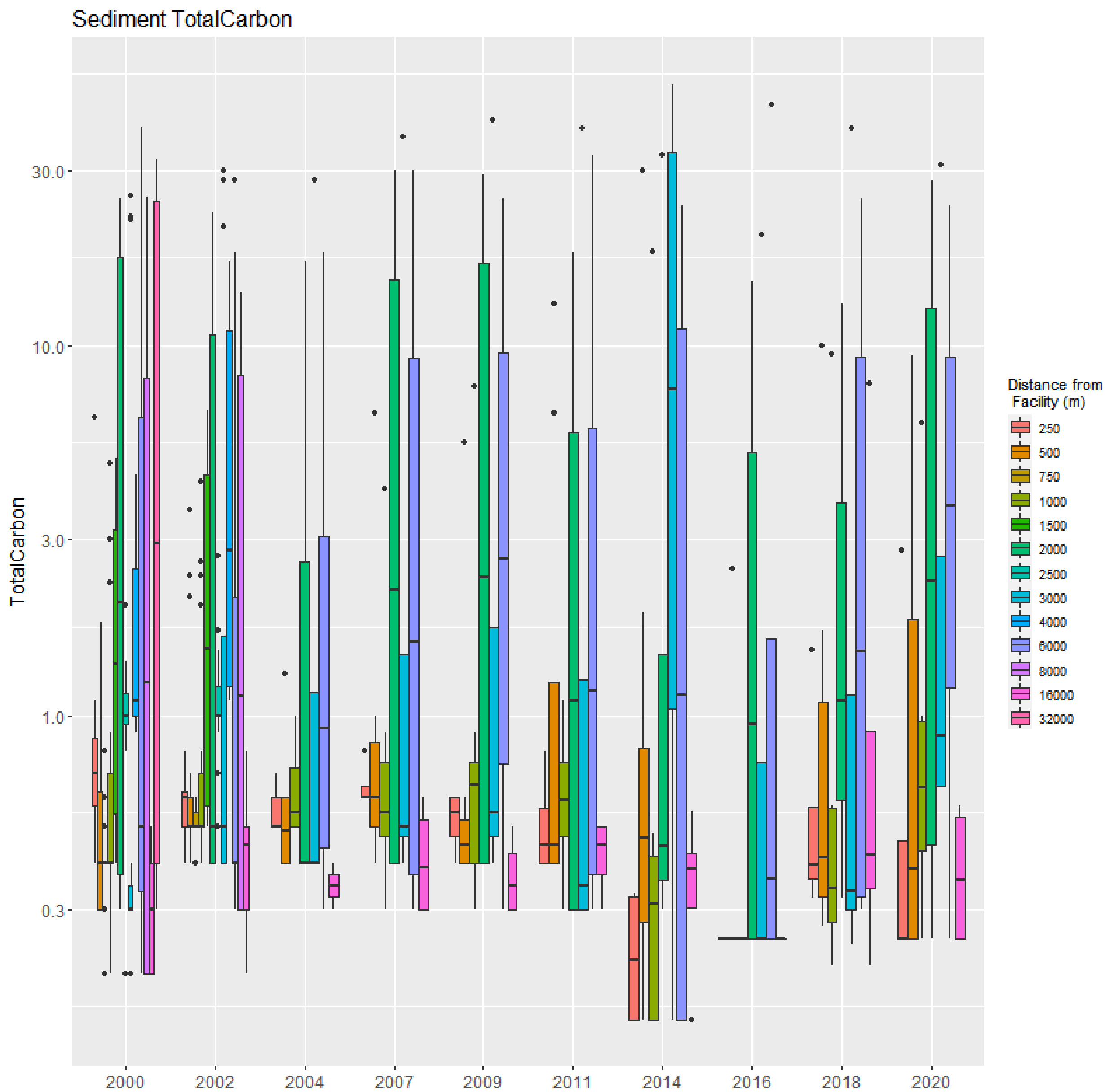


Figure 4-31: Boxplot of Total Carbon (g/kg) (log_{10} scale) in sediment by Distance and Year at the Hibernia Platform. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

Total Organic Carbon

At the HSE, TOC was correlated to clay (r=0.537, Table 4-15). The interaction terms were not statistically significant and an ANCOVA was performed with the covariate clay (Table 4-21). In the Whole- and Near-Field analyses the Year x Field and Year x Distance interaction terms were not statistically significant and do not indicate a Project-related change.

In the Whole-Field the Year and Field terms were statistically significant ($p<0.001$). In the Near-Field analysis, the Year term was statistically significant ($p<0.001$). Median TOC concentrations within 500 m from the HSE have been on an upward trend since 2015 with the 2020 levels being the highest recorded (Figure 4-30).

Table 4-25: Two-factor ANCOVA table for TOC at HSE (log_{10} transformed).

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2014-2020)					
Year	4	6.883	1.721	10.888	**<0.001**
Field	2	12.226	6.113	38.677	**<0.001**
Year x Field	3	0.313	0.104	0.661	0.579
Field x Clay	2	0.092	0.046	0.292	0.748
Residuals	60	9.483	0.158		
Near-Field (2011-2020)					
Year	5	8.008	1.602	8.591	**<0.001**
Distance	2	0.578	0.289	1.549	0.226
Year x Distance	10	2.267	0.227	1.216	0.314
Distance x Clay	2	0.489	0.244	1.311	0.282
Residuals	36	6.711	0.186		
Notes: Bolded p-value denotes a significant result ($p<0.05$)					

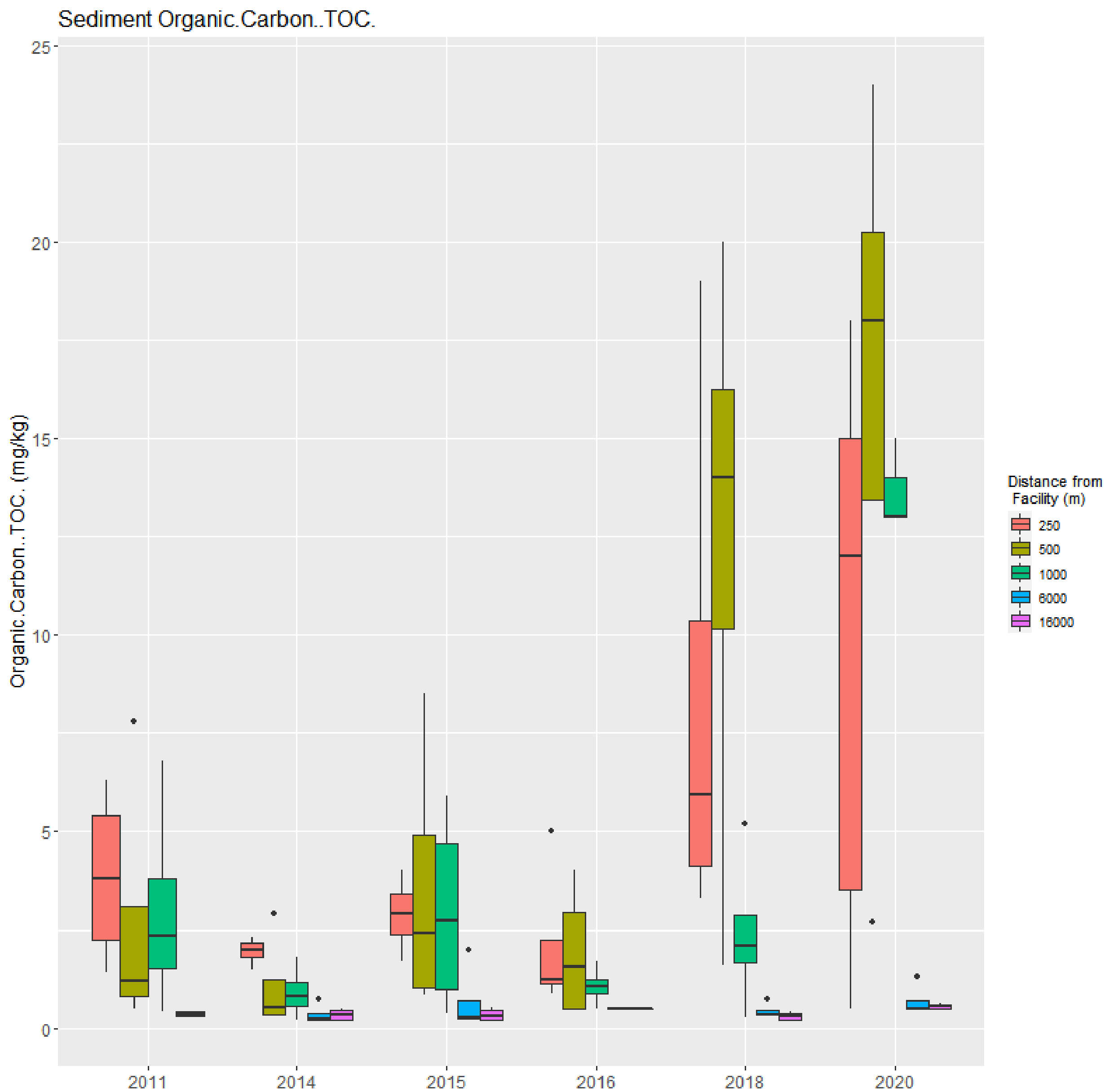


Figure 4-32: Boxplot of TOC (g/kg) (log_{10} scale) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

4.2.3 Physical and Chemical Multivariate Analysis

Multivariate visualization and statistical methods were used to understand the overarching spatial and temporal trends and patterns of the sediment composition of each production field. Sediment types and chemical analytes were log transformed and normalized to provide equal weight in the subsequent analyses. Spatial and temporal trends are presented below in a non-parametric Multi-Dimensional Scaling (nMDS) plot with Euclidean distances. To test hypotheses, a permutation-based multivariate analog of ANOVA (PERMANOVA) was used (Anderson et al. 2008). Sample similarities were modeled as a function of Distance (Hibernia Platform: 250 m, 500 m, 1,000 m, 2,000 m, 3,000 m, 6,000 m, 16,000 m; HSE: 250 m, 500 m, 1,000 m, 6,000 m, 16,000 m) and Year (Hibernia Platform: 2004, 2014, 2016, 2018, 2020; HSE: 2011, 2014, 2015, 2016, 2018, 2020). Analyses were performed in the statistical software package PRIMER v6 (Clarke and Warwick 2001).

For the Hibernia production field, the nMDS plots show across years that the reference stations (light green) generally clustered together (Figure 4-33). Stations along radial 7 at distances >2,000 m were more closely associated with the sediment fractions gravel and silt while all other stations were more closely associated with sand. Stations within 500 m of the Hibernia Platform were grouped together closer to barium, and fuel and lube range hydrocarbons.

In the HSE production field, the 16,000 m reference stations for all years closely grouped together and correlated with the sediment type sand more than other parameters (Figure 4-34). Similarly, most other stations across all years and distances also grouped near the reference stations with a few notable exceptions. Five stations at a distance of 250 m for the years 2018 and 2020 grouped separately from all other stations. These stations were more closely associated with the analytes clay, silt, barium, WAM barium, and fuel and lube range hydrocarbons. This continuing shift of these stations away from the reference stations could indicate a Project-related change.

When both production fields are combined and examined together, similar trends are observed (Figure 4-35). The reference stations at 16,000 m mainly group together near the sediment fraction sand. The Hibernia Platform stations mainly group together and are correlated with sand. The HSE stations are correlated more strongly with other chemical analytes, mainly barium, WAM barium, fuel range and lube range hydrocarbons. Stations within 500 m of the HSE have the strongest correlations with these chemical analytes. This is similar to the 2016 and 2018 EEM findings in which these stations began to shift towards these same chemical analytes.

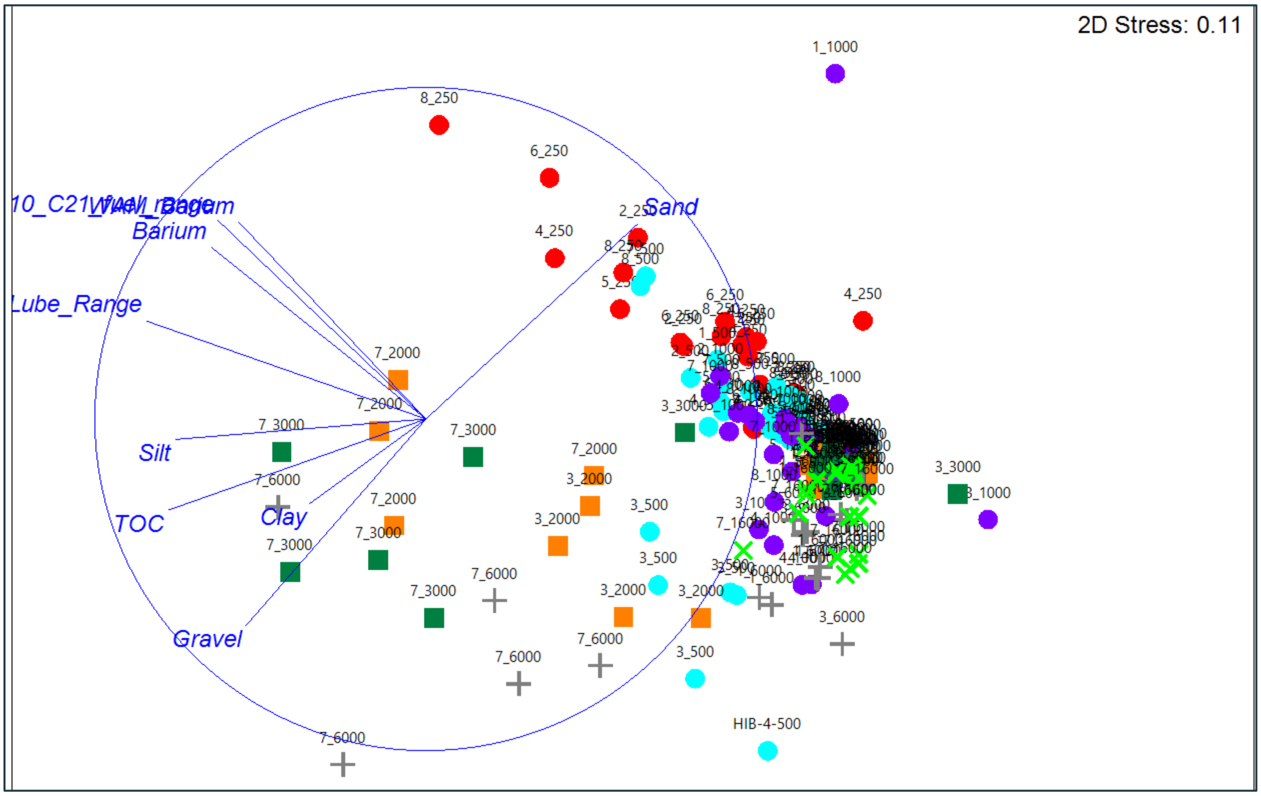


Figure 4-33: Two-dimensional nMDS plot of Hibernia Platform sediment data across sample distances and years with Pearson correlation overlay of sediment analytes. Colours denote station distance: 250 m (red), 500 m (light blue), 1,000 m (purple), 2,000 m (orange), 3,000 m (dark green), 6,000 m (grey), 16,000 m (light green). Each point is labelled by station.

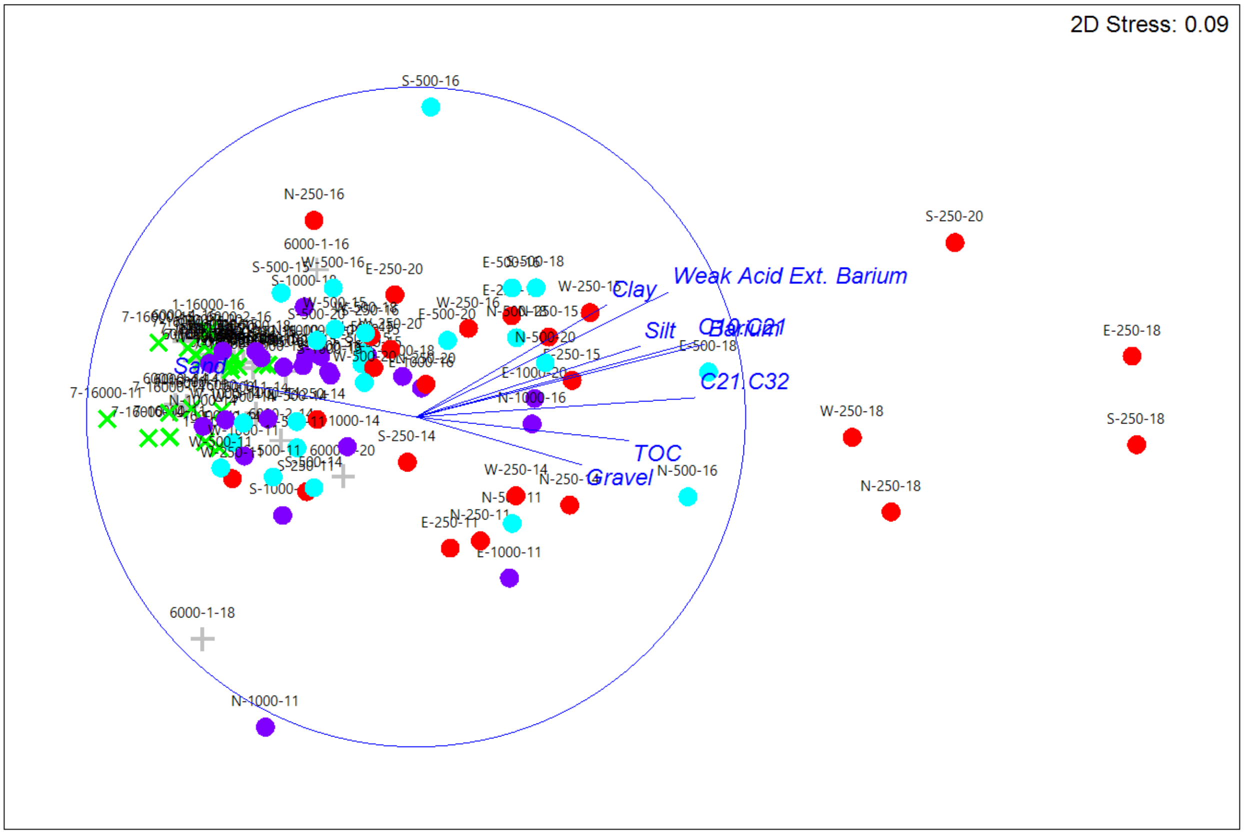


Figure 4-34: Two-dimensional nMDS plot of HSE sediment data across sample distances and years with Pearson correlation overlay of sediment analytes. Colours denote station distance: 250 m (red), 500 m (light blue), 1,000 m (purple), 6,000 m (grey), 16,000 m (green). Each point is labelled by station.

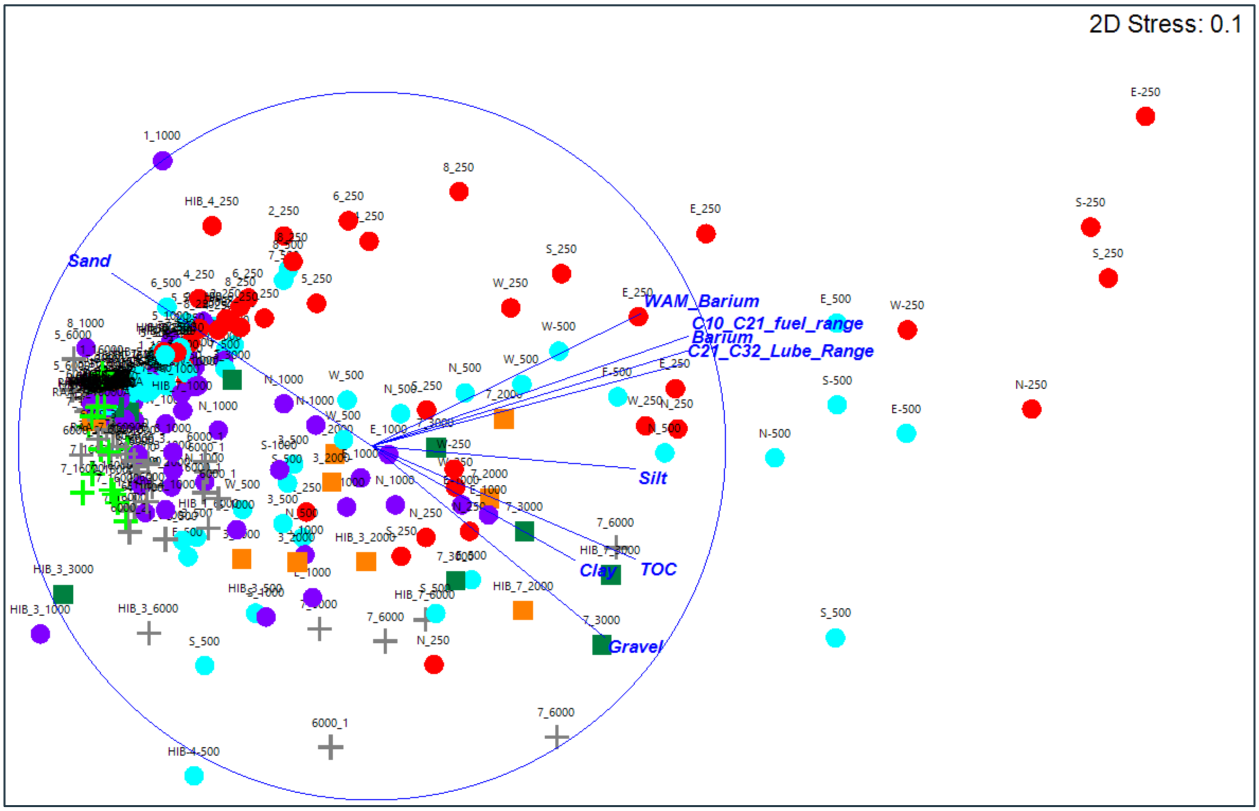


Figure 4-35: Two-dimensional nMDS plot of the Hibernia Platform and HSE sediment chemistry across sample distances and years with Pearson correlation overlay of sediment analytes. Colours denote distance: 250 m (red), 500 m (light blue), 1,000 m (purple), 2,000 m (orange), 3,000 m (dark green), 6,000 m (grey), 16,000 m (light green). Each point is labelled by station.

4.2.4 Combined Field (Hibernia Platform and HSE) Comparisons

To assess potential changes in the environment over time, combined datasets of both production fields were examined. The combined field analysis contained two parts: a combined Whole-Field analysis (combination of both Hibernia and HSE production fields), and a combined Near-Field analysis (combination of all Near-Field stations at both production fields). The combined Whole-field analysis examined data from stations up to 6,000 m from both production fields. However, stations up to 6,000 m from the HSE were only sampled since the 2014 EEM. Thus, a combined Near-Field analysis of both production fields was also conducted. The combined Near-Field analysis included all stations up to and within 1,000 m from the source (drill centre) of each production field. The combined Near-Field analysis contains a three-way interaction between Distance, Field and Year. The data were analyzed using ANOVAs with post-hoc Tukey's pair-wise comparison test. As post-hoc pairwise comparisons were not possible with ANOVAs if a statistically significant interaction term is present, a linear regression was used when required.

The use of a linear regression allows for post-hoc pair-wise comparison even if the interaction term is significant, using an adjusted means method implemented in the R package phia for the combined Near-Field analysis (De Rosario-Martinez, 2015). Due to the potential for a significant three-way interaction term in the combined Whole-Field analysis, the contrast (equivalent of pair-wise comparison) between the factors was conducted using the least-squares means method as implemented in the R package lsmeans (Lenth 2016). Analytes that had significant interaction terms in the combined-Field analyses were summarized in Table 4-26 for Whole-Field and Table 4-27 for Near-Field. When there were multiple two-way statistically significant interactions, the Akaike Information Criterion (AIC) was used to determine which model was more appropriate. Only the model chosen by the AIC was used for the contrast analysis.

Combined Whole-Field Analysis

From the Whole-Field analysis, several analytes were statistically significant across Distance, Field, and the interaction term Distance x Field. For clay, the term Field and the interaction term Field x Distance were statistically significant. The composition of clay differed between the two production fields and between years. At the Hibernia Platform (referred to as HIB in the plots), the percent composition of clay increased with increasing distance from the drill center. In the HSE field, percent clay exhibited a downward trend with increasing distance. Overall, the HSE field has higher percentages of clay than the Hibernia field.

Barium, WAM barium, and fuel range and lube range hydrocarbons were statistically significant ($p<0.001$) for all terms and the interaction term. Analyte concentrations decreased with increasing distance from the drill centers. In both production fields, barium decreased sharply from 250 m to 500 m. The main effect (Distance) is moderated by the interaction effect with each Field and how the interaction term influences the estimates of the sediment composition and analytes are summarized in Figure 4-36 to Figure 4-45.

Table 4-26: Statistical significance of the interaction and main terms in the combined Whole-Field analysis.

Analyte	Distance	Field	Field x Distance
Clay		***	**
Barium	***	***	***
WAM Barium	***	***	***
>C_{10}-C_{21} (Fuel range)	***	***	***
>C_{21}-C_{32} (Lube Range)	***	***	*
Total Carbon		***	***
Total Organic Carbon	***	***	***

Notes:
* and red indicates p<0.05
** and red indicates p<0.01
*** and red indicates p<0.001
"." and black 0.05<p<0.1
Blank indicates no significance.

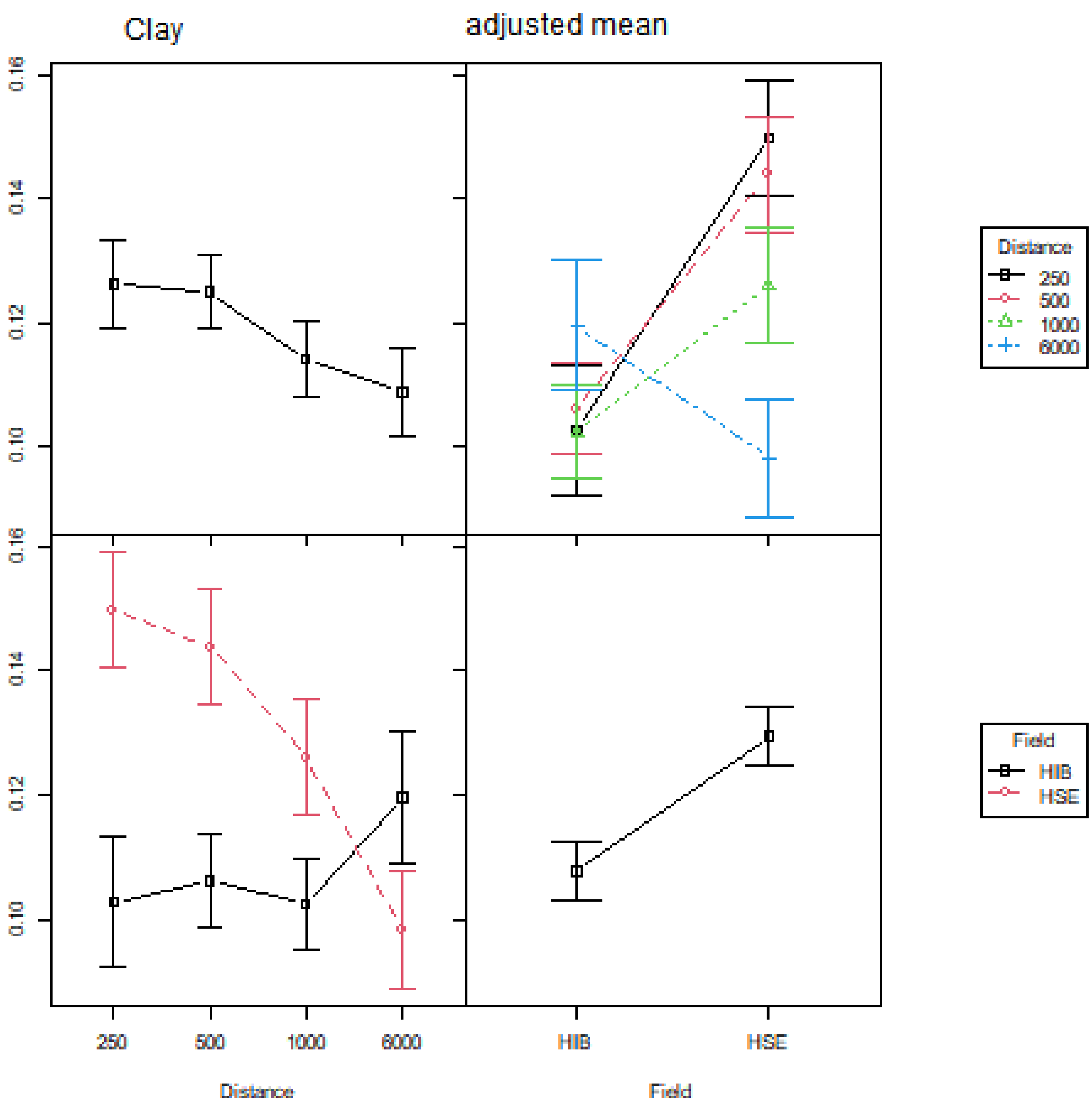


Figure 4-36: Adjusted means factorial comparison for the sediment type clay at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

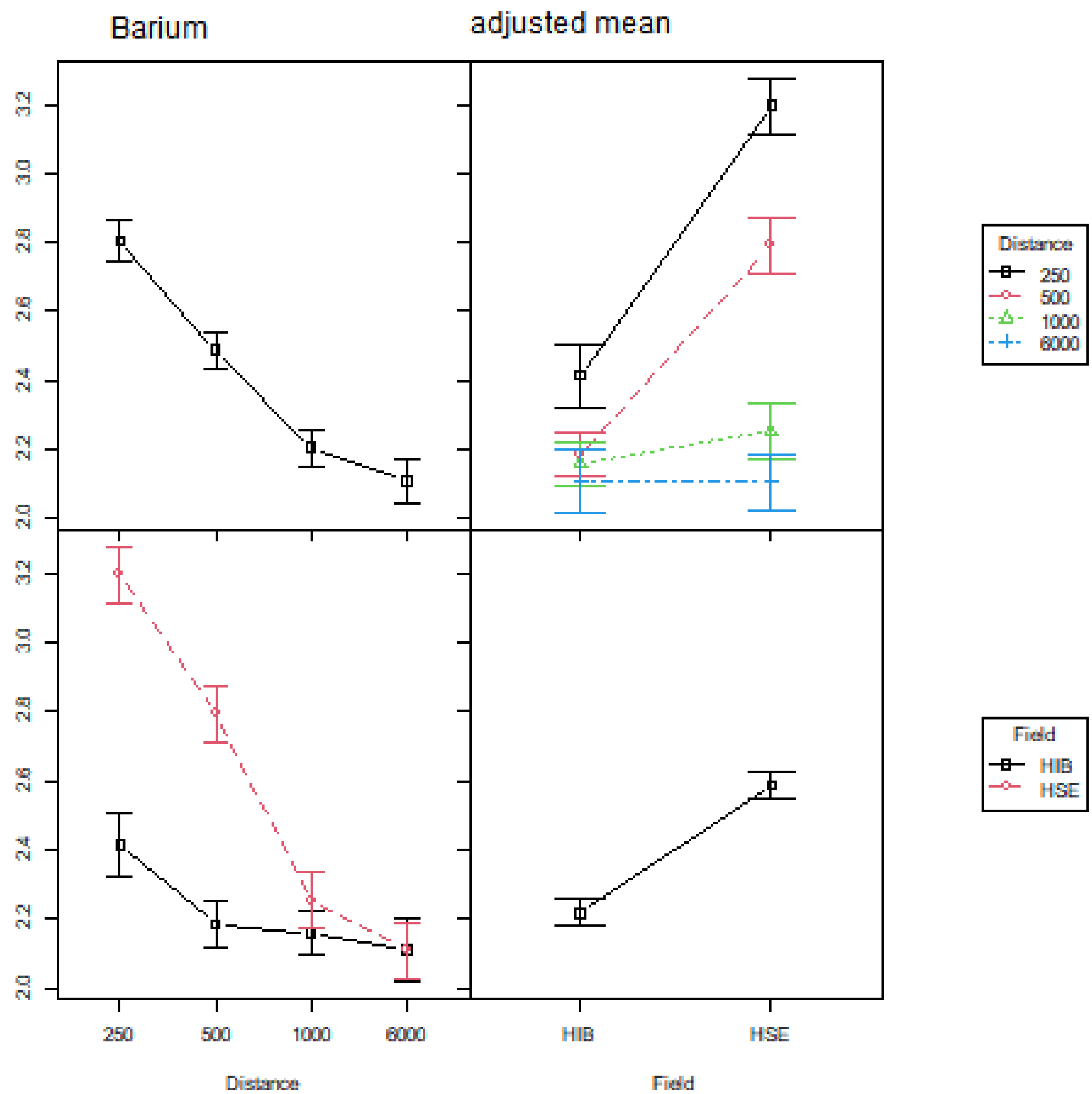


Figure 4-37: Adjusted means factorial comparison for the sediment type barium at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

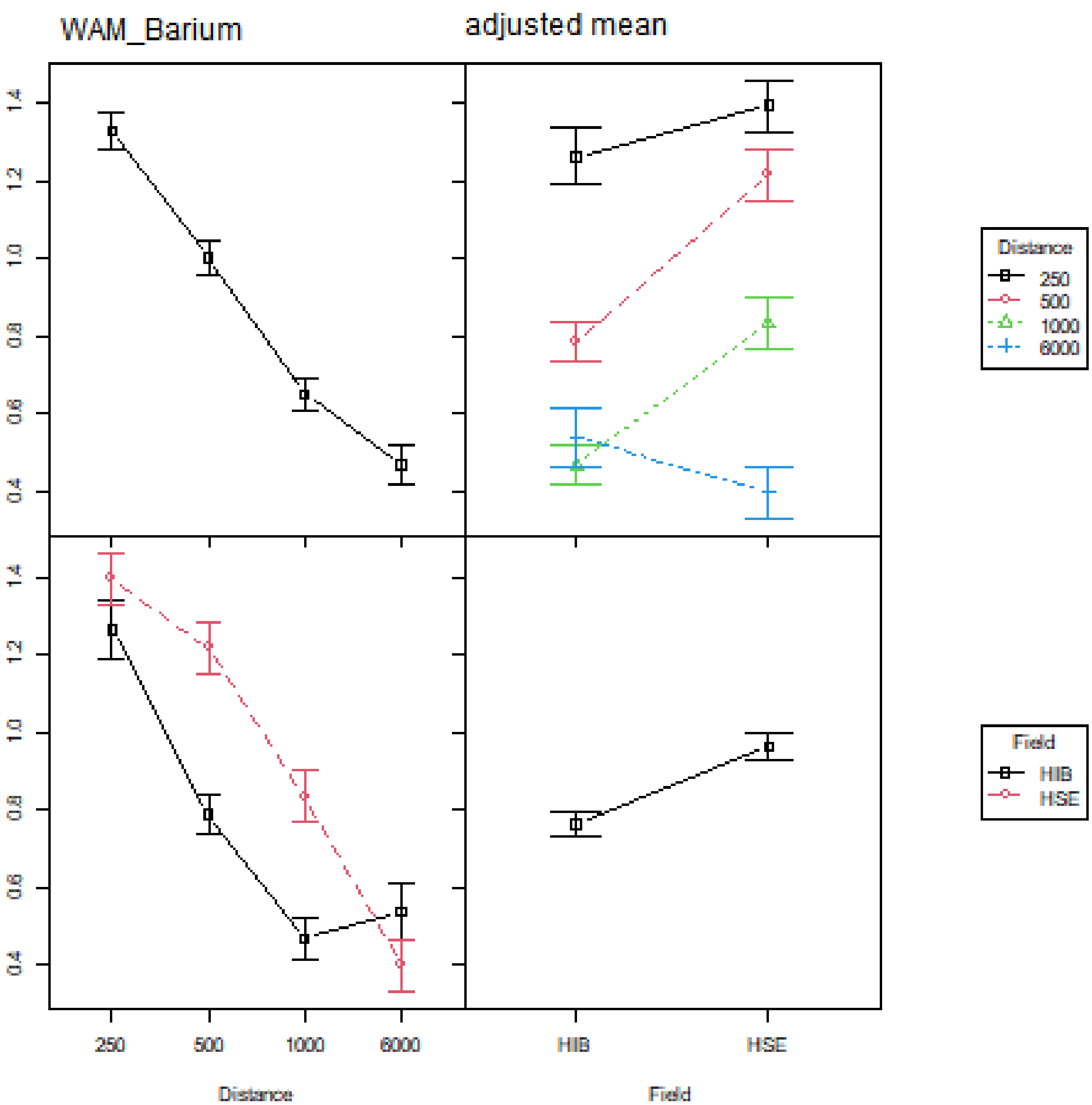


Figure 4-38: Adjusted means factorial comparison for the sediment type WAM barium at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

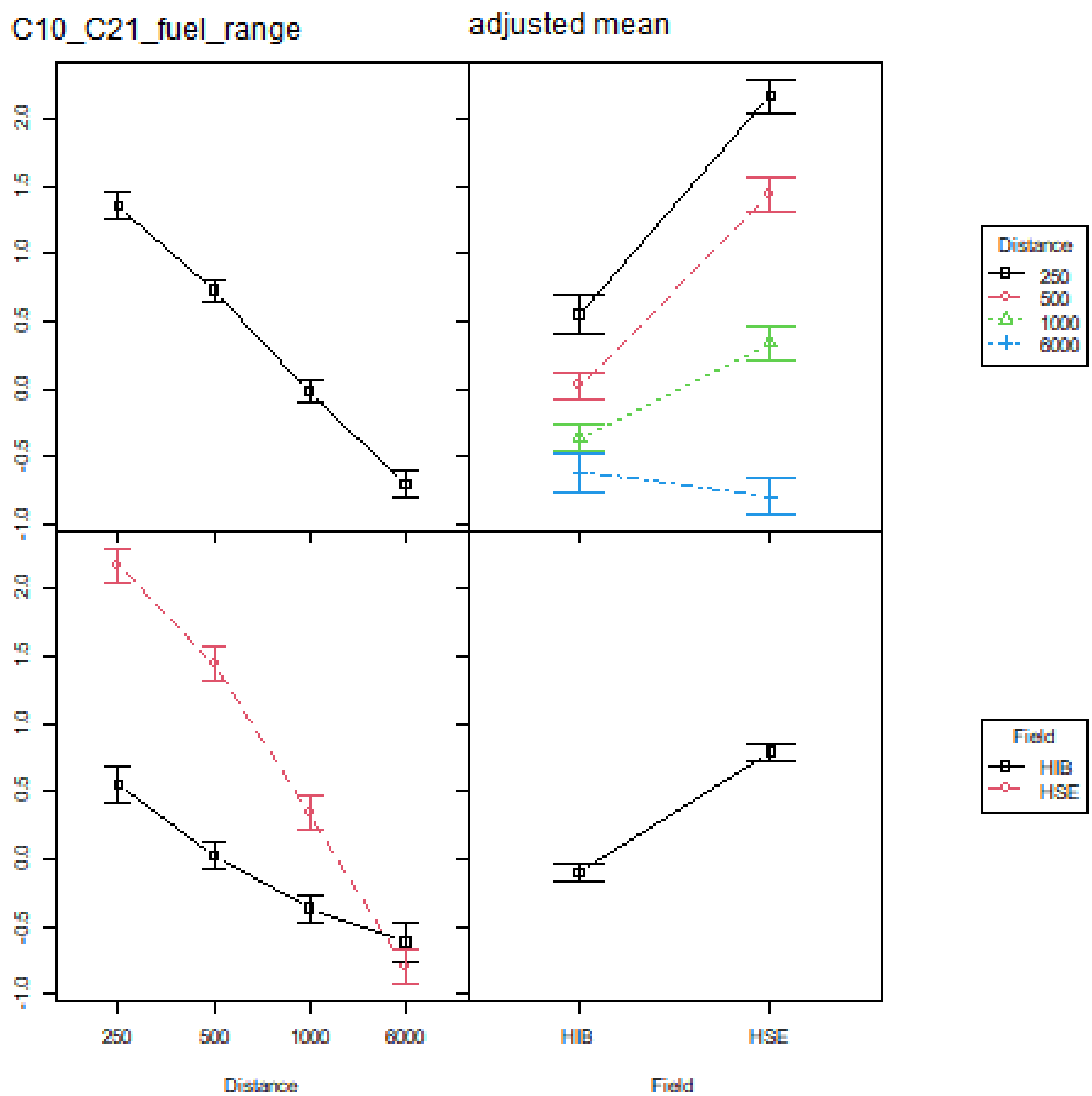


Figure 4-39: Adjusted means factorial comparison for the fuel range hydrocarbons (>C_{10}-C_{21}) at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

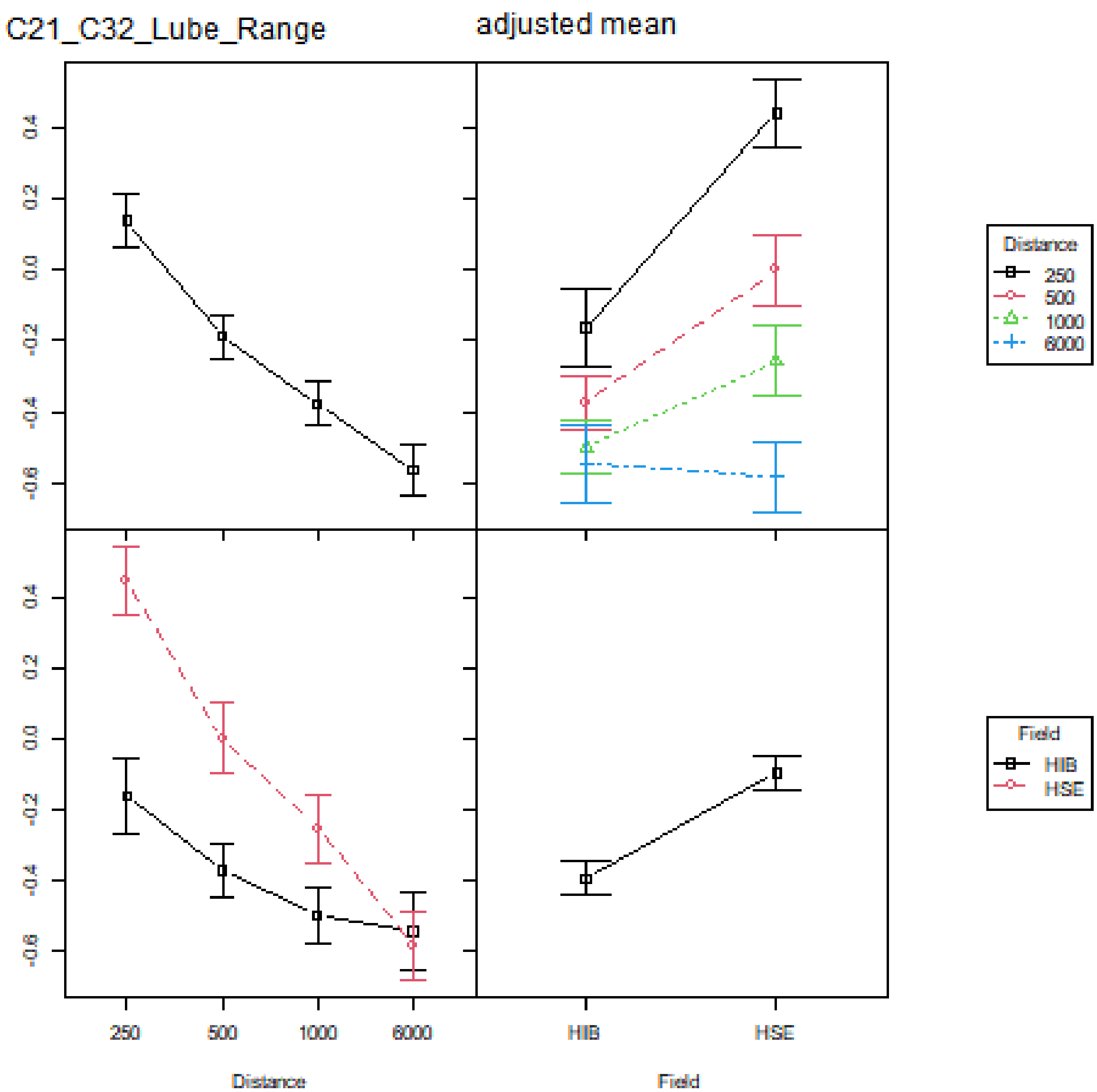


Figure 4-40: Adjusted means factorial comparison for the fuel range hydrocarbons (>C_{21}-C_{32}) at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

Combined Near-Field Analysis

In the combined Near-Field analysis, for all analytes screened-in, the term Field was statistically significant (Table 4-27). Combined Near-Field analysis results are graphically depicted in Figure 4-41 to Figure 4-45. Clay concentrations are higher in the HSE production field than the Hibernia field. In both fields, concentrations of clay decrease with increasing distance from the source. The three-way interaction term was only statistically significant for barium and $>C_{10}$-C_{21} hydrocarbons. From the least-squares mean analysis, a difference in the proportion of barium between the two production fields begins in 2014. However, there was no statistical difference between the distances at the two production fields in this year. Barium concentrations reported at 250 m and 500 m from the HSE begin to increase with the highest concentrations reported in 2018 (Figure 4-42). There were statistically significant ($p<0.001$) differences between the pairwise contrasts of 250 m and 500 m with stations 1,000 m between both production fields. The 2020 EEM shows a downward trend in analyte concentrations in HSE sediments and moving towards levels similar to analyte concentrations in Hibernia Platform sediments.

As with barium, $>C_{10}$-C_{21} hydrocarbons concentrations differed between the two production fields beginning in 2014 and peaked within 500 m from the HSE in 2018 (Figure 4-43). The 2020 EEM marks a downward trend in concentrations within 500 m from the HSE. Only stations 250 m from the source were statistically different from stations 1,000 m away when comparing both production fields. Similarly, $>C_{21}$-C_{32} hydrocarbons concentrations at the HSE peaked in 2018 (Figure 4-44) and the pairwise contrasts between 250 m and 1,000 m were statistically different between production fields. In 2020, none of the pairwise contrasts were statistically significant ($p<0.05$).

WAM barium concentrations decreased with increasing distance from the source (Figure 4-45). Between production fields, HSE has higher concentrations of WAM barium however, at both production fields there was a downward trend between 2018 concentrations and those reported in the 2020 EEM. Total carbon was the only analyte with just one statistically significant term (Field). The HSE production field sediment samples had higher concentrations of total carbon than the Hibernia production field (Figure 4-46). TOC concentrations differed between Distance, Field, and Years. TOC concentrations decreased with increasing distance from the source. Concentrations at both the HSE and Hibernia Platform were on an upward trend since 2018 at Hibernia and 2016 at the HSE. Most analytes at the HSE were higher at 250 m from the drill center and decreased with distance including barium, fuel range and lube range hydrocarbons, and WAM barium. The higher analyte concentrations at stations within 250 m of the HSE between 2016 and 2018 is likely due to the greater daily discharge rate than that observed in 2011 and 2014.

Table 4-27: Statistical significance of the interaction and main terms in the combined Near-Field analysis.

Analyte	Distance	Field	Year	Distance x Field	Distance x Year	Field x Year	Distance x Field x Year
Clay		***	***			**	
Barium	***	***	***	***	**	***	***
WAM Barium	***	***	***	***	***	***	.
>C_{10}-C_{21} (Fuel range)	***	***	***	**	**	***	*
>C_{21}-C_{32} (Lube Range)	***	***	***	*	**	***	.
Total Carbon		***					
Total Organic Carbon	***	***	***			***	

Notes:
* and red indicates $p<0.05$
** and red indicates $p<0.01$
*** and red indicates $p<0.001$
"." and black $0.05<p<0.1$
Blank indicates no significance.

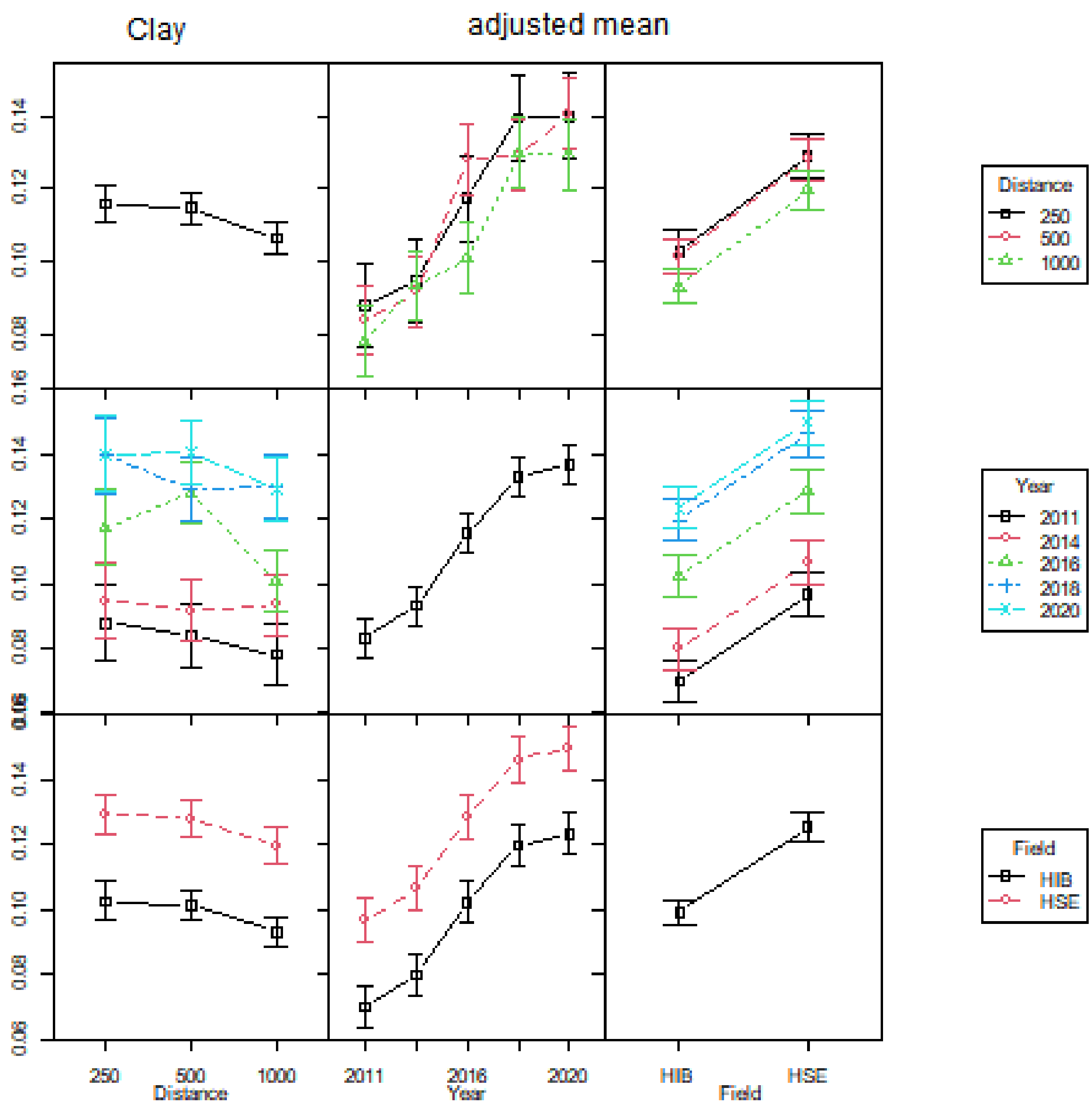


Figure 4-41: Adjusted means factorial comparison for the sediment type clay at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

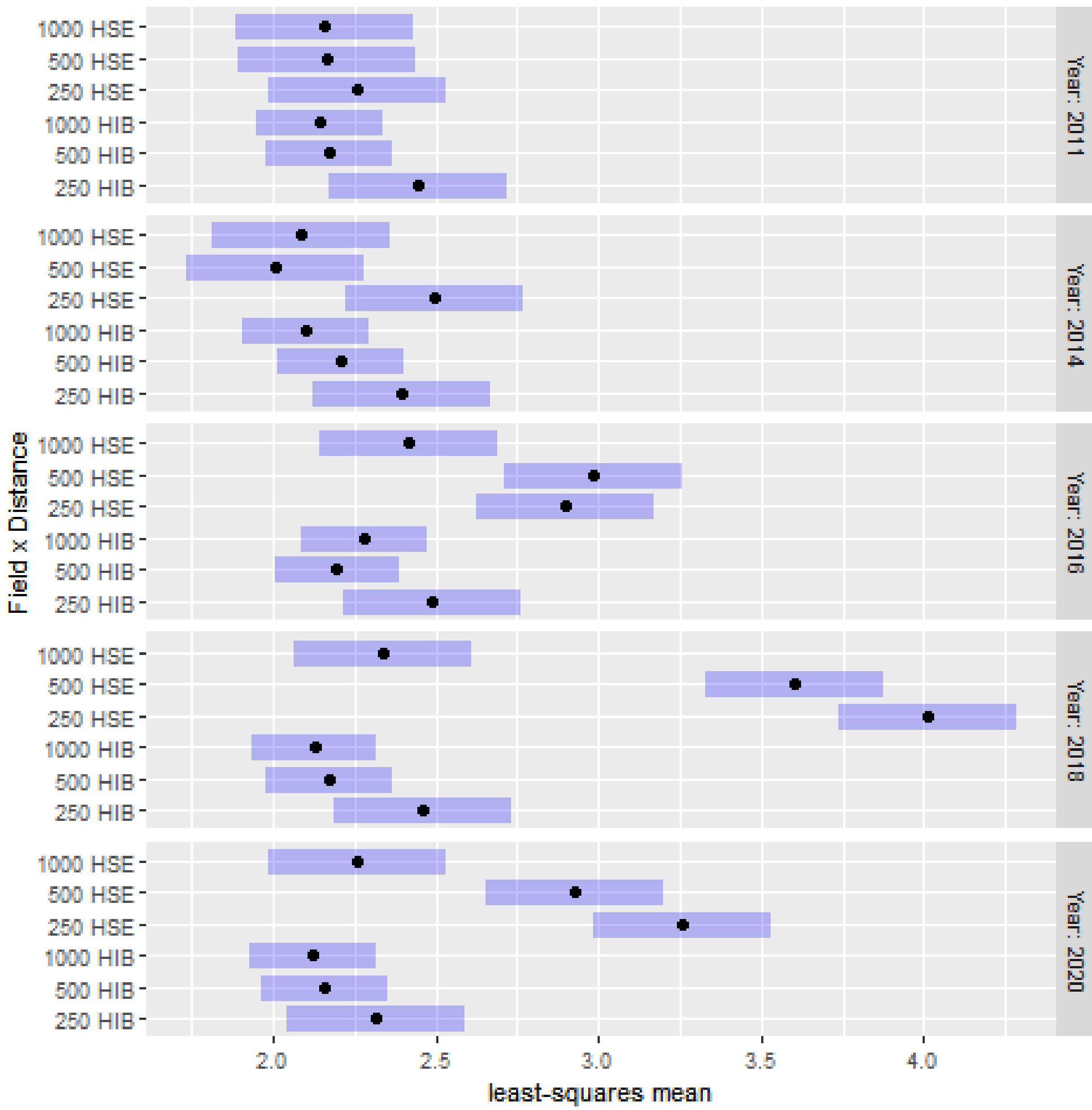


Figure 4-42: Least squares mean concentrations of barium. For visualization, the linear regression was conditioned on Year. The two-way interaction between production Field and station Distance is on the y-axis with the first number indicating the Distance and the second the Field. Means of barium percentages are on an arcsine scale and 95% confidence intervals are shown.

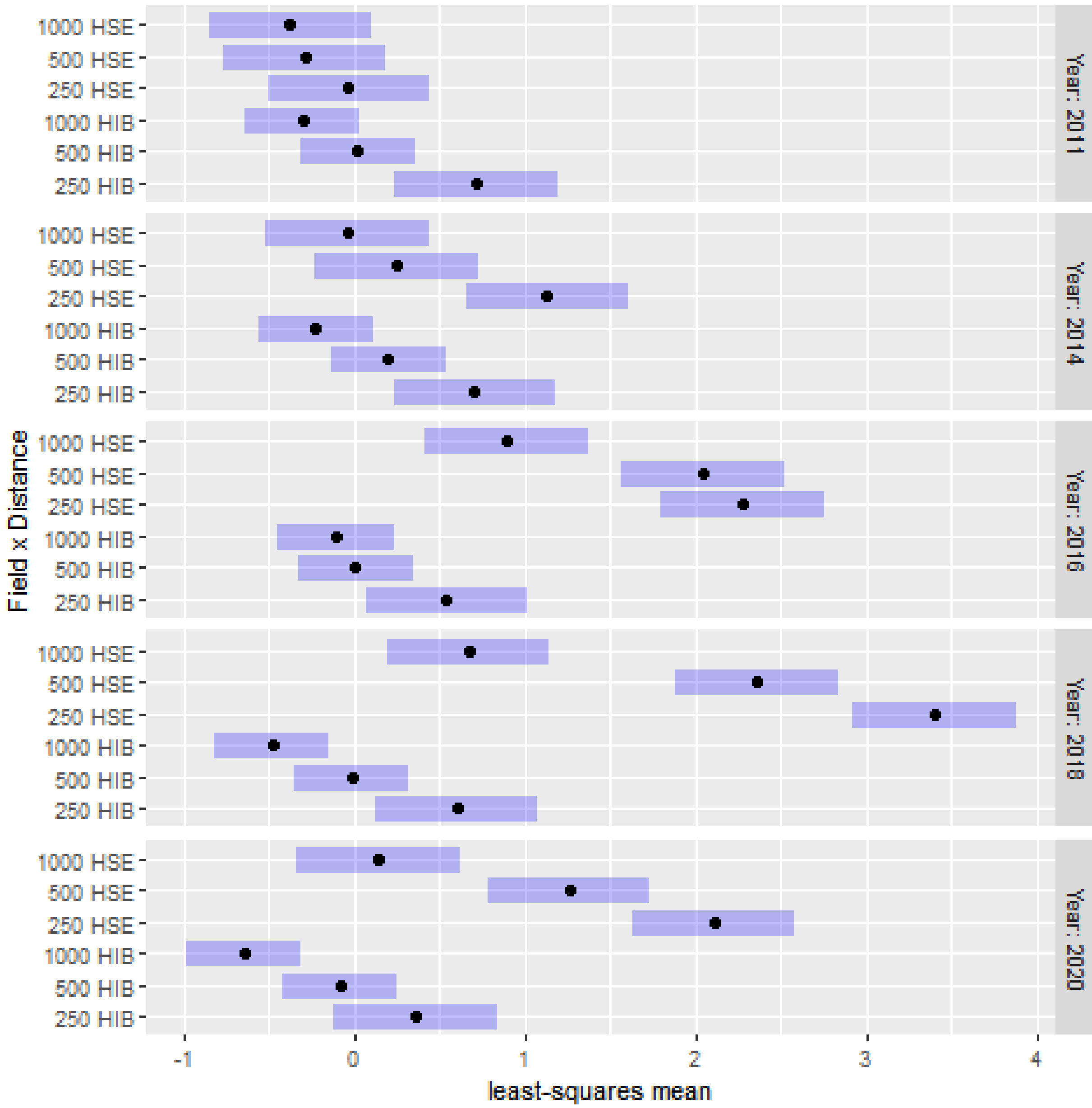


Figure 4-43: Least squares mean concentrations of fuel range hydrocarbons (>C_{10}-C_{21}). For visualization the linear regression was conditioned on Year. The two-way interaction between production Field and station Distance is on the y-axis with the first number indicating the Distance and the second the Field. Means of fuel range hydrocarbons (>C_{10}-C_{21}) percentages are on an arcsine scale and 95% confidence intervals are shown.

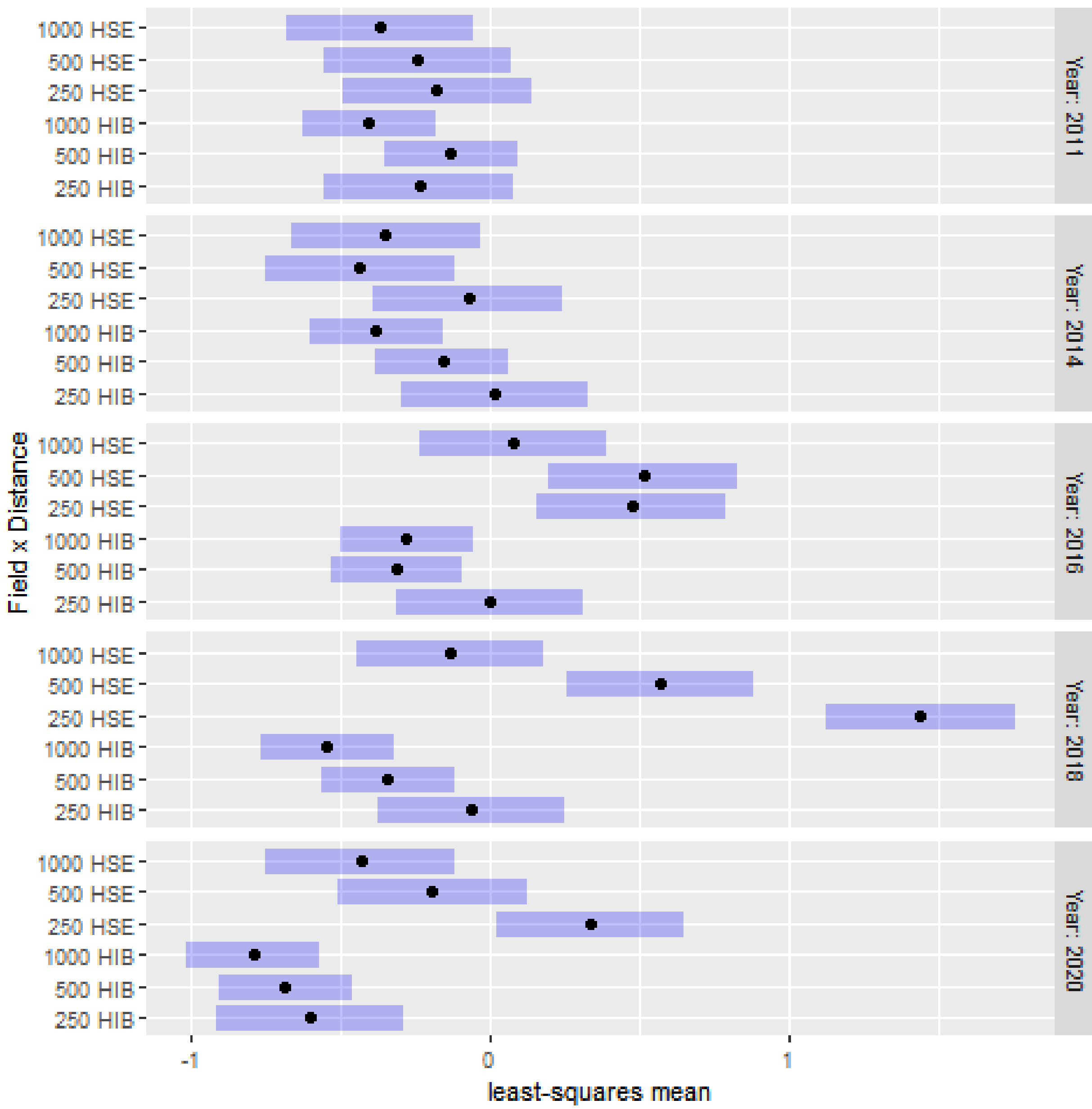


Figure 4-44: Least squares mean concentrations of lube range hydrocarbons (C_{21}-C_{32}). For visualization the linear regression was conditioned on Year. The two-way interaction between production Field and station Distance is on the y-axis with the first number indicating the Distance and the second the Field. Means of fuel range hydrocarbons (C_{21}-C_{23}) percentages are on an arcsine scale and 95% confidence intervals are shown.

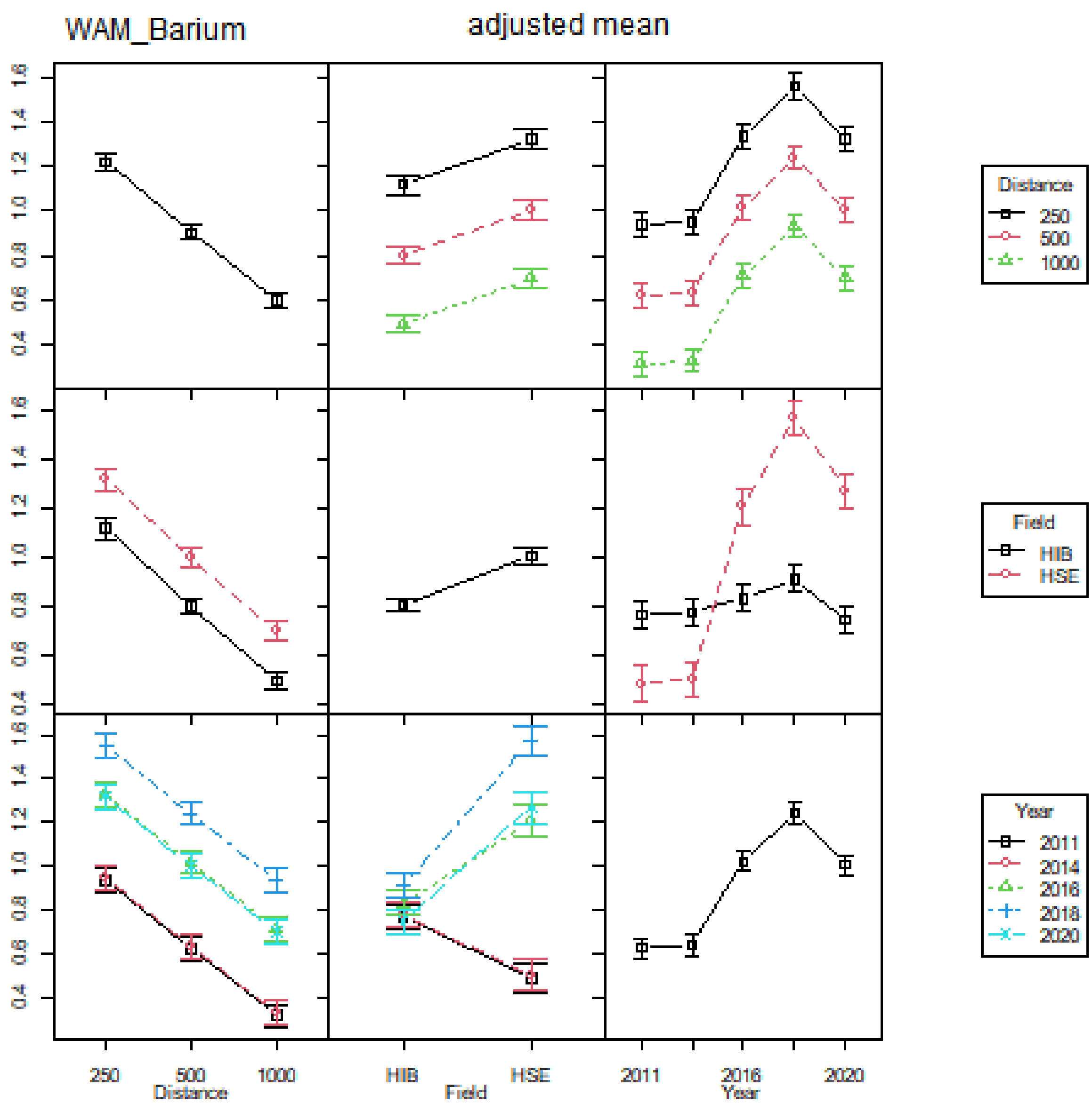


Figure 4-45: Adjusted means factorial comparison for WAM barium at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

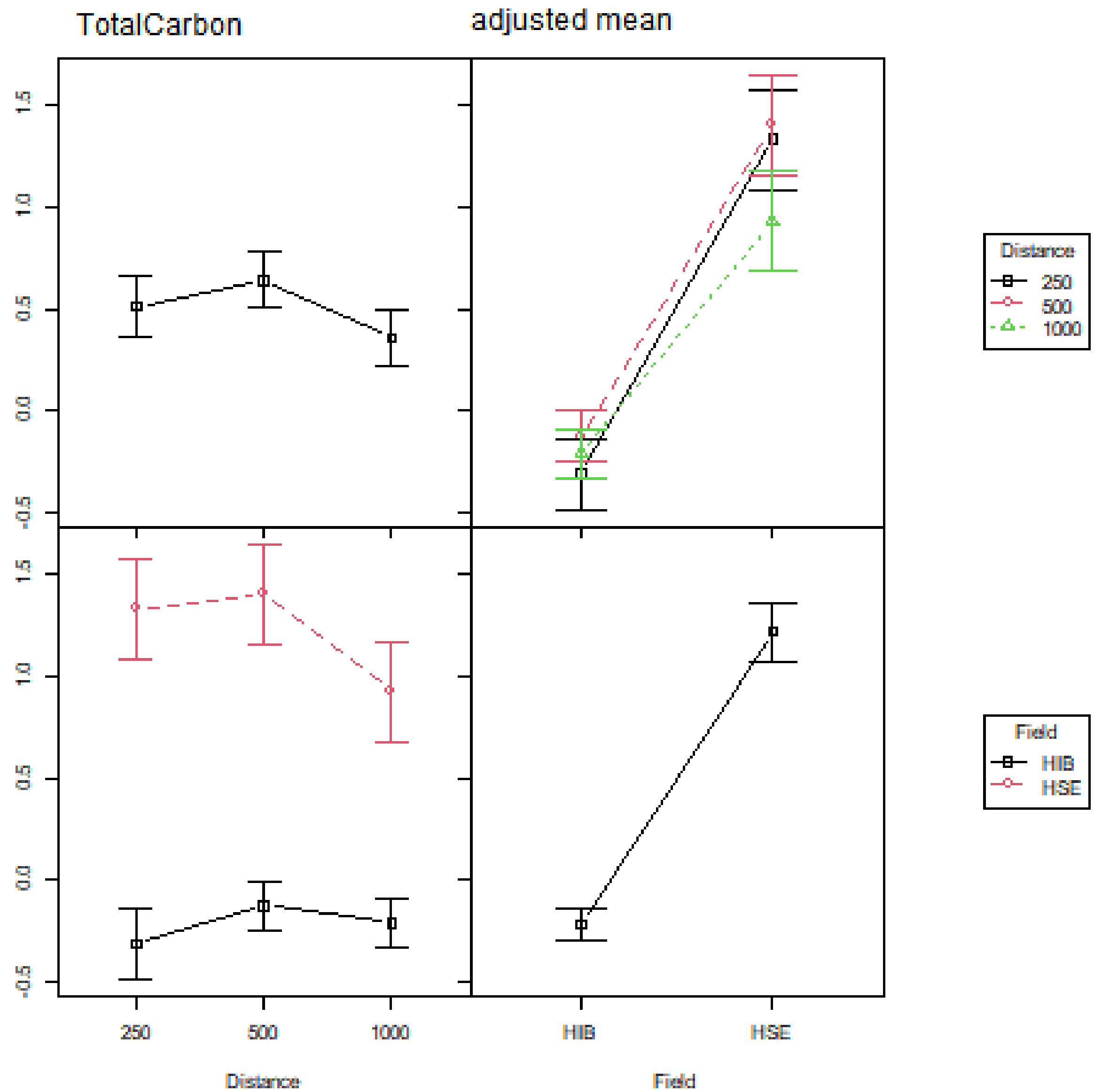


Figure 4-46: Adjusted means factorial comparison for total carbon at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

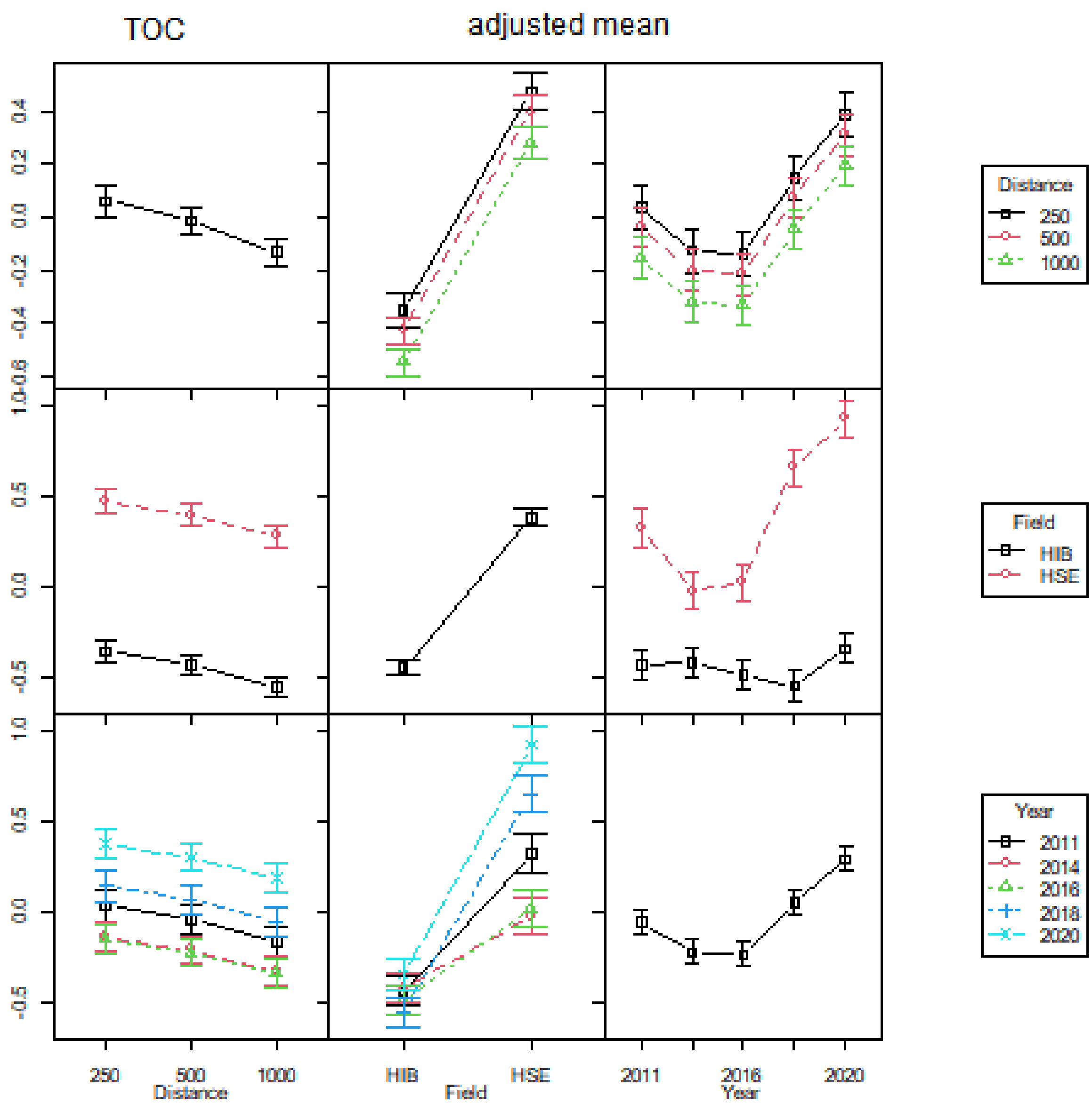


Figure 4-47: Adjusted means factorial comparison for TOC at Hibernia Platform (HIB) and HSE. The main effects are shown on the diagonal and the interactions are represented by different colours. The y-axis shows the sediment type percentage on an arcsine transformed scale. Confidence intervals shown are 95%.

4.2.5 Sediment Toxicity Component

The Hibernia EEM sediment toxicity component consisted of two bioassays which used sub-lethal and lethal methods (amphipod mortality, and juvenile polychaete growth and biomass) according to ECCC guidelines (EC 1992, 1998, 2001, HMDC 2019a). In 2020, the Petrotox threshold method (≥150 mg/kg >C_{10}-C_{21}) was used to screen-in sediment samples for toxicity testing. All stations around the Hibernia Platform were below the Petrotox threshold. Two HSE stations were screened-in for toxicity testing. The reference stations (1-16000 a, b and 7-16000 a, b) were obligatorily assessed for toxicity (all were below Petrotox levels). Results from the bioassays are presented in Table 4-28. All the samples tested for amphipod survival at the HSE were collected within 250-m of the EDC (Table 4-28).

Of the six sediment samples assessed for toxicity, only station S-250 was deemed to be toxic in both bioassays based on a 20% reduction compared to reference stations (1, 7-16000 a, b). Amphipod and polychaete survival in station S-250 sediments was 50% and 80% respectively. Reduced amphipod and polychaete survivability is likely due to elevated metals and fuel range hydrocarbons (>C_{10}-C_{21}) in sediments collected at S-250. This is the second instance of S-250 sediments being deemed toxic. At this station in 2018, amphipod survival was 13% (Figure 4-48) and polychaete survival was 96% (Figure 4-49). E-250 was also screened-in for toxicity testing but was deemed non-toxic in both assays (80% and 100% survival respectively). This station was previously deemed toxic in 2016 and 2018 from amphipod bioassay (42% and 26%, respectively). Results at both stations show improvements in amphipod survival from previous EEMs (HMDC 2019b, 2021c). Polychaete survivability is similar to the previous EEM year as survivability in 2020 ranged between 80 to 100% and in 2018 ranged between 84 to 100% (HMDC 2021c).

Table 4-28: HSE and Reference Station sediment toxicity test summary.

Station ID	Petrotox (>C_{10}-C_{21} mg/kg)	Amphipod Survival (%)	Polychaete Survival (%)	Individual Growth Rate (mg/worm/day) Mean ± SD	Total Dry Weight Mean ± SD
E-250	**420**	80	100	0.56 ± 0.26	61.40 ± 26.30
S-250	**2,890**	**50**	**80**	0.33 ± 0.05	30.83 ± 11.98
1-16000a	<0.25	98	100	0.80 ± 0.13	85.25 ± 13.45
1-16000b	<0.25	96	100	0.78 ± 0.08	83.58 ± 8.21
7-16000a	<0.25	95	100	0.92 ± 0.10	96.60 ± 10.17
7-16000b	<0.25	95	100	0.71 ± 0.24	75.70 ± 23.81
Control Sediment*	-	99	100	0.61 ± 0.27	66.06 ± 26.55

Notes:
Toxic responses are in bold.
The Petrotox threshold is 150 mg/kg.
* Control Sediment was used as the control for the statistical analyses of Hibernia reference stations (1-, 7-16000 a, b)

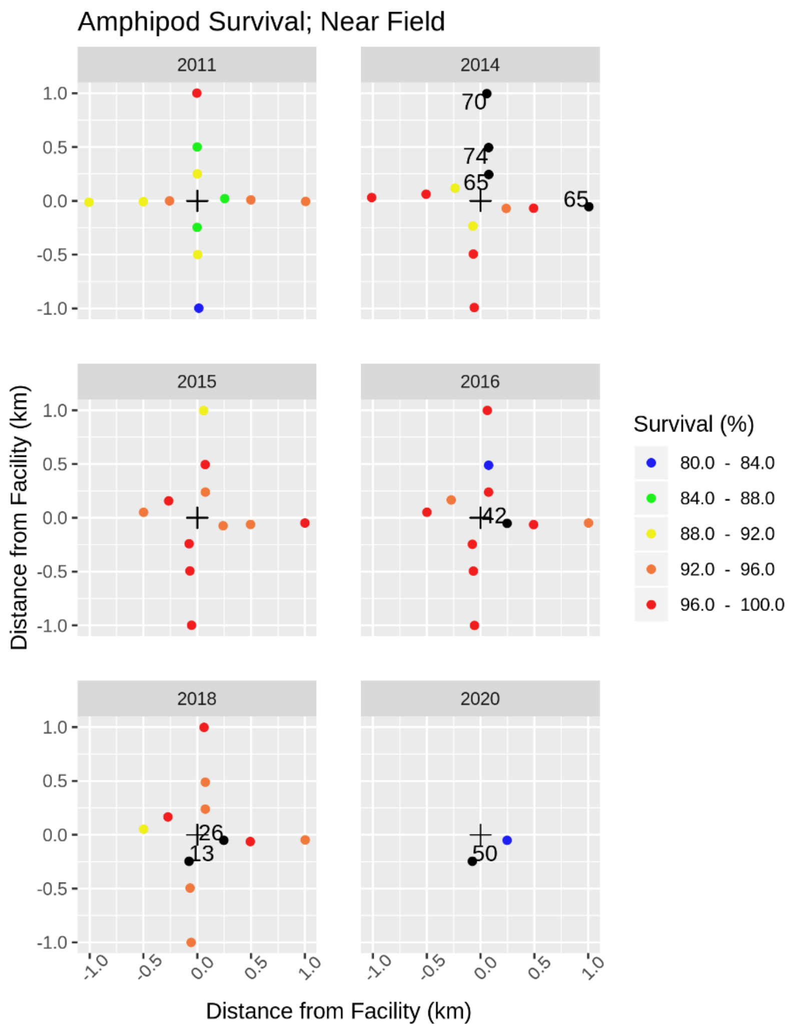


Figure 4-48: Two dimensional spatial and temporal pattern of amphipod survival (%) in HSE (+) sediment samples within 1,000 m of the of the EDC for Baseline (2011), and EEM programs (2014 through 2020).

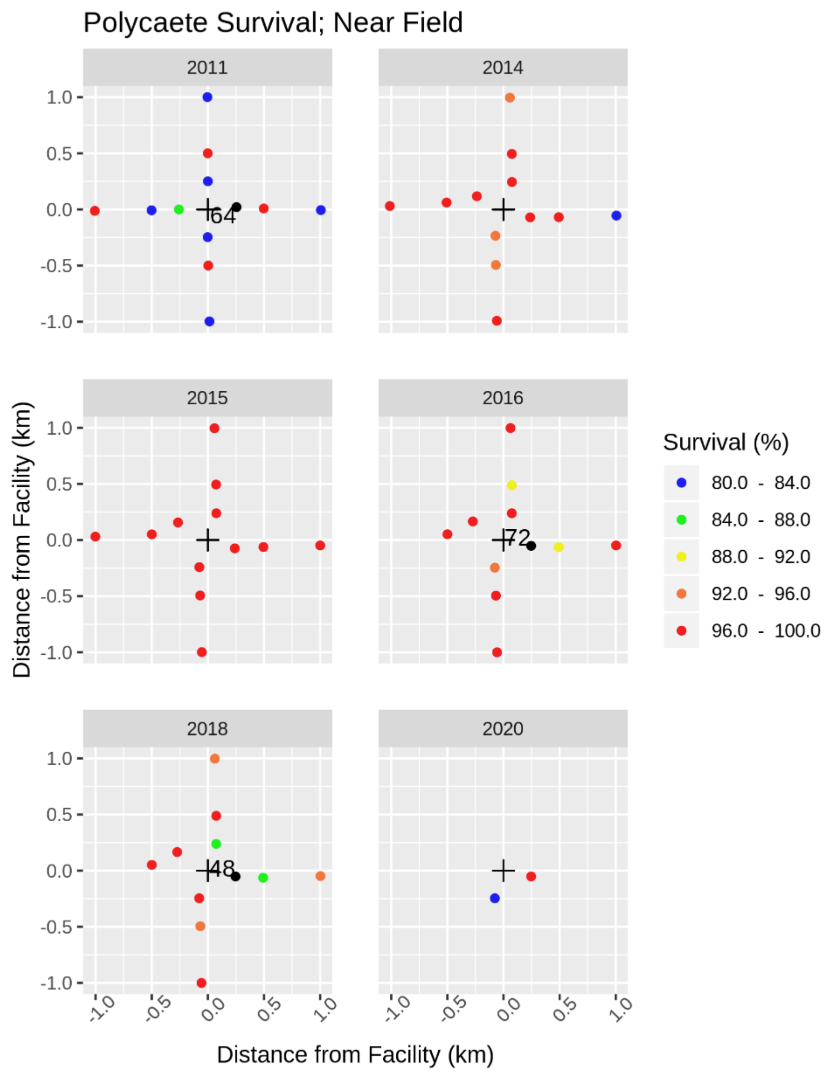


Figure 4-49: Two dimensional spatial and temporal pattern of juvenile polychaete survival (%) in HSE (+) sediment samples within 1 km of the of the EDC for Baseline (2011), and EEM programs (2014 through 2020).

4.2.5.1 Statistical Analyses of HSE Toxicity Results

Statistical analysis of amphipod survival found there was not a significant Year x Field interaction in either the Whole- or Near-Field analyses (p= 0.345 and p=0.257, respectively) (Table 4-29). This indicates there is not a project induced change in the area as a whole.

However, in both the Whole- and Near-Field analyses, amphipod survival varied by Field/Distance (p<0.001). Two stations within 250 m of the EDC have been deemed toxic in the past two EEM monitoring years including the current study (E-250 and S-250) (HMDC 2019b, 2021c). The median survival rates for 2020, while only depicting two stations, are higher than the 2018 median survival (Figure 4-50).

Statistical analysis of juvenile polychaete survival found the interaction term Year x Field was not statistically significant in either the Whole- or Near-Field analyses (Table 4-30) and does not indicate a Project-related change in the area.

However, in both analyses the terms Year and Field/Distance were statistically significant ($p<0.05$). The polychaete survival rates in the Near-Field are higher than those reported at baseline (Figure 4-50). Percent polychaete survival reported at station E-250 has increased in 2020 (100% survivability reported in 2020) from levels reported in 2016 (72%) and 2018 (48%).

Table 4-29: Whole-and Near-Field ANOVA table for amphipod survival (arcsine transformed) in HSE sediment.

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2011-2020)					
Year	5	0.257	0.051	1.271	0.286
Field	1	0.579	0.579	14.350	**<0.001**
Year x Field	5	0.231	0.046	1.144	0.345
Residuals	74	2.988	0.040		
Near-Field (2011-2020)					
Year	5	0.257	0.051	1.432	0.226
Distance	4	0.936	0.234	6.526	**<0.001**
Year x Distance	15	0.676	0.045	1.257	0.257
Residuals	61	2.187	0.036		
Notes: Bold p-value denotes a significant result (p<0.05)					

Table 4-30: Whole-and Near-Field ANOVA table for juvenile polychaete survival (log_{10} transformed) in 2020 HSE sediment.

Source	Degrees of freedom	Sum of Squares	Mean Square	F-value	p-value
Whole-Field (2011-2020)					
Year	5	0.754	0.151	4.885	**<0.001**
Field	1	0.139	0.139	4.507	**0.037**
Year x Field	5	0.314	0.063	2.031	0.082
Residuals	85	2.624	0.031		
Near-Field (2011-2020)					
Year	5	0.754	0.151	5.502	**<0.001**
Distance	4	0.576	0.144	5.257	**<0.001**
Year x Distance	16	0.555	0.035	1.265	0.244
Residuals	71	1.946	0.027		
Notes: Bold p-value denotes a significant result (p<0.05)					

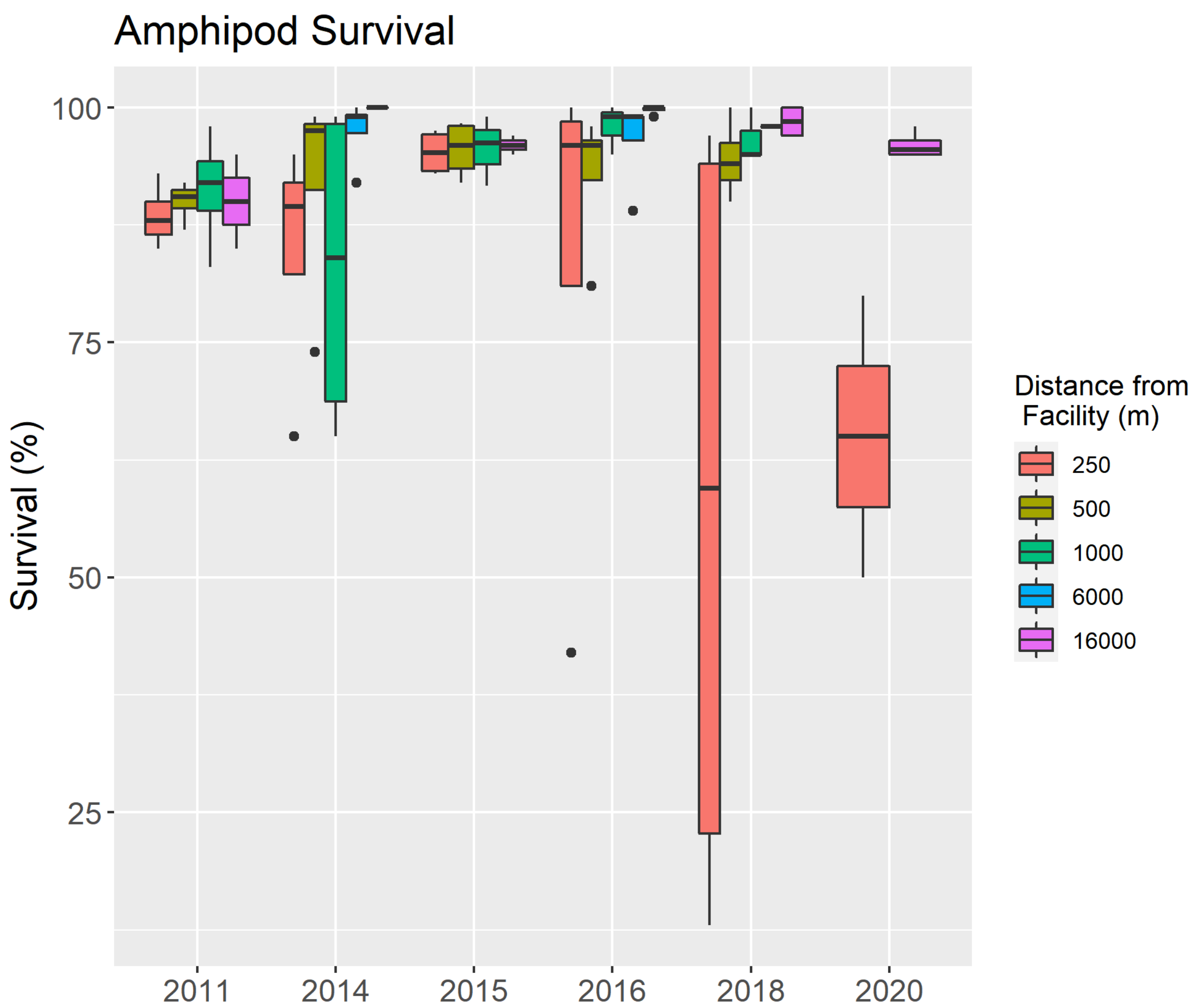


Figure 4-50: Boxplots of amphipod survival (%) in sediment by Distance and Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

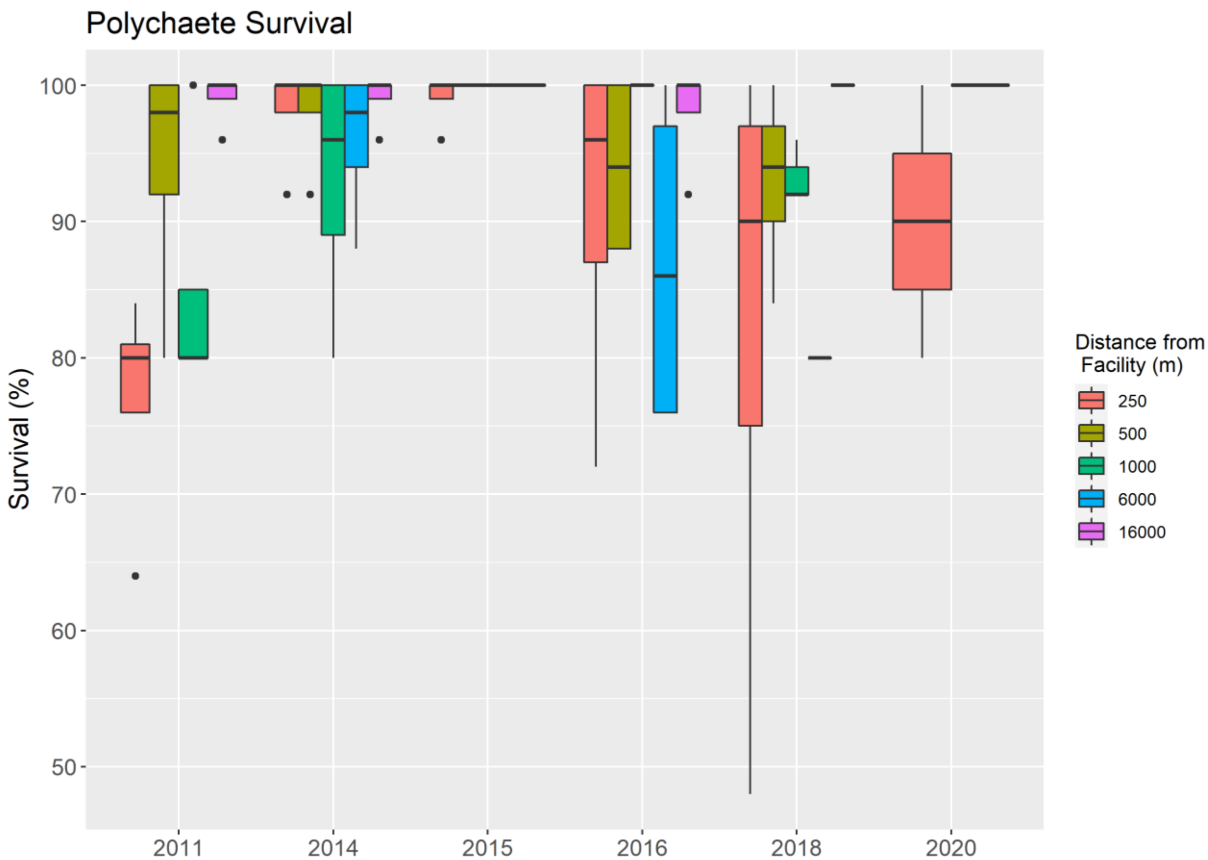


Figure 4-51: Boxplots of polychaete survival (%) in sediment samples by Distance for each EEM Year at the HSE. Horizontal lines represent median concentrations, boxes represent the middle quartiles and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual data points.

Multivariate Analysis of Sediment Toxicity Results

To understand spatial and temporal trends between toxicity and sediment chemistry results, multivariate analyses (PERMANOVA) were applied. No Hibernia sediment samples met the criteria to be screened-in for toxicity testing and only HSE stations underwent multivariate analysis. Analyses were conducted between samples using Euclidean distance. A non-parametric Multi-Dimensional (nMDS) plots the relative similarity distances between each sample and visualizes the spatial and temporal trends (Figure 4-52).

As observed in previous EEM monitoring years, most other stations from all years clustered near the reference stations (Figure 4-52). There are four stations from three years that were shifted away from the reference stations. Stations E-250 (years 2016 and 2018) and S-250 (years 2018 and 2020) are shifted away from the majority of the stations and each other. All four of these stations have reported at least one toxic response (from either bioassay). These southern stations were more closely associated with the fuel and lube range hydrocarbons, barium, and WAM barium. S-250 in 2020 reported a toxic response (or over the Petrotox threshold) in all three of the toxicity triad and had the highest reported concentrations of those analytes. However, the nMDS illustrates the noticeable improvement in amphipod survivability at station S-250 and E-250 in 2020 compared to results in previous EEM years. Additionally, station E-250 which reported toxic responses in amphipod survivability in 2016 and 2018, was not deemed toxic in 2020 and groups with the majority of stations that have been deemed non-toxic for the duration of the HSE EEM program.

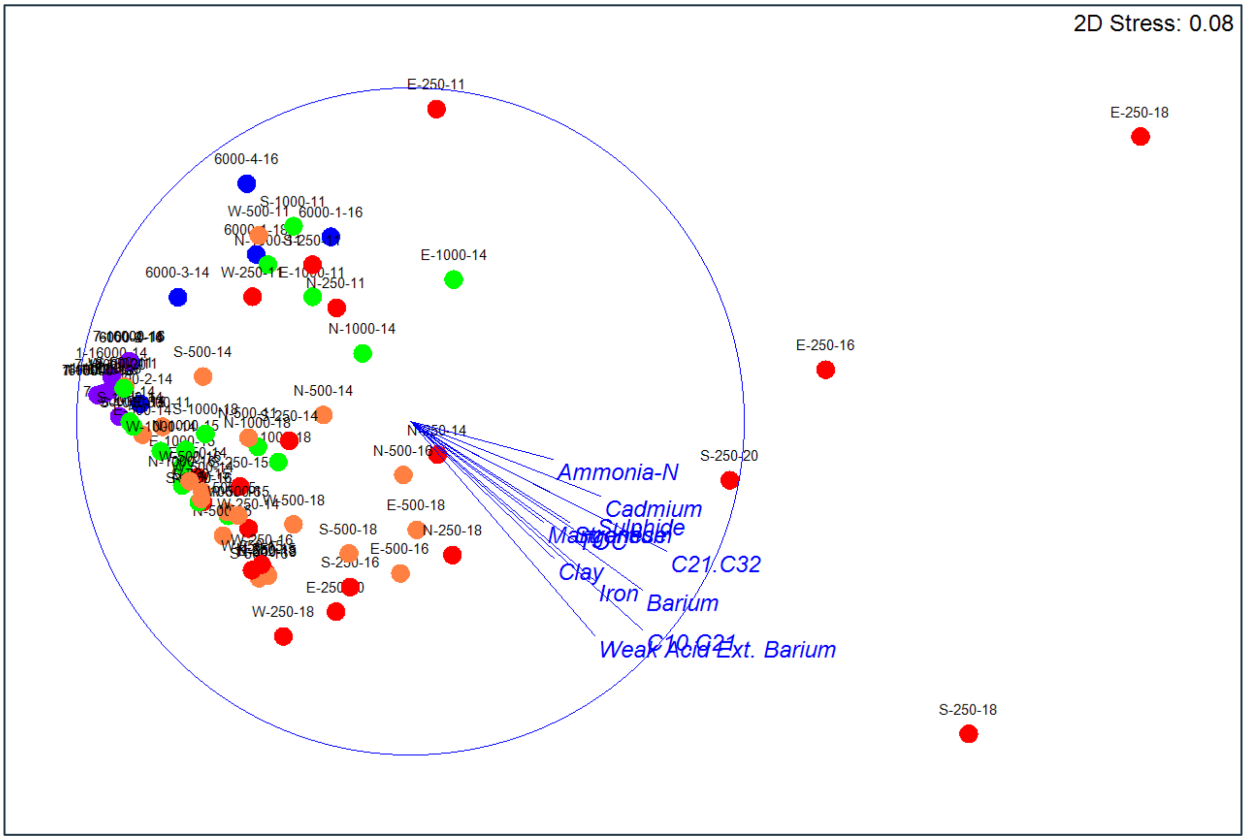


Figure 4-52: Two-dimensional nMDS plot of HSE toxicity data (Petrotox, amphipod, and juvenile polychaete survival) across sample distances and years with Pearson correlation overlay of sediment analytes. Each point is labelled by station and year. Colours denote distance: 250 m (red), 500 m (orange), 1,000 m (green), 6,000 m (blue), 16,000 m (purple).

4.3 Summary of Results

4.3.1 Summary of Physical and Chemical Characteristics

The dominant sediment type sampled at the Hibernia Platform and the HSE was sand. Following the screening-in criteria as described in HMDC (2019a), only clay was screened-in for further analysis at the HSE. At baseline (for the HSE), percent clay concentrations ranged between 0.32% and 1.42%. In 2020, percent clay concentrations ranged between 0.54% and 4% (S-250). Overall, there appears to be a downward trend in clay concentrations between most fields across years. While there are statistical differences between percent clay concentrations between years and fields, there is no indication of a Project-related effect.

4.3.2 Summary of Combined Hibernia Platform and HSE Sediment Chemistry

In the Hibernia production field, barium concentrations continue a downward trend from concentration highs reported in 1999 and 2002. While in previous EEM monitoring years the highest concentrations of barium occurred within 250 m of the Hibernia Platform (ranging between 450 mg/kg and 3,100 mg/kg), the highest concentration in 2020 was reported at 7-3000 (700 mg/kg). The decrease in barium concentrations between years and fields could be a Project-related effect and are likely from the re-injection of drilling muds. Concentrations of WAM barium in the Hibernia production field continue a downward trend from reported highs in 2007. Similarly, the downward trend of WAM barium concentrations was statistically significant. Fuel and lube range hydrocarbons reported concentrations have been on a downward trend at stations around the Hibernia Platform since 1999. This trend continues in the concentrations reported in 2020. The mean concentration for both fuel and lube range hydrocarbons are below the detection limit used during baseline. The downward trend of fuel and lube range hydrocarbons across years and fields/distances was statistically significant. The analyte total carbon was screened-in for Hibernia sediments for further analysis. Concentrations of total carbon were first reported in 2000 with relatively higher concentrations reported in the Far-Field towards the west. There was no statistical difference between years or distances of total carbon concentrations. There was a statistical difference between fields with median total carbon concentrations increasing in the Far-Field in 2020 from 2018 levels.

In the HSE production field, concentrations of barium have trended downward from 2018 levels (excluding S-250). Station S-250 had the highest reported concentrations of both barium and WAM barium. Barium and WAM barium concentrations were on an upward trend since 2014 with peak concentrations reported in 2018. However, concentrations reported in 2020 mark a downward trend from levels observed in 2018. These decreases were statistically significant, and differences were noted between years across all fields and distances. Fuel range hydrocarbon concentrations are on a downward trend from levels reported in 2018. Notably station E-250 has decreased by thousands of mg/kg. While station S-250 had the highest reported concentrations of both fuel and lube range hydrocarbons in 2018, concentrations have decreased by thousands of mg/kg from levels reported at this station since then. Additionally, the lube range concentration of four stations within 500 m from the EDC have returned to at or below baseline levels. As observed at Hibernia, the downward trend of fuel and lube range hydrocarbons across years and fields/distances at the HSE was statistically significant. For HSE sediments, the analyte TOC was screened-in for further analysis. TOC concentrations to the north, east, and south of the HSE had relatively higher concentrations of TOC (at all distances). There was a statistically significant difference between TOC concentrations between years. Median concentrations within 500 m have been on an upward trend since 2015 and should continue to be monitored.

4.3.3 Summary of Sediment Toxicity

Two HSE stations were above the Petrotox threshold in 2020, of which only one was deemed toxic from amphipod and polychaete survival assays (S-250). Reduced amphipod and polychaete survivability is likely due to elevated metals and fuel range hydrocarbons (>C_{10}-C_{21}) in sediments collected at S-250. While S-250 was deemed toxic in amphipod bioassays, reported survivability has improved from previous EEMs (2016 and 2018). There was no evidence for a significant Project-related effect for either of the bioassays at either the Whole- or Near-Field analyses. While there are changes in the sediment chemical analyte levels at these stations within 250 m, there was not a Project-related effect for the area. Overall, sediment toxicity responses around the HSE are non-toxic with the exception of S-250.

5.0 WATER QUALITY

The produced water monitoring program is intended to determine estimates of dispersion of produced water discharged from the Hibernia Platform into the surrounding water column and provide an indication of a potential zone of effects from the chemistry and toxicity data for the produced water stream (HMDC 2019a). Water samples were collected following the completion of the sediment portion of the program to accommodate the shorter hold times for these samples (7-day maximum).

5.1 Methods

5.1.1 Field Collection

Water quality sampling was conducted on September 30, 2020 aboard the supply vessel Avalon Sea. Water samples were collected at fixed stations along three radials that were located from 50 and 150 m from the produced water outfall and two reference stations 16,000 m away (Figure 5-1). Based on an EEM Program risk assessment conducted in 2019, no “real-time” stations were sampled in 2020, instead fixed stations were set at 50 m and 150 m from the discharge point on the platform (Figure 5-1). Due to proximity to the lifeboat stations aboard the platform, two 50 m sampling station (50-1 and 50-2) locations were relocated to remain 50 m from infrastructure (Figure 5-1). Therefore, 50-3 is the closest station to the produced water discharge point. Two reference stations located 16,000 m north and west from the Hibernia Platform were also sampled (same locations as the sediment reference stations).

Weather conditions during water sampling were generally good with winds ranging from 17-20 kts and wave height approximately 1.4-1.9 m. Marine weather forecasts indicated direction of primary surface swells were north northwest. Mean current speeds measured with an ADCP at Hibernia in September 2020 ranged from 11 cm/s near-bottom to 24 cm/s near-surface (HMDC 2020).

Water was collected using 10 L Niskin bottles (Figure 5-2) at three depths; 1) top – approximately 5 m below the surface, 2) middle – below the mixed layer at ~35 m, and 3) bottom – 10 m above the sea floor. The middle Niskin depth was determined with a Sea-bird Conductivity, Temperature, Depth (CTD) profiler (Figure 5-2) by comparing the water column at the nearest sampling station to the produced water outfall (50-1) to a reference station. Data was collected on pH, temperature, conductivity, salinity, and dissolved oxygen through the water column. CTD profiles were uploaded to a field laptop, plotted, and viewed for changes to temperature, conductivity, dissolved oxygen, and salinity. Upon retrieval of the Niskin bottles, water was decanted into appropriate laboratory provided sample containers and stored at 4°C. Field duplicates were collected at 50-1 (mid depth), 150-1 (bottom), and 1-16000 (bottom). Water sampling raw data and QA/QC procedures are presented in Volume II of this report.

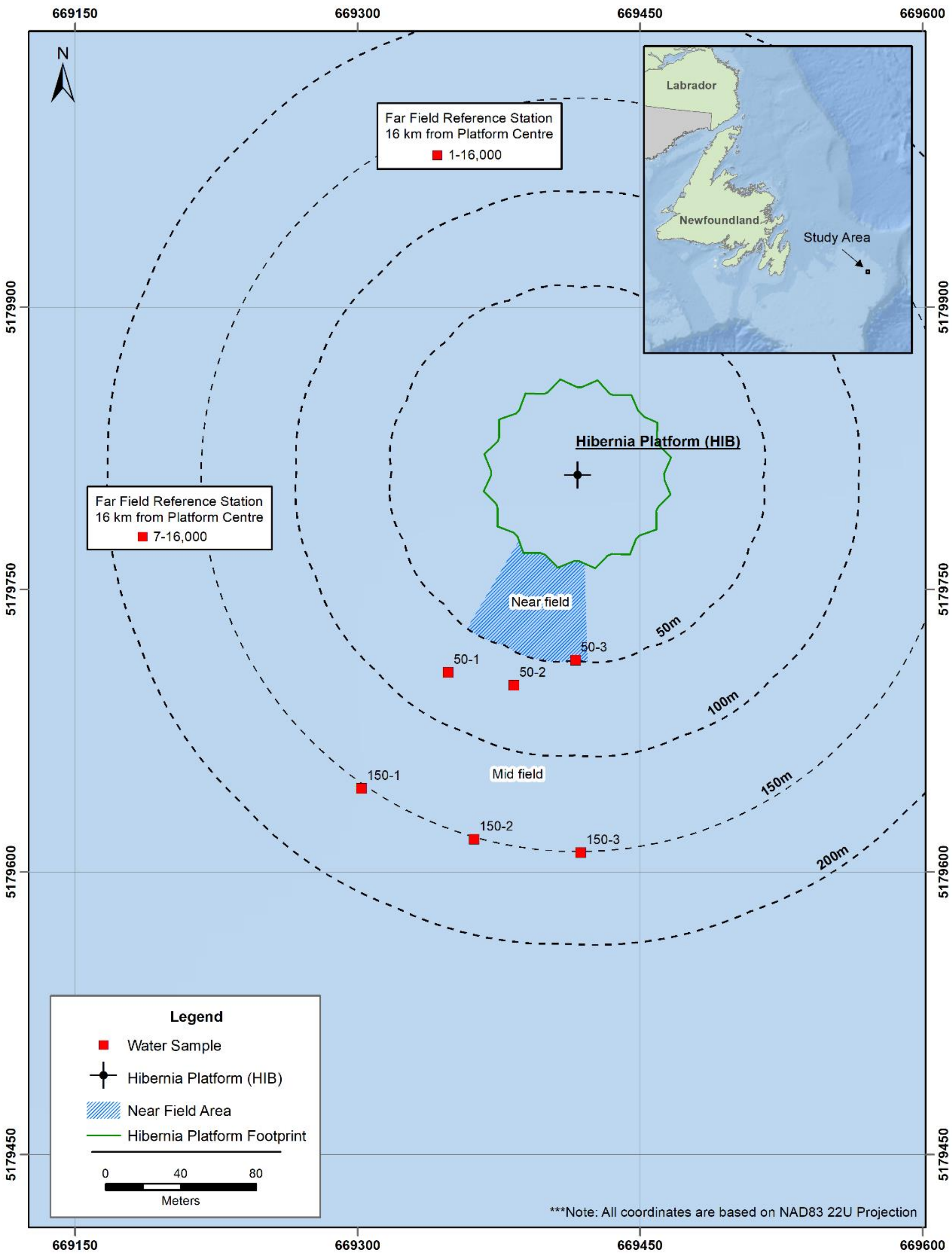


Figure 5-1: Water column sampling stations, September 30, 2020.

Table 5-1: Coordinates (proposed and actual) for the Hibernia 2020 water quality program.

Station ID	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
50-1	669348.12	5179706.76	3	669348.21	5179706.19
50-2	669381.98	5179697.49	1	669383.15	5179699.29
50-3	669415.83	5179712.48	2	669415.76	5179712.63
150-1	669302.70	5179646.69	6	669302.10	5179644.60
150-2	669362.57	5179618.36	4	669361.93	5179617.57
150-3	669419.63	5179610.82	5	669418.53	5179610.35
1-16000	668966.00	5195809.00	8	668967.12	5195808.48
7-16000	653424.00	5179363.00	7	653422.42	5179363.92
Notes: All coordinates presented in UTMs, Zone 22, NAD83					

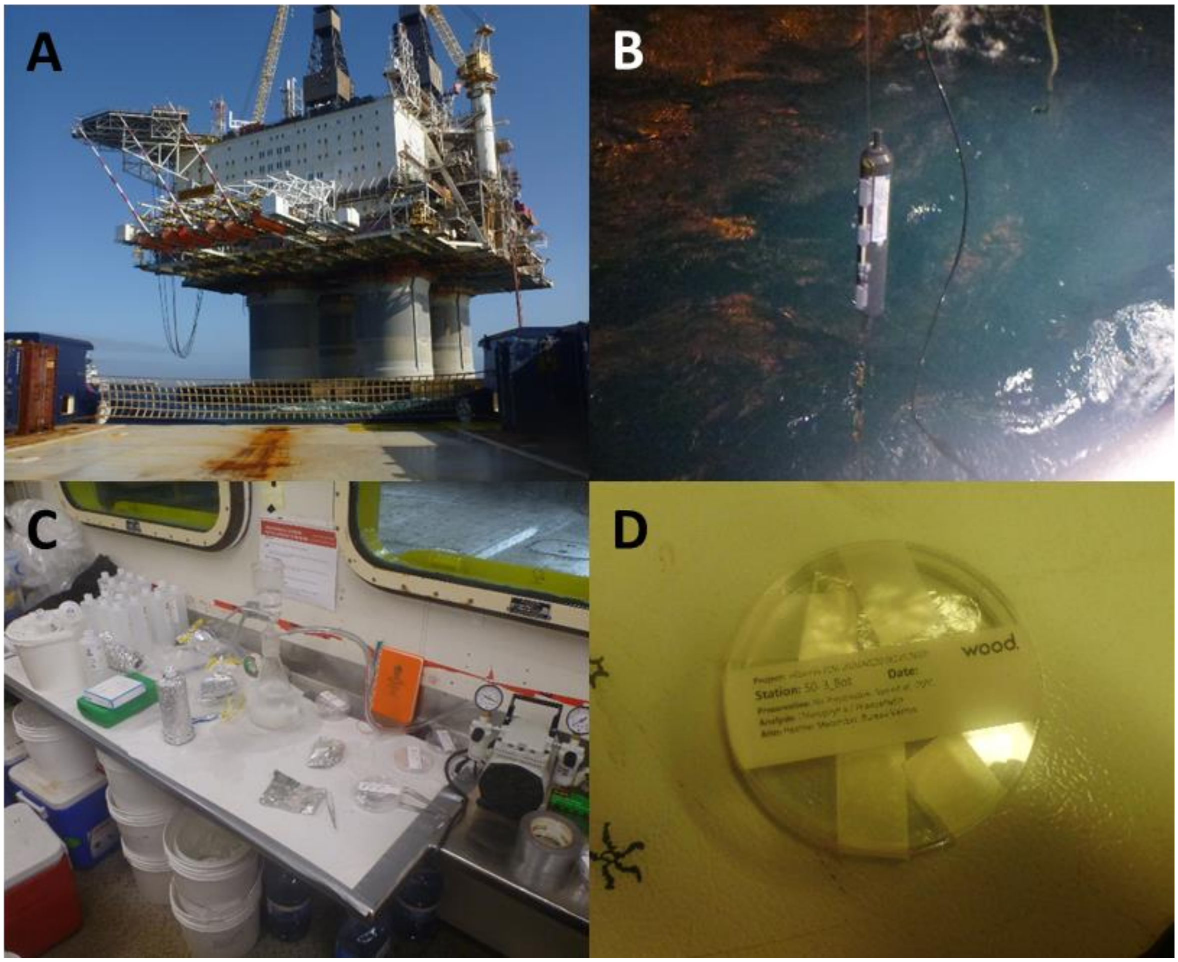


Figure 5-2: A) View of Hibernia Platform during water sampling, B) Niskin bottle returning with sample, C) Water filtration set-up in main laboratory container, and D) Chlorophyll *a* sample.

5.1.1.1 Discharged Produced Water Sampling

Produced water chemistry and toxicological analysis is conducted annually as described in the Hibernia Environmental Compliance Monitoring Plan (HMDC 2017a). Produced water was sampled prior to discharge by a Hibernia Platform technician on September 30, 2020. Samples were stored in coolers with ice packs and shipped back to shore via helicopter. Produced water was sampled for chemistry (metals, inorganics, hydrocarbons, BTEX, alkylated phenols, PAHs) and toxicity (sea urchin fertilization and silverside survival) analyses. Chemical characteristics of the overboard produced water was used to identify analytes associated with potential enrichment or depletion in the marine environment based on field sampling.

5.1.2 Laboratory and Statistical Analysis

5.1.2.1 Chemical and Physical Characteristics

All stations were sampled for chemical analysis including metals, hydrocarbons (BTEX, range hydrocarbons, TPH, PAHs), radionucleotides, nutrients/general chemistry, and pigments. Several screening steps were taken to focus the analysis including:

- Summary statistics and comparisons were given for all metals that had guidelines or whose mean values appeared higher at the platform stations compared to the reference station. The guidelines used were the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life (CCME 2021)
- Summary statistics were given for all general hydrocarbons, radionucleotides, general chemistry, and pigments.
- Summary statistics were given for all PAHs where at least one station was above the detection limit
- Comparison summaries for all hydrocarbons, radionucleotides, general chemistry, and pigments were given for analytes that were detected in at least one station (i.e., above reportable detection limits).

5.1.2.2 Dispersion Analysis

Analytes that were detected in the vicinity of the Hibernia Platform and not at the reference area were selected for further evaluation as well as analytes that had mean concentrations several factors greater compared to those of the 16,000 m away reference areas.

For dispersion analysis, the ratio of produced water to *in situ* concentration was assessed. Undiluted produced water prior to discharge was sampled by trained technicians and transported to St. John's via helicopter for analysis. To collect samples for analysis, produced water sampling was scheduled in advance of, and conducted on, September 30, 2020 – the same day as the field water sampling program. To estimate the dispersion of produced water in the receiving environment, percent concentration (that is the concentration in the receiving environment relative to the produced water concentration) and Dilution Ratio (how dispersed the analyte is in the receiving environment) were both calculated and compared to model results from the Environmental Assessment (HMDC 2011). They were calculated using the following formulas:

$$\%\,Concentration\ ([\%]) = \frac{[WC]}{[PW]} \text{ x } 100$$

$$Dilution\ Ratio\ (DR) = [PW]:[WC]$$

Where:

[PW] = Concentration in the Produced Water

[WC] = Concentration in the water column (i.e., the receiving environment)

To obtain meaningful descriptive summaries for samples with values below RDL, the value of the RDL was used for calculation so as not to present mean values below the detection limit. To further focus analyses, concentrations of analytes from pre-discharged produced water were compared against seawater sampling results from mean value of stations less than 200 m. For metals, to narrow down the analysis, analytes that were ten times or higher the levels observed for reference stations with at least one value above the detection limit (RDL) were considered potential produced water analytes that may result in local enrichment.

5.1.2.3 Produced Water Toxicity Testing

The same undiluted produced water samples described in Section 5.1 (collected from the pumps on the platform) were subjected to annual toxicity testing. Toxicity testing for produced water includes Microtox testing, an assay using invertebrates (sea urchin fertilization, *Lytechinus pictus*) and two assays using fish (Inland Silverside growth and survival, *Menidia beryllina*).

All water chemistry laboratory results are included in Volume II, Appendix N with some discussion of the more relevant results below.

5.2 Results

5.2.1 Water Column Profiles

Water column profiles were collected at a reference station outside the water sampling area and at station N-50 for determination of the middle depth range for sampling within the produced water plume. The depth ranges identified from the profiles included surface (<16 m), middle (16-62 m), and bottom (63-85 m), with the middle water sample set at 35 m. Unfortunately, there was an issue with the laptop communicating with the CTD during the report write up and graphs could not be generated.

5.2.2 Chemical and Physical Characteristics

Summary statistics for stations within 200m of the platform and reference stations are given in Table 5-2 and Table 5-3, respectively. Some general trends with this data are provided below.

Table 5-2: Summary of water quality results for stations within 200 m of the platform.

Parameter	RDL	Units	CCME	#	#>RDL	Mean	SD	Median	Min	Max
Metals										
Total Arsenic (As)	0.5	µg/L	12.5	18	18	1.7	0.1	1.7	1.4	1.9
Total Barium (Ba)	1.0	µg/L	n/a	18	18	7.23	1.39	6.60	5.90	11.90
Total Cadmium (Cd)	0.05	µg/L	0.012	18	0	0.05	0.00	0.05	0.05	0.05
Total Iron (Fe)	2.0	µg/L	n/a	18	4	3.17	3.64	2.00	2.00	17.20
Total Manganese (Mn)	0.5	µg/L	n/a	18	3	0.7	0.5	0.5	0.5	2.3
Total Mercury (Hg)	0.013	µg/L	0.016	18	1	0.013	0.00	0.01	0.01	0.017
Total Zinc (Zn)	1	µg/L	n/a	18	8	9.7	31.3	1.0	1.0	135.0
General Hydrocarbons										
Total Oil & Grease	0.5	mg/L	n/a	18	2	0.528	0.083	0.500	0.500	0.800
Benzene	0.001	mg/L	0.11	18	4	0.003	0.006	0.001	0.001	0.025
Toluene	0.001	mg/L	0.215	18	3	0.002	0.003	0.001	0.001	0.012
Ethylbenzene	0.001	mg/L	0.025	18	0	0.001	0.000	0.001	0.001	0.001
Xylenes	0.002	mg/L	n/a	18	0	0.002	0.000	0.002	0.002	0.002
C_6 - C_{10} (less BTEX)	0.01	mg/L	n/a	18	0	0.090	0.00	0.09	0.09	0.09
>C_{10}-C_{16} Hydrocarbons	0.05	mg/L	n/a	18	1	0.050	0.00	0.05	0.05	0.06
>C_{16}-C_{21} Hydrocarbons	0.05	mg/L	n/a	18	1	0.050	0.00	0.05	0.05	0.06
>C_{21}-<C_{32} Hydrocarbons	0.1	mg/L	n/a	18	0	0.091	0.00	0.09	0.09	0.10
Modified TPH (Tier1)	0.1	mg/L	n/a	18	0	0.091	0.00	0.09	0.09	0.10
PAHs and Alkyl PAHs										
Fluorene	0.005	µg/L	n/a	18	3	0.006	0.004	0.005	0.005	0.023
2-Methylnaphthalene	0.005	µg/L	n/a	18	7	0.046	0.105	0.005	0.005	0.420
Naphthalene	0.005	µg/L	n/a	18	9	0.08	0.19	0.01	0.01	0.76
Phenanthrene	0.005	µg/L	n/a	18	3	0.01	0.01	0.01	0.01	0.03
C1-Naphthalene	0.005	µg/L	n/a	18	8	0.10	0.24	0.01	0.01	0.94
C3-Naphthalene	0.005	µg/L	n/a	18	4	0.02	0.04	0.01	0.01	0.15
C4-Naphthalene	0.005	µg/L	n/a	18	2	0.01	0.01	0.01	0.01	0.05
C2-Naphthalene	0.005	µg/L	n/a	18	7	0.05	0.12	0.01	0.01	0.49
Biphenyl	0.005	µg/L	n/a	18	3	0.01	0.01	0.01	0.01	0.05
C1-Biphenyl	0.005	µg/L	n/a	18	3	0.01	0.01	0.01	0.01	0.04
C2-Biphenyl	0.005	µg/L	n/a	18	1	0.01	0.00	0.01	0.01	0.01
C1-Fluorene	0.005	µg/L	n/a	18	3	0.007	0.006	0.005	0.005	0.029
C2-Fluorene	0.005	µg/L	n/a	18	1	0.01	0.00	0.01	0.01	0.01
Dibenzothiophene	0.005	µg/L	n/a	18	2	0.006	0.002	0.005	0.005	0.013
C1-Dibenzothiophene	0.005	µg/L	n/a	18	2	0.006	0.004	0.005	0.005	0.023

Parameter	RDL	Units	CCME	#	#>RDL	Mean	SD	Median	Min	Max
C2-Dibenzothiophene	0.005	µg/L	n/a	18	2	0.01	0.00	0.01	0.01	0.02
C1-Phenanthrene/Anthracene	0.005	µg/L	n/a	18	3	0.01	0.01	0.01	0.01	0.04
C2-Phenanthrene/Anthracene	0.005	µg/L	n/a	18	2	0.006	0.003	0.005	0.005	0.019
C3-Phenanthrene/Anthracene	0.005	µg/L	n/a	18	1	0.005	0.001	0.005	0.005	0.011
1-Methylnaphthalene	0.005	µg/L	n/a	18	7	0.054	0.126	0.005	0.005	0.500
Radionucleotides										
Lead-210	0.1, 0.5	Bq/L	n/a	18	0	0.281	0.333	0.130	0.100	1.200
Radium-228	0.5	Bq/L	n/a	18	0	0.500	0.000	0.500	0.500	0.500
Radium-226	0.01	Bq/L	n/a	18	0	0.010	0.000	0.010	0.010	0.010
Nutrients / General Chemistry										
Nitrogen (Ammonia Nitrogen)	0.05	mg/L	n/a	18	9	0.071	0.030	0.053	0.050	0.160
Total Organic Carbon (C)	0.5	mg/L	n/a	18	18	1.689	0.382	1.700	1.100	2.500
Total Phosphorus	0.02	mg/L	n/a	18	9	0.033	0.021	0.021	0.020	0.100
Total Suspended Solids	1.0,2.0	mg/L	n/a	18	0	2.333	1.636	1.800	1.000	7.400
Total Hardness (CaCO3)	0.5	mg/L	n/a	18	18	0.120	0.062	0.086	0.064	0.214
Total Nitrogen (N)	0.02	mg/L	n/a	18	2	0.528	0.083	0.500	0.500	0.800
Pigments										
Chlorophyll a	-	µg/L	n/a	18	-	0.43	0.25	0.53	0.09	0.90
Phaeophytin	-	µg/L	n/a	18	-	0.21	0.10	0.21	0.08	0.36

Table 5-3: Summary of water quality results for reference stations (16,000 m from the platform).

Parameter	RDL	Units	CCME	#	#>RDL	Mean	SD	Median	Min	Max
Metals										
Total Arsenic (As)	0.5	µg/L	12.5	6	6	1.7	0.1	1.7	1.6	1.8
Total Barium	1.00	µg/L	n/a	6	6	6.60	0.85	6.35	5.80	7.80
Total Cadmium (Cd)	0.05	µg/L	0.12	6	0	0.05	0.00	0.05	0.05	0.05
Total Iron (Fe)	2.00	µg/L	n/a	6	3	4.05	2.98	2	2.0	9.2
Total Manganese (Mn)	0.5	µg/L	n/a	6	0	0.5	0.0	0.5	0.5	0.5
Total Mercury (Hg)	0.013	µg/L	0.016	6	0	0.013	0.00	0.013	0.013	0.013
Total Zinc (Zn)	1	µg/L	n/a	6	1	2.2	2.9	1.0	1.0	8.0
General Hydrocarbons										
Total Oil & Grease	0.5	mg/L	n/a	6	0	0.50	0.00	0.50	0.50	0.50
Benzene	0.001	mg/L	0.11	6	0	0.001	0.000	0.001	0.001	0.001
Toluene	0.001	mg/L	0.215	6	0	0.001	0.000	0.001	0.001	0.001
Ethylbenzene	0.001	mg/L	0.025	6	0	0.001	0.000	0.001	0.001	0.001
Xylenes	0.002	mg/L	n/a	6	0	0.002	0.000	0.002	0.002	0.002
C_6 - C_{10} (less BTEX)	0.01	mg/L	n/a	6	0	0.09	0.00	0.09	0.09	0.09
>C_{10}-C_{16} Hydrocarbons	0.05	mg/L	n/a	6	0	0.05	0.00	0.05	0.05	0.06
>C_{16}-C_{21} Hydrocarbons	0.05	mg/L	n/a	6	0	0.05	0.00	0.05	0.05	0.06
>C_{21}-<C_{32} Hydrocarbons	0.1	mg/L	n/a	6	0	0.09	0.00	0.09	0.09	0.10
Modified TPH (Tier1)	0.1	mg/L	n/a	6	0	0.09	0.00	0.09	0.09	0.10
PAHs and Alkyl PAHs										
Fluorene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
2-Methylnaphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Naphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Phenanthrene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C1-Naphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C3-Naphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C4-Naphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C2-Naphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Biphenyl	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C1-Biphenyl	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C2-Biphenyl	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C1-Fluorene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C2-Fluorene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Dibenzothiophene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C1-Dibenzothiophene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01

Parameter	RDL	Units	CCME	#	#>RDL	Mean	SD	Median	Min	Max
C2-Dibenzothiophene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C1-Phenanthrene/Anthracene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C2-Phenanthrene/Anthracene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
C3-Phenanthrene/Anthracene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
1-Methylnaphthalene	0.005	µg/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Radionucleotides										
Lead-210	0.1, 0.5	Bq/L	n/a	6	0	0.16	0.07	0.19	0.10	0.28
Radium-228	0.5	Bq/L	n/a	6	0	0.50	0.00	0.50	0.50	0.50
Radium-226	0.01	Bq/L	n/a	6	0	0.01	0.00	0.01	0.01	0.01
Nutrients / General Chemistry										
Nitrogen (Ammonia Nitrogen)	0.05	mg/L	n/a	6	2	0.07	0.04	0.05	0.05	0.14
Total Organic Carbon (C)	0.5	mg/L	n/a	6	6	1.40	0.13	1.40	1.20	1.60
Total Phosphorus	0.02	mg/L	n/a	6	4	0.03	0.01	0.02	0.02	0.05
Total Suspended Solids	1.0, 2.0	mg/L	n/a	6	0	2.37	0.88	1.90	1.60	4.00
Total Hardness (CaCO3)	0.5	mg/L	n/a	6	6	0.69	0.80	0.22	0.11	1.91
Total Nitrogen (N)	0.02	mg/L	n/a	6	0	0.50	0.00	0.50	0.50	0.50
Pigments										
Chlorophyll a	-	µg/L	n/a	6	-	0.51	0.34	0.51	0.14	0.95
Phaeophytin	-	µg/L	n/a	6	-	0.26	0.18	0.19	0.12	0.58

5.2.2.1 Metals

The summary of results for screened in metals is listed in Table 5-2 and Table 5-3. Of the 32 metals analysed, 11 were detected in all Hibernia Platform seawater samples (n=18) and all 16,000 m HRA samples (n=6) analysed. Six analytes were detected in seawater samples collected at either the Hibernia Platform or the reference area, but not at both locations. Although these metals are constituents of produced water, they are also naturally abundant in seawater (reviewed by Yeung et al. 2011).

For the metals, the mean values were all below CCME guidelines. The only analytes above guidelines on individual sampling stations were mercury (Table 5-4); one station 50-2 surface had a value of 0.017 µg/L (guideline is 0.016 µg/L). Comparing average values of screened in metals within 200m of the platform and reference areas, manganese and zinc were higher closer to the platform.

5.2.2.2 Hydrocarbons

The mean and individual values of hydrocarbons were all below CCME guidelines. Benzene and toluene were detected at the surface of stations 50-2 and 50-3, the mid depth of station 50-3 and surface of 150-3 (0.0011 µg/L). $>C_{10}$-C_{16} and $>C_{16}$-C_{21} were also detected at 50-3 (mid depth). For PAHs, all stations within the 50 m range (50-1, 50-2, 50-3) had some detections of PAHs at the surface and mid-depth. Stations 150-2 (mid depth) and 150-3 (surface depth) also had some detections of PAHs. There was no detection of PAHs at the reference stations.

5.2.2.3 General Chemistry and Other Analytes

Other analytes (10) that are not metals or hydrocarbons include radioactive species (lead-210, radium-228, radium-226), pigments, nitrogen species (ammonia, total nitrogen), TOC, total suspended solids (TSS), total hardness ($CaCO_3$), and total sulphur. Radionucleotides were below detection limits at all stations. For pigments and general chemistry, the values appear to be within the natural variation as refence values were not statistically different (based on means and standard deviations) than stations closer to the platform.

5.2.2.4 Summary of Results by Station

A review of the results by station is as follows:

- All values at all stations were below CCME guidelines for metal and hydrocarbons.
- Seawater samples from the surface and mid-depth stations approximately 50 m from the discharge point (50-1, 50-2, and 50-3) generally have the highest percentage of analytes above the detection levels for some metals (iron, manganese), general hydrocarbons (Benzene, Toluene, $>C_{10}$-C_{16}, and $>C_{16}$-C_{21}) and 20 PAHs.
- Mid-depth seawater sample at station 50-3 (the station closest to the discharge point) had the highest number of analytes above detection limits that includes metals, general hydrocarbons, and PAHs.
- Some other stations (150-3 surface and 150-2 mid-depth) did have seawater samples that generally had values above detection levels for some analytes (Benzene, five PAHs). The reference stations were not above detection levels for mercury or any hydrocarbons.

Table 5-4: Analytes in water samples with at least one sample above CCME guidelines (metals) or above detection limits (hydrocarbons)

Stations	Metals	General Hydrocarbons				
	Total Mercury	Total Oil & Grease	Benzene	Toluene	$>C_{10}$-C_{16}	$>C_{16}$-C_{21}
Units	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L
RDL	0.013	0.5	0.001	0.001	0.05-0.55	0.05-0.55
CCME	0.016	n/a	0.11	0.215	n/a	n/a
50-1_SUR	0.013	0.5	0.001	0.001	0.05	0.05
50-1_MID	0.013	0.5	0.001	0.001	0.05	0.05
50-1_BOT	0.013	0.7	0.001	0.001	0.05	0.05
50-2_SUR	**0.017**	0.5	0.0054	0.0024	0.05	0.05
50-2_MID	0.013	0.5	0.001	0.001	0.05	0.05
50-2_BOT	0.013	0.8	0.001	0.001	0.05	0.05
50-3_SUR	0.013	0.5	0.011	0.005	0.05	0.05
50-3_MID	0.013	0.5	0.025	0.012	0.058	0.058
50-3_BOT	0.013	0.5	0.001	0.001	0.05	0.05
150-1_SUR	0.013	0.5	0.001	0.001	0.05	0.05
150-1_MID	0.013	0.5	0.001	0.001	0.05	0.05
150-1_BOT	0.013	0.5	0.001	0.001	0.05	0.05
150-2_SUR	0.013	0.5	0.001	0.001	0.05	0.05
150-2_MID	0.013	0.5	0.001	0.001	0.05	0.05
150-2_BOT	0.013	0.5	0.001	0.001	0.05	0.05
150-3_SUR	0.013	0.5	0.0011	0.001	0.05	0.05
150-3_MID	0.013	0.5	0.001	0.001	0.05	0.05
150-3_BOT	0.013	0.5	0.001	0.001	0.05	0.05
1-16000_SUR	0.013	0.5	0.001	0.001	0.05	0.05
1-16000_MID	0.013	0.5	0.001	0.001	0.05	0.05
1-16000_BOT	0.013	0.5	0.001	0.001	0.05	0.05
7-16000_SUR	0.013	0.5	0.001	0.001	0.05	0.05
7-16000_MID	0.013	0.5	0.001	0.001	0.055	0.055
7-16000_BOT	0.013	0.5	0.001	0.001	0.05	0.05

Notes:
Highlighted cells represent values above detection limits. All other values are below detection limits.
Bolded values indicated values above CCME guidelines (mercury).

Table 5-5: PAHs detected in water samples. Reference area values not shown as all were below detection limits (units in µg/L).

Stations	PAH (µg/L)*																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
RDL	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**
50-1_SUR	0.005	0.0079	0.014	0.005	0.017	0.005	0.005	0.0095	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0089
50-1_MID	0.005	0.017	0.027	0.005	0.036	0.0063	0.005	0.025	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.019
50-1_BOT	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
50-2_SUR	0.0051	0.090	0.160	0.0067	0.200	0.022	0.005	0.100	0.0098	0.0083	0.005	0.0054	0.005	0.005	0.005	0.005	0.0073	0.005	0.005	0.110
50-2_MID	0.005	0.005	0.0059	0.005	0.0063	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
50-2_BOT	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
50-3_SUR	0.011	0.200	0.350	0.014	0.450	0.069	0.010	0.230	0.022	0.018	0.005	0.014	0.005	0.0061	0.0092	0.0077	0.017	0.0059	0.005	0.24
50-3_MID	0.023	0.42	0.760	0.028	0.940	0.150	0.049	0.490	0.047	0.038	0.0072	0.029	0.0098	0.013	0.023	0.023	0.036	0.019	0.011	0.500
50-3_BOT	0.005	0.005	0.0066	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-1_SUR	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-1_MID	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-1_BOT	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-2_SUR	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-2_MID	0.005	0.0074	0.012	0.005	0.016	0.005	0.005	0.0092	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.0078
150-2_BOT	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-3_SUR	0.005	0.030	0.054	0.005	0.066	0.005	0.005	0.036	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.035
150-3_MID	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
150-3_BOT	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005

Notes:

Highlighted cells represent values above detection limits. All other values are below detection limits. Numbers represent the following PAH names:

1	Fluorene	6	C3-Naphthalene	11	C2-Biphenyl	16	C2-Dibenzothiophene
2	2-Methylnaphthalene	7	C4-Naphthalene	12	C1-Fluorene	17	C1-Phenanthrene/Anthracene
3	Naphthalene	8	C2-Naphthalene	13	C2-Fluorene	18	C2-Phenanthrene/Anthracene
4	Phenanthrene	9	Biphenyl	14	Dibenzothiophene	19	C3-Phenanthrene/Anthracene
5	C1-Naphthalene	10	C1-Biphenyl	15	C1-Dibenzothiophene	20	1-Methylnaphthalene

5.2.3 Dispersion Analysis

Percent concentration and dilution ratio for analytes that had detected concentrations among any samples are summarized in Table 5-6 to Table 5-10 for metals, hydrocarbons, PAHs, and other analytes, respectively. The concentration values for comparison are also provided below for most analytes with the exception of PAHS (due to the size of the table) but those values are available in Appendix N.

5.2.3.1 Metals

The selected metal concentrations were below detection limits for the majority of stations (Table 5-6). Barium, iron, and manganese were all produced water constituents that were above detection limits in seawater samples. For barium, the concentrations were above detection limits at all stations with the values similar at all stations (including those 16,000 m away from discharge point) indicating natural variation (1.9 to 3.8% concentration). Where Iron was detected (50-1 Surface-depth sample, 50-2 Surface depth sample, 50-3 Surface and mid depth sample, 1-16000 mid- and bottom- depth sample) concentrations were all less than 1% with the highest concentrations of 0.3% produced water concentration and the lowest dilution ratio of 359:1 (at 50-3 surface depth) at. Manganese was above detection limits at the surface of stations 50-2 and 50-3 and the mid depth sample of 50-3 with a percentage ranging from 0.1 to 0.3% and dilution ratio of 3589:1 to 1679:1.

5.2.3.2 Hydrocarbons

Five sample stations had concentrations of hydrocarbons above detection limits (50-2 surface depth sample, 50-3 Surface and mid depth sample, 150-3 surface depth, and 7-16000 mid depth sample) with the highest concentration at 0.058 mg/L (1.04% concentration) (Table 5-7). Benzene was measured at all of these locations ranging from 0.05% (50-2 Surface depth sample) to 0.24 % (50-3 mid depth sample). Toluene was measured at three locations (0-2 surface depth sample, 50-3 Surface and mid depth sample) ranging from 0.04 % /2622:1 Dilution Ratio (50-2 Surfaced depth sample) to 0.19 %/524:1 Dilution Ratio (50-3 mid depth sample). The mid depth sample at 50-3 was also the only station that had detections of >C_{10}-C_{16} (1.04%, 96:1 Dilution Ratio) and >C_{16}-C_{21} (2.03%; 49:1 dilution ratio).

PAHs were detected in 50-1 (Surface and Mid depth sample), 50-2 (Surface and Mid Depth sample), 50-3 (all three depths), 150-2 (Mid), and 150-3 (Surface) although all below 0.3% (Table 5-8 and

Table 5-9). The maximum concentration in the receiving environment was at 0.262% (50-3 mid depth sample, #10 C1-Biphenyl) meaning the concentration in the receiving environment was 0.262% of the produced water value for the given analyte (C1-Biphenyl). Conversely, the lowest dilution ratio (worst-case) was 381:1 dilution meaning the concentration in the receiving environment was approximately 380 times lower concentration than in the Produced Water for #10 C1-Biphenyl at 50-3 mid depth. Similar to other analytes, the 50-3 station (surface and mid depth sample; closest station to discharge) has the most detections (and highest concentrations/lowest dilution ratio).

5.2.3.3 General Chemistry and Other Analytes

The other analytes that were above detection that are naturally occurring in seawater (Libes 1992) were Nitrogen (ammonia), TOC, and total phosphorous. As illustrated in Table 5-10, The concentrations for ammonia and phosphorus appear to be higher at depth but no trend with distance from platform. For TOC, all values were above detection limits with no discernible trends in relation to distance from platform.

Table 5-6: Dispersion Analysis (Percent Concentration and Dilution Ratio) for selected metals in water quality samples.

Sample	Barium			Iron			Manganese		
Units	µg/L	[%]	DR	µg/L	[%]	DR	µg/L	[%]	DR
RDL	1.00	-	-	2.00	-	-	0.50	-	-
PW	310	100	1	6166	100	1	840	100	1
50-1_SUR	6.4	2.1	48	2.7	0.0	2284	0.5	0.1	1679
50-1_MID	6.5	2.1	48	2	0.0	3083	0.5	0.1	1679
50-1_BOT	7.7	2.5	40	2	0.0	3083	0.5	0.1	1679
50-2_SUR	6.6	2.1	47	3.1	0.1	1989	1.12	0.1	750
50-2_MID	6	1.9	52	2	0.0	3083	0.5	0.1	1679
50-2_BOT	7.6	2.5	41	2	0.0	3083	0.5	0.1	1679
50-3_SUR	8.7	2.8	36	6.1	0.1	1011	1.29	0.2	651
50-3_MID	11.9	3.8	26	17.2	0.3	358	2.34	0.3	359
50-3_BOT	7.7	2.5	40	2	0.0	3083	0.5	0.1	1679
150-1_SUR	6.6	2.1	47	2	0.0	3083	0.5	0.1	1679
150-1_MID	5.9	1.9	53	2	0.0	3083	0.5	0.1	1679
150-1_BOT	7.6	2.5	41	2	0.0	3083	0.5	0.1	1679
150-2_SUR	6.4	2.1	48	2	0.0	3083	0.5	0.1	1679
150-2_MID	6.5	2.1	48	2	0.0	3083	0.5	0.1	1679
150-2_BOT	7.7	2.5	40	2	0.0	3083	0.5	0.1	1679
150-3_SUR	6.4	2.1	48	2	0.0	3083	0.5	0.1	1679
150-3_MID	6.4	2.1	48	2	0.0	3083	0.5	0.1	1679
150-3_BOT	7.6	2.5	41	2	0.0	3083	0.5	0.1	1679
1-16000_SUR	6	1.9	52	2	0.0	3083	0.5	0.1	1679
1-16000_MID	5.8	1.9	53	6.1	0.1	1011	0.5	0.1	1679
1-16000_BOT	7.8	2.5	40	9.2	0.1	670	0.5	0.1	1679
7-16000_SUR	5.9	1.9	53	2	0.0	3083	0.5	0.1	1679
7-16000_MID	6.7	2.2	46	2	0.0	3083	0.5	0.1	1679
7-16000_BOT	7.4	2.4	42	3	0.0	2055	0.5	0.1	1679

Notes:
Highlighted cells represent values above detection limits. All other values are below detection limits.
RDL = Reportable Detection Limit
PW = Concentration of analyte in on-board produced water. Percent Concentration [%] for PW would be 100 and the Dilution Ration would be 1
[%] = percent concentration
DR = Dilution Ratio

Table 5-7: Dispersion Analysis (Percent Concentration and Dilution Ratio) for selected hydrocarbons in water quality samples.

Sample	Benzene			Toluene			>C_{10}-C_{16} Hydrocarbons			>C_{16}-C_{21} Hydrocarbons		
Units	mg/L	[%]	DR	mg/L	[%]	DR	mg/L	[%]	DR	mg/L	[%]	DR
RDL	0.001	-	-	0.001	-	-	0.05-0.55	-	-	0.05-0.55	-	-
PW	10.48	100	1	6.29	100	1	5.60	100	1	2.86	100	1
50-1_SUR	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
50-1_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
50-1_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
50-2_SUR	0.0054	0.05	1941	0.0024	0.04	2622	0.05	0.89	112	0.05	1.75	57
50-2_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
50-2_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
50-3_SUR	0.011	0.10	953	0.005	0.08	1259	0.05	0.89	112	0.05	1.75	57
50-3_MID	0.025	0.24	419	0.012	0.19	524	0.058	1.04	96	0.058	2.03	49
50-3_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-1_SUR	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-1_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-1_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-2_SUR	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-2_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-2_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-3_SUR	0.0011	0.01	9529	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-3_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
150-3_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
1-16000_SUR	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
1-16000_MID	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
1-16000_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
7-16000_SUR	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57
7-16000_MID	0.001	0.01	10482	0.001	0.02	6293	0.055	0.98	102	0.055	1.93	52
7-16000_BOT	0.001	0.01	10482	0.001	0.02	6293	0.05	0.89	112	0.05	1.75	57

Notes:
Highlighted cells represent values above detection limits. All other values are below detection limits.
RDL = Reportable Detection Limit
PW = Concentration of analyte in on-board produced water. Percent Concentration [%] for PW would be 100 and the Dilution Ration would be 1
[%] = percent concentration
DR = Dilution

Table 5-8: Dispersion Analysis (Percent Concentration and Dilution Ratio) for selected PAHs in water quality samples (PAHs #1 through #10).

PAH	1		2		3		4		5		6		7		8		9		10	
Sample	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR
50-1_SUR	0.045	2200	0.004	22785	0.005	21429	0.040	2496	0.004	22637	0.008	12200	0.026	3896	0.005	21053	0.023	4296	0.035	2896
50-1_MID	0.045	2200	0.009	10588	0.009	11111	0.040	2496	0.009	10690	0.010	9683	0.026	3896	0.013	8000	0.023	4296	0.035	2896
50-1_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
50-2_SUR	0.046	2157	0.050	2000	0.053	1875	0.054	1863	0.052	1924	0.036	2773	0.026	3896	0.050	2000	0.046	2192	0.057	1745
50-2_MID	0.045	2200	0.003	36000	0.002	50847	0.040	2496	0.002	61083	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
50-2_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
50-3_SUR	0.100	1000	0.111	900	0.117	857	0.112	892	0.117	855	0.113	884	0.051	1948	0.115	870	0.102	976	0.124	805
50-3_MID	0.209	478	0.233	429	0.253	395	0.224	446	0.244	409	0.246	407	0.252	398	0.245	408	0.219	457	0.262	381
50-3_BOT	0.045	2200	0.003	36000	0.002	45455	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-1_SUR	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-1_MID	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-1_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-2_SUR	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-2_MID	0.045	2200	0.004	24324	0.004	25000	0.040	2496	0.004	24052	0.008	12200	0.026	3896	0.005	21739	0.023	4296	0.035	2896
150-2_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-3_SUR	0.045	2200	0.017	6000	0.018	5556	0.040	2496	0.017	5831	0.008	12200	0.026	3896	0.018	5556	0.023	4296	0.035	2896
150-3_MID	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
150-3_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
1-16000_SUR	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
1-16000_MID	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
1-16000_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
7-16000_SUR	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
7-16000_MID	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896
7-16000_BOT	0.045	2200	0.003	36000	0.002	60000	0.040	2496	0.001	76965	0.008	12200	0.026	3896	0.003	40000	0.023	4296	0.035	2896

Notes:
Highlighted cells represent values above detection limits. Only percentages were given due to the size of the table with values available in Appendix N of Volume II. [%] = percent concentration, DR = Dilution
Numbers represent the following PAH names:

1	Fluorene	5	C1-Naphthalene	9	Biphenyl
2	2-Methylnaphthalene	6	C3-Naphthalene	10	C1-Biphenyl
3	Naphthalene	7	C4-Naphthalene		
4	Phenanthrene	8	C2-Naphthalene		

Table 5-9: Dispersion Analysis (Percent Concentration and Dilution Ratio) for selected PAHs in water quality samples (PAHs #11 through #20).

PAH	11		12		13		14		15		16		17		18		19		20	
Sample	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR	[%]	DR
50-1_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.004	22472
50-1_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.010	10526
50-1_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
50-2_SUR	0.164	610	0.045	2222	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.044	2258	0.048	2096	0.050	2000	0.055	1818
50-2_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
50-2_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
50-3_SUR	0.164	610	0.117	857	0.087	1150	0.109	917	0.084	1196	0.059	1688	0.103	970	0.056	1777	0.050	2000	0.120	833
50-3_MID	0.236	423	0.242	414	0.170	587	0.232	430	0.209	478	0.177	565	0.218	458	0.181	552	0.110	909	0.250	400
50-3_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-1_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-1_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-1_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-2_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-2_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.004	25641
150-2_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-3_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.018	5714
150-3_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
150-3_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
1-16000_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
1-16000_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
1-16000_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000

PAH	11		12		13		14		15		16		17		18		19		20	
Sample	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**	**[%]**	**DR**
7-16000_SUR	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
7-16000_MID	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000
7-16000_BOT	0.164	610	0.042	2400	0.087	1150	0.089	1119	0.045	2200	0.038	2600	0.030	3296	0.048	2096	0.050	2000	0.003	40000

Notes:
Highlighted cells represent values above detection limits. Only percentages were given due to the size of the table with values available in Appendix N of Volume II. [%] = percent concentration, DR = Dilution
Numbers represent the following PAH names:

11	C2-Biphenyl	15	C1-Dibenzothiophene	19	C3-Phenanthrene/Anthracene
12	C1-Fluorene	16	C2-Dibenzothiophene	20	1-Methylnaphthalene
13	C2-Fluorene	17	C1-Phenanthrene/Anthracene		
14	Dibenzothiophene	18	C2-Phenanthrene/Anthracene		

Table 5-10: Dispersion Analysis (Percent Concentration and Dilution Ratio) for other analytes in water quality samples.

Sample	Nitrogen (Ammonia Nitrogen)			Total Organic Carbon (C)			Total Phosphorus		
Units	mg/L	[%]	DR	mg/L	[%]	DR	mg/L	[%]	DR
RDL	0.05	-	-	0.5	-	-	0.02	-	-
PW	6.348	100	1	46.9	100	1	2.70	100	1
50-1_SUR	0.069	1.09	92	1.5	3.20	31	0.02	0.74	135
50-1_MID	0.05	0.79	127	1.9	4.05	25	0.02	0.74	135
50-1_BOT	0.12	1.89	53	2	4.27	23	0.048	1.78	56
50-2_SUR	0.055	0.87	115	1.4	2.99	33	0.02	0.74	135
50-2_MID	0.082	1.29	77	1.7	3.63	28	0.02	0.74	135
50-2_BOT	0.16	2.52	40	1.2	2.56	39	0.1	3.70	27
50-3_SUR	0.05	0.79	127	1.7	3.63	28	0.02	0.74	135
50-3_MID	0.05	0.79	127	1.8	3.84	26	0.025	0.92	108
50-3_BOT	0.091	1.43	70	2.3	4.91	20	0.046	1.70	59
150-1_SUR	0.05	0.79	127	1.7	3.63	28	0.02	0.74	135
150-1_MID	0.05	0.79	127	1.3	2.77	36	0.02	0.74	135
150-1_BOT	0.089	1.40	71	1.5	3.20	31	0.043	1.59	63
150-2_SUR	0.05	0.79	127	1.3	2.77	36	0.02	0.74	135
150-2_MID	0.05	0.79	127	1.5	3.20	31	0.022	0.81	123
150-2_BOT	0.081	1.28	78	2.5	5.34	19	0.046	1.70	59
150-3_SUR	0.05	0.79	127	1.9	4.05	25	0.02	0.74	135
150-3_MID	0.05	0.79	127	1.1	2.35	43	0.024	0.89	113
150-3_BOT	0.075	1.18	85	2.1	4.48	22	0.053	1.96	51
1-16000_SUR	0.05	0.79	127	1.4	2.99	33	0.02	0.74	135
1-16000_MID	0.05	0.79	127	1.2	2.56	39	0.021	0.78	129
1-16000_BOT	0.14	2.21	45	1.4	2.99	33	0.049	1.81	55
7-16000_SUR	0.05	0.79	127	1.4	2.99	33	0.02	0.74	135
7-16000_MID	0.05	0.79	127	1.4	2.99	33	0.028	1.04	97
7-16000_BOT	0.077	1.21	82	1.6	3.41	29	0.049	1.81	55

Notes:
Highlighted cells represent values above detection limits. All other values are below detection limits.
RDL = Reportable Detection Limit
PW = Concentration of analyte in on-board produced water. Percent Concentration [%] for PW would be 100 and the Dilution Ration would be 1
[%] = percent concentration
DR = Dilution Ratio

5.2.4 Produced Water Toxicity

The produced water samples that were collected from the pumps on the platform (Section 5.1), were subjected to annual toxicity testing. Toxicity testing for produced water includes Microtox testing, an assay using invertebrates (sea urchin fertilization) and two assays using fish (Inland Silverside growth and survival). The results of these assays, including the range of toxicity values reported from previous Hibernia EEM water monitoring programs, are summarized in Table 5-11.

The Microtox effective concentration (EC50), where the 50% halfway response was observed was 14.99% produced water concentration. The EC50 value is outside the range of previous Hibernia Produced Water toxicity results (Table 5-10) meaning that according to Microtox, the produced water is now less toxic than in previous years.

The sea urchin fertilization assay for the Hibernia program is conducted in accordance with the Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars) EPS 1/RM/27, (EC 2011). The percentages of produced water concentrations for sea urchin assays including: IC25, IC50, and lowest observable effect concentration (LOEC) were all below the ranges previously reported for the Hibernia EEM program (Table 5-10). This means that according to sea urchin fertilization, the produced water is more toxic than previous testing. The no observable effects concentration (NOEC) concentration, however, was within the range of values from previous years but at the lowest level.

The Inland Silverside survival and growth inhibition bioassay (based on biomass) is a seven day test method performed according to "Short-term Methods for Estimating the chronic toxicity of Effluents and receiving waters to marine and estuarine organisms" (US EPA 2002) (EPA-821-R-02-014 with Canadian adaptations according to Environment Canada Guidance Documents).The percentages of produced water concentration for inland silversides survival and growth assays including: IC25, IC50, NOEC and LOEC were all within ranges previously reported for the Hibernia EEM program (Table 5-10).

Table 5-11: Summary of Hibernia Platform produced water toxicity testing results from 2004 - 2020.

Toxicity Test parameter	Result	
	Historical Range (2004-2018) (%)	2020 (%)
Microtox EC50	1.7 - 11.4	14.99
Sea Urchin (*Lytechinus pictus*) Fertilization		
IC25	10.3 - >100	<1.56
IC50	14.7 - >100	<1.56
NOEC	1.56 - >100	<1.56
LOEC	3.13 - >100	1.56
Inland Silverside (*Menidia beryllina*) - Survival		
LC50	31.5 - 51.6	47.8
NOEC	9 - 30	30
LOEC	30 - 100	100
Inland Silverside (*Menidia beryllina*) - Growth		
IC25	9.93 - 55.3	31.1
IC50	9 - 67.4	46
NOEC	2.7 - 50	9
LOEC	9 - 100	30

Notes:

Effective Concentration (EC)50 - concentration of toxicant that induces a response halfway (50%) between baseline and maximum after a specified exposure time.

Inhibitory Concentration (IC)25 - concentration likely to cause a 25% inhibition in the rate of survival, growth, or reproduction among test organisms.

IC25 - concentration likely to cause a 25% reduction in the rate of survival, growth, or reproduction among test organisms.

IC50 - concentration likely to cause a 50% reduction in the rate of survival, growth, or reproduction among test organisms.

Lethal Concentration (LC)50 – concentration required to kill 50% of sample population.

NOEC – No Observable Effect Concentration

LOEC – Lowest Observed Effect Concentration

NOEC and LOEC are expressed as the percentage of the original produced water sample. If the undiluted effluent causes no statistically significant reduction in survival, growth, or reproduction, the NOEC and LOEC are >100%. If the undiluted effluent causes a statistically significant reduction in survival, growth, or reproduction, but the negative effects are eliminated when the effluent is diluted in a 1:1 ratio using laboratory control water, then the NOEC equals 50% (reflecting the dilution factor of the original sample).

5.3 Summary of Results

For the 2020 water quality monitoring, samples were collected approximately 50 and 150-m from the produced water discharge outlet from the Hibernia Platform and reference areas 16,000 m away from the platform (Figure 5-1). Sampling depths were based on a CTD profile at N-50.

Reviewing all the results as a whole, the surface and mid-depth stations approximately 50 m from the discharge point (50-1, 50-2, and 50-3) appear to have the highest percentage of analytes above the detection levels with some other stations (150-3 surface and 150-2 mid depth) showing occasional values above detection levels. For metals, all values were below CCME guidelines with the exception of mercury at one station (50-2 surface sample). The value was 0.017 µg/L and the CCME guidelines is 0.016 µg/L. Mercury was below detection limits in all other samples (Table 5-4). For hydrocarbons, all values were also below guidelines. Benzene and toluene were detected at the surface of stations 50-2 and 50-3, the mid depth of station 50-3 and surface of 150-3 (benzene only; 0.0011 mg/L). $>C_{10}$-C_{16} and $>C_{16}$-C_{21} were also detected at 50-3 (mid depth). For PAHs, all stations within the 50 m range (50-1, 50-2, 50-3) had some detections of PAHs at the surface and mid-depth. Stations 150-2 (mid depth) and 150-3 (surface depth) also had some detections of PAHs. There was no detection of PAHs at the reference stations.

The percent dispersion calculation showed a similar pattern. For metals, the highest concentrations with the potential to be project-induced were 3.8% of the produced water values at approximately 50 m from the discharge point (the closest station (s) to the discharge point). For hydrocarbons, the same stations had detections of benzene, toluene and $>C_{10}$-C_{16} and $>C_{16}$-C_{21} hydrocarbons with the highest percent dispersion of 2.03% at the 50-m distance. In addition, based on the Environmental Assessment of the produced water (HMDC 2011), the dilution ratio of the produced water into the receiving environment were projected to have a near-field dilution ratio of 10:1 to 60:1 (depending on the scenario) with a produced water concentration of 1-0.03% between 0-50m, less than 0.11% at 50 to 100 m, less than 0.004% at 100-250 m, and less than 0.01% at 250-1250 m. Analysis of those analytes that are more likely project-related (i.e., have higher concentrations within 50 m of the platform) show dispersion rates within those predicted in the model with the lowest dilution ratio (worst-case) of 49:1 and the highest percent concentration (worst-case) of 2% (both for $>C_{16}$-C_{21} Hydrocarbons at 50-3 Mid).

The toxicity testing showed mixed results with Microtox showing the produced water being less toxic than previous studies and the sea urchin fertilization showing the produced water being more toxic (that is a lower concentration to have an effect). However, the percent dispersion calculations indicate that the concentrations in the receiving environment at all stations monitored would be lower than the concentrations need to induce a toxicity effect. The only exception to this is one analyte ($>C_{16}$-C_{21}) at one stations (middle sampling depth of 50-3) had a value of 2.03% produced water concentration (the lowest percent concentrations of produced water deemed to have an effect (<1.56%). All other stations and analytes that appeared to be affected by the produced water discharge had values of 1.04% or less.

The results indicate that the effects are localized mostly to within 50-m of the discharge and even those concentrations at those distances are likely to be non-toxic (based on toxicity testing). The only potential exception to this would be station 50-3 (mid-depth). Note that 50-3 is the closest station to the discharge as the other two close stations (50-1 and 50-2) were moved slightly due to the proximity to the platform structures.

6.0 COMMERCIAL FISH

6.1 Methods

6.1.1 Field Collection

The 2020 commercial fish and fish health sampling program was conducted aboard the OCI vessel *Aqviq* using a Goldentop 31 trawl towed within approximately 5 km of the Hibernia Field and associated Reference Area. The Reference Area was located 50 km NW away from the Hibernia Platform (Figure 6-1). All sampling was conducted according to the requirements of the Experimental License issued by Fisheries and Oceans Canada (DFO, NL-5945-20) (see Volume II). All fish processing and sampling was performed by WSP personnel. The crew of the *Aqviq* operated the trawl and aided in fish sorting of the trawl contents. Tows were 15 minutes in duration and the start and finish coordinates were recorded on bridge sheets. American plaice (*Hippoglossoides platessoides*) were immediately removed from the cod-end and placed in a large fish tub with flow-through sea water.

For each trawl, all species were identified, counted, and recorded. American plaice greater than 25 cm and appearing free of trawl damage were retained for sampling. The fish length, weight (whole and gutted), sex, maturity, and liver and gonad weight were recorded. A blood sample was collected for blood cell count analyses. The liver, gills, stomach, and fillet tissues were preserved for histology, bioassays, body burden, and taint (taste) testing. Where necessary, livers and top fillets were sampled from additional fish to ensure sample volumes were sufficient for analyses. Sample handling and storage was completed as quickly as possible to maintain sample integrity; prepared samples were stored in appropriate facilities on-board the vessel. Furthermore, the deck of the vessel was cleaned with degreaser after each tow to mitigate against contamination between trawls/sites and ship sources.

In 2019, the EEM Plan was updated and fish sampling was based on an overall field design with a single, larger sampling area for both Hibernia Platform and HSE collectively referred to as the Hibernia Field (HMDC 2019a). The sampling radius for the Reference Area was also expanded to 8 km (Figure 6-1). This plan was implemented for the first time during the 2020 Hibernia EEM program. Accordingly, sample sizes for commercial fish were increased from those in previous years (Table 6-1).

Table 6-1: Commercial Fish sampling design differences between the 1998 to 2018 Hibernia EEM and current methodologies.

Parameters	1998-2018 Hibernia EEMs	2020 Hibernia EEM
Number of trawls	7 trawls minimum	12 trawls minimum
Body burden samples	10 individual fillets and 10 liver composites (min. 7 fish each)	12 individual fillets and 12 liver composites (min. 7 fish each)
Fish health samples	70 fish total, 50 sent for aging, haematology, histopathology, MFO	84 fish total, 60 sent for aging, haematology, histopathology, MFO

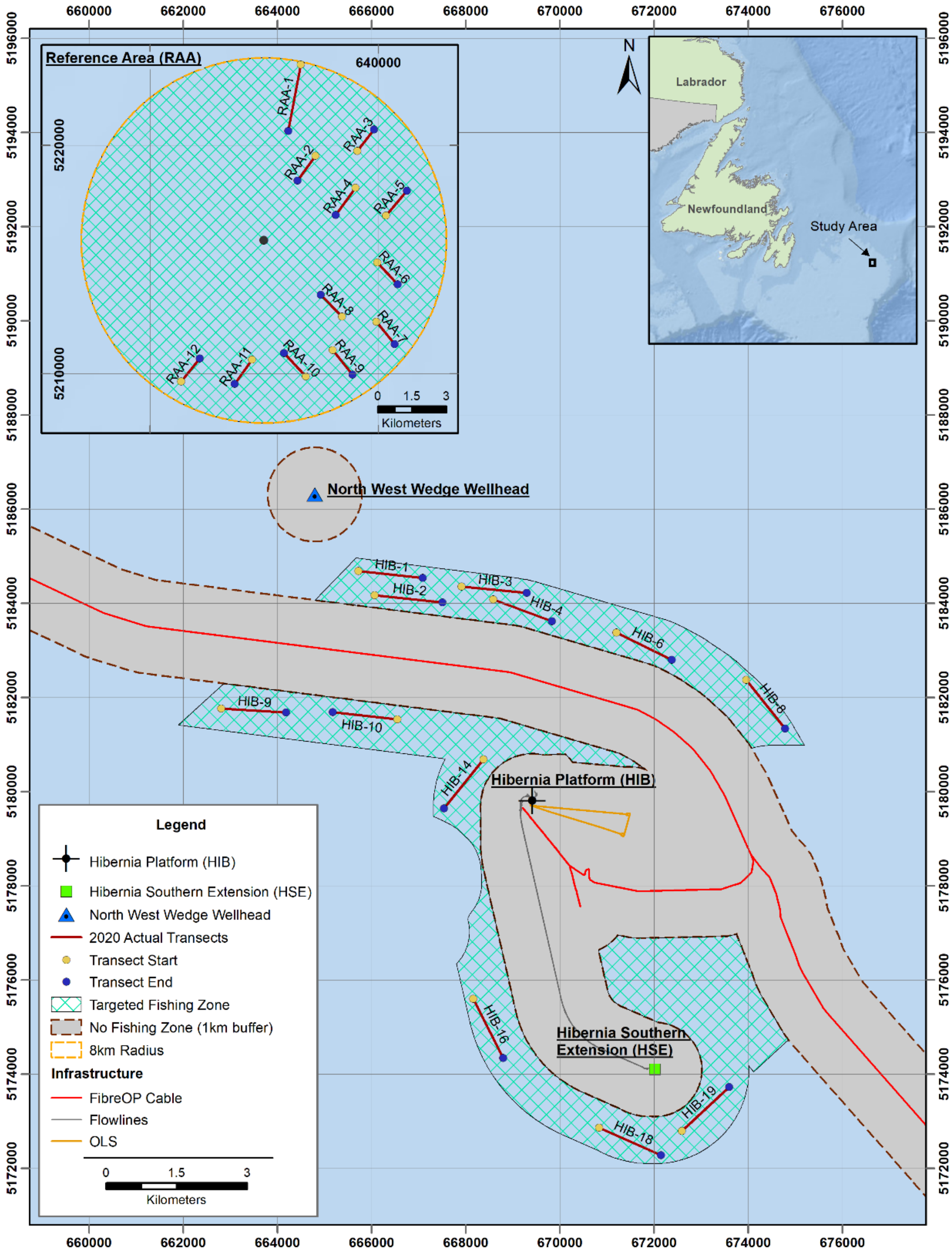


Figure 6-1: Hibernia 2020 EEM commercial fish sampling program trawl locations.

6.1.2 Field Sampling

A summary of sample processing and laboratory analysis is detailed below, with example photos in Figure 6-2. Fish were processed to gather information and samples for fish health, body burden and sensory evaluation based on the following:

1. Live fish had blood drawn for haematology analyses. Two blood smears on microscope slides were prepared, dried and fixed in methanol.
2. Morphometrics (total length, and wet and gutted weight) were measured for each fish. Notes were made on the external condition of each fish and presence of any parasites or lesions for gross pathology (Goede and Barton 1990, Adams et al. 1993). The fish was then processed further by severing the spinal cord.
3. The first gill arch was removed and stored in a Bio-Tite container with 10% neutral buffered formalin for gill histology analysis.
4. The top fillet was removed for sensory evaluations and stored in a labelled Ziploc bag (-20°C freezer).
5. The internal tissues were examined for parasites, lesions, and any abnormalities. The sex, maturity stage, gonad weight, liver weight, stomach contents, and other relevant information were recorded. Incidental observations of anomalous observations (such as hydrocarbon odours) would also recorded if they were to occur.
6. Liver tissue was sampled for mixed function oxygenase analysis (Whirl-pak; -80°C preservation), histology (Bio-tite container with 10% neutral buffered formalin), and body burden (Whirl-pak; -20°C freezer).
7. The heart, spleen, gonad and kidney were removed and stored in a Bio-Tite® container with 10% neutral buffered formalin for archival purposes.
8. The bottom fillet was removed for body burden analysis and stored in a Ziploc bag (-20°C freezer).
9. The otoliths were removed and stored in a coin envelope for fish aging.
10. Samples were grouped together by area and trawl number.

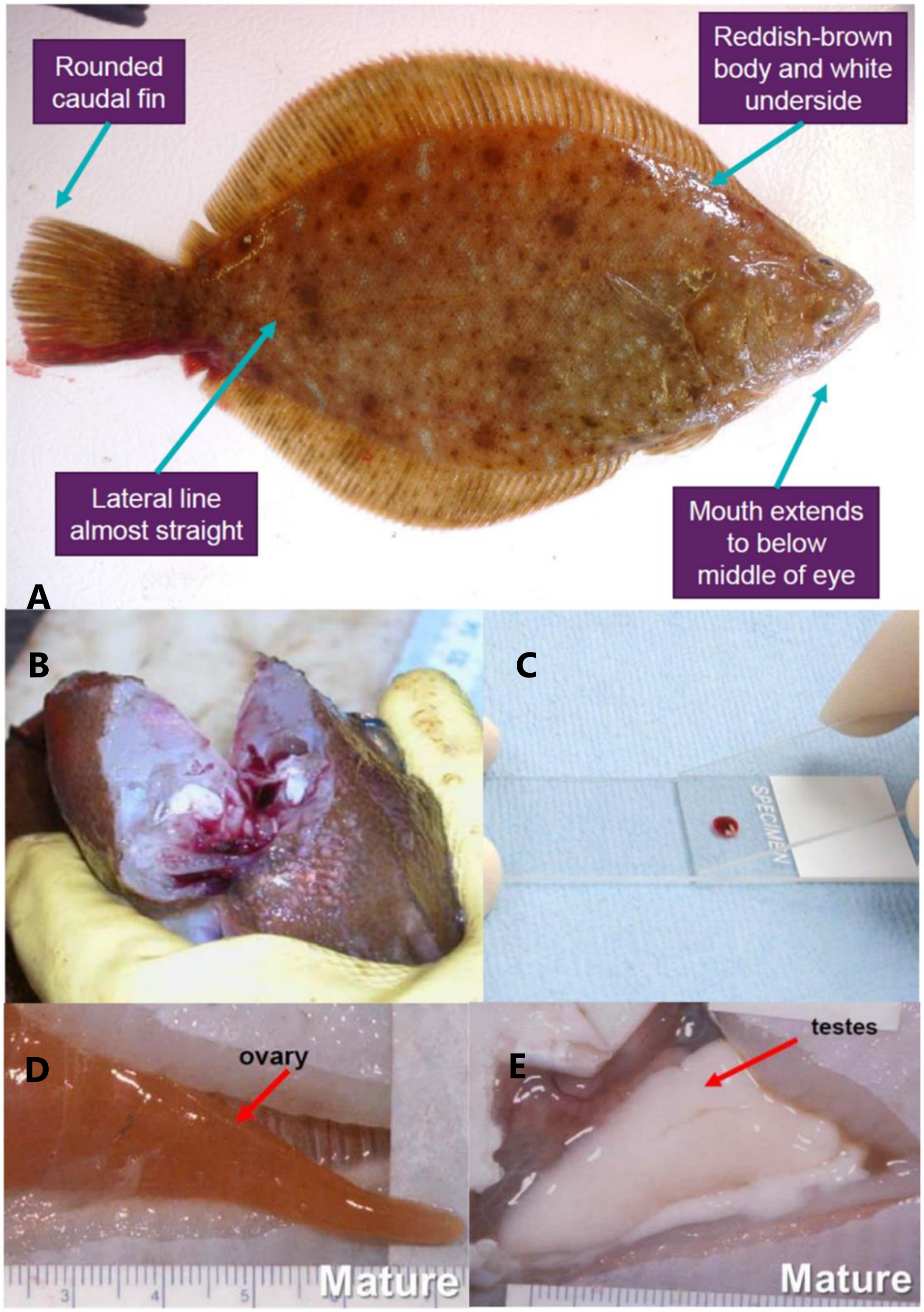


Figure 6-2: Examples of field sampling measures taken aboard the *Aqviq*: A) American plaice with identifying characteristics, B) otoliths being extracted, C) creating a blood smear, D) mature female ovary, and E) mature male testes.

6.1.3 Laboratory and Statistical Analysis

6.1.4 Chemical Profiling

All fillet and composite liver samples were analysed for metals, fuel and lube range hydrocarbons (>C_{10}-C_{32}), and polycyclic aromatic hydrocarbons (PAHs) (HMDC 2019a). Liver samples were composites of at least seven individual fish per sample, and composites were used to ensure sufficient portions for tests. Analytes listed in the design plan and additional tested analytes are listed in Table 6-2. Laboratory results for metals, hydrocarbons and PAHs were screened in for reporting and further analysis, if 50% or more of tested samples exceeded their reported detection limit (RDL) at one or more sites. One-way ANOVAs were used to compare between the Hibernia Field and Reference Area in 2020, and two-way ANOVAs were used to compare across years and sites. Where ANOVAs were used, assumptions (heterogeneity, normality, and independence) were checked to ensure a normal error structure was appropriate for analysis (Quinn and Keough 2002). Two methods were used to process samples below detection limits (RDL) as outlined in the Hibernia EEM Design Plan (HMDC 2019a):

- For descriptive statistics, the value of the RDL was used for calculation so as not to present mean values below the detection limit as per the design plan (HMDC 2019a).
- For statistical analysis, half RDL was used as a conservative value (HMDC 2019a).

Table 6-2: Analytes tested in American plaice fillets and liver composites in 2020.

Metals in Design Plan	Additional Metals	Hydrocarbons	PAHs in design plan	Additional PAHs
Arsenic	Aluminum	>C_{10}-C_{16}	1-Methylnaphthalene	Benzo(b/j)fluoranthene
Barium	Antimony	>C_{16}-C_{21}	2-Methylnaphthalene	
Cadmium	Beryllium	>C_{21}-C_{32}	Acenaphthene	
Chromium	Boron		Acenaphthylene	
Copper	Cobalt		Anthracene	
Iron	Lithium		Benzo(a)anthracene	
Lead	Molybdenum		Benzo(a)pyrene	
Manganese	Nickel		Benzo(b)fluoranthene	
Mercury	Silver		Benzo(g,h,i)perylene	
Selenium	Strontium		Benzo(j)fluoranthene	
Zinc	Thallium		Benzo(k)fluoranthene	
	Tin		Chrysene	
	Uranium		Dibenz(a,h)anthracene	
	Vanadium		Fluoranthene	
			Fluorene	
			Indeno.1.2.3.cd.pyrene	
			Naphthalene	
			Perylene	
			Phenanthrene	
			Pyrene	

6.1.5 Taste Testing

Chemical analysis of American plaice tissues may not necessarily detect an overall difference in sensory perception of the sampled tissues. Therefore, sensory evaluations were performed using two qualitative assays; the triangle test and the Hedonic Scaling test (HMDC 2019a).

The triangle test was used to qualitatively assess American plaice fillet samples for any disparities in sensory perception between samples collected from the Hibernia Field versus the Reference Area (HMDC 2019a). As described in Chapter 3, a panel of 24 people were each provided three unidentified fish tissue samples (homogenized and cooked to 35°C) and were asked to discriminate one from the other two. The test was ranked according to the number of panelists who were correctly able to discriminate the outlier sample.

The hedonic test was used to evaluate a preferential taste between two samples; one from each sampling area (also homogenized and cooked to 35°C). Preferences were ranked on a scale of according to 'dislike extremely' (1) to 'like extremely' (9). A one-way ANOVA was used to compared results between the Hibernia Field and Reference Area.

6.1.6 Fish Health Program

The fish health survey was conducted to qualitatively assess American plaice collected adjacent to the Hibernia Field and the Reference Area (Figure 6-1). Tissues were subsampled and used as health indicators as indicated in Section 5.3 of the EEM Design Plan (HMDC 2019a). As American plaice are sexually dimorphic, each sex was analyzed separately to account for growth differences and maturation rates (Swain and Morgan 2001). Raw data for measures reported in this section are found in Volume II.

6.1.7 Biological Characteristics

Many biological characteristics, such as delayed sexual maturity, stunted growth, and smaller livers or gonads can be caused by a variety of stressors which can occur naturally or due to the project. Sexual maturity stage was assessed for males and females according to standard Fisheries and Oceans indices and procedures (Templeman et al. 1978). Morphometric characters assessed included total fish length, total and gutted weight, liver and gonad weight, and age, as well as three indices: Fulton's condition index (FCI), hepatosomatic index (HSI), and gonadosomatic index (GSI). FCI is an indicator of overall body mass (length and gutted weight relationship) (Stevenson and Woods 2006). HSI is an indicator of liver mass relative to fish size and provides an indication of an animals' energy stores (Jan and Ahmed 2016). GSI is an indicator of gonad size relative to the size of the fish and variations provide an indicator of reproductive seasonality (Jan and Ahmed 2016). Parameters were compared between the Hibernia Field and Reference Area using one-way ANOVAs and across years and sites with two-way ANOVAs.

6.1.8 Gross Pathology

Body condition of fish, such as parasite load or poor condition of various organs, can be the result of long-term stressors which can occur naturally or due to the project. Gross pathology of specimens was documented using a fish autopsy-based condition assessment adapted from Goede and Barton (1990) (see Adams et al. 1993) for field codes and for assignment of a health assessment index value (Volume II). Three health assessment indices are used: all values, a modified value excluding skin and fins (as these may be a result of trawl damage), and another value excluding skin, fins, and parasites (as they may simply be a result of different life history of fishes). Assessments of the fish thymus were not conducted as it may have interfered with otolith extraction. Fish were examined individually in the onboard vessel laboratory by biologists and any macroscopic indications of disease, abnormalities, or lesions were noted for each specimen. Fisher's t-test was used to compare each pathology between the Hibernia Field and Reference Area, and one-way ANOVAs were used to compare the health assessment indices.

6.1.9 Haematology

Haematological changes are strongly related to fish health in response to environmental changes as blood integrates multiple levels of biological organization including the physiology, histology, cytology and hormonal regulation within and among organs and tissues (Corrêa et al. 2016). The percentage of neutrophils, lymphotcytes, and thrombocytes in 200 cell counts were completed by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University of Newfoundland (MUN) (HMDC 2019a). Comparisons between sites in 2020 were done using one-way ANOVAs, and across years and sites used two-way ANOVAs.

6.1.10 Mixed Function Oxygenases

Mixed function oxygenases (MFOs), fish liver detoxification enzymes, 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 et al. 2003). Measurement of MFO activity is used as a monitoring tool to indicate the presence of chemical contamination in fish (Hodson et al. 1991, Van Der Oost et al. 2003). To quantify MFO, the fluorometric activity of one of the most important bio-transforming enzymes in this group, ethoxyresorufin-O-deethylase (EROD), was measured via spectrophotometry (Hodson et al. 1991, Brooks et al. 2015, HMDC 2019a). 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). One-way ANOVAs were used to compare between sites in 2020, and two-way ANOVAs to compare across years and sites.

6.1.11 Histopathology

Chronic exposure of fish to crude oils is known to produce histopathological changes (Khan 1990, Stentiford et al. 2003, Agamy 2012). 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 are 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 2019a). The histological parameters examined included the presence of different lesions defined according to standard methods (Khan and Kiceniuk 1984, Khan 1990, 1995, Khan et al. 1994). Gill and liver samples were processed for histopathology comparisons by the CDRF using haematoxylin and eosin, which stains nuclei purple-blue and cytoplasm red-pink, respectively. Gill samples were assessed by the CDRF and liver samples were assessed by Dr. Rasul Khan. Fisher's t-test was used to compare each liver histology in 2020, while one-way ANOVAs were used to compare gill histology. Cross-year comparisons were completed using multivariate analysis of variance (MANOVA) incorporating each histopathology factor that was detected in fish, with two-way ANOVAs used to compare each factor in the MANOVA to verify which are driving any significant differences found.

6.2 Results

6.2.1 Field Collection

There were 12 trawls conducted at the Hibernia Field and 12 conducted at the Reference Area in 2020 (Figure 6-1). Trawl catches from the Hibernia Field and Reference Area are summarized in Figure 6-3 and representative specimens are shown in Figure 6-4. Total catches and catch per unit effort (CPUE) for both locations are summarized in Table 6-3. The most common catch at both sites was American plaice (*Hippoglossoides platessoides*), followed by yellowtail flounder (*Pleuronectes ferruginea*), followed by stalked tunicate (*Boltenia ovifera*) at the Hibernia Field and snow crab (*Chionoecetes opilio*) at the Reference Area (Table 6-3). The number of American plaice retained for processing from each tow is given in Table 6-4, and the start and end coordinates for each tow is given in Table 6-5.

Length-frequency distributions were created using 84 American plaice collected from each survey location in 2020 (Figure 6-5). Few male fish were caught overall in 2020 (n=14), and similar to previous years male fish were smaller than females on average (Figure 6-5). Male and female American plaice retained from both sites were comparable in size, though fish tended to be larger at the Reference Area for both sexes (Figure 6-5).

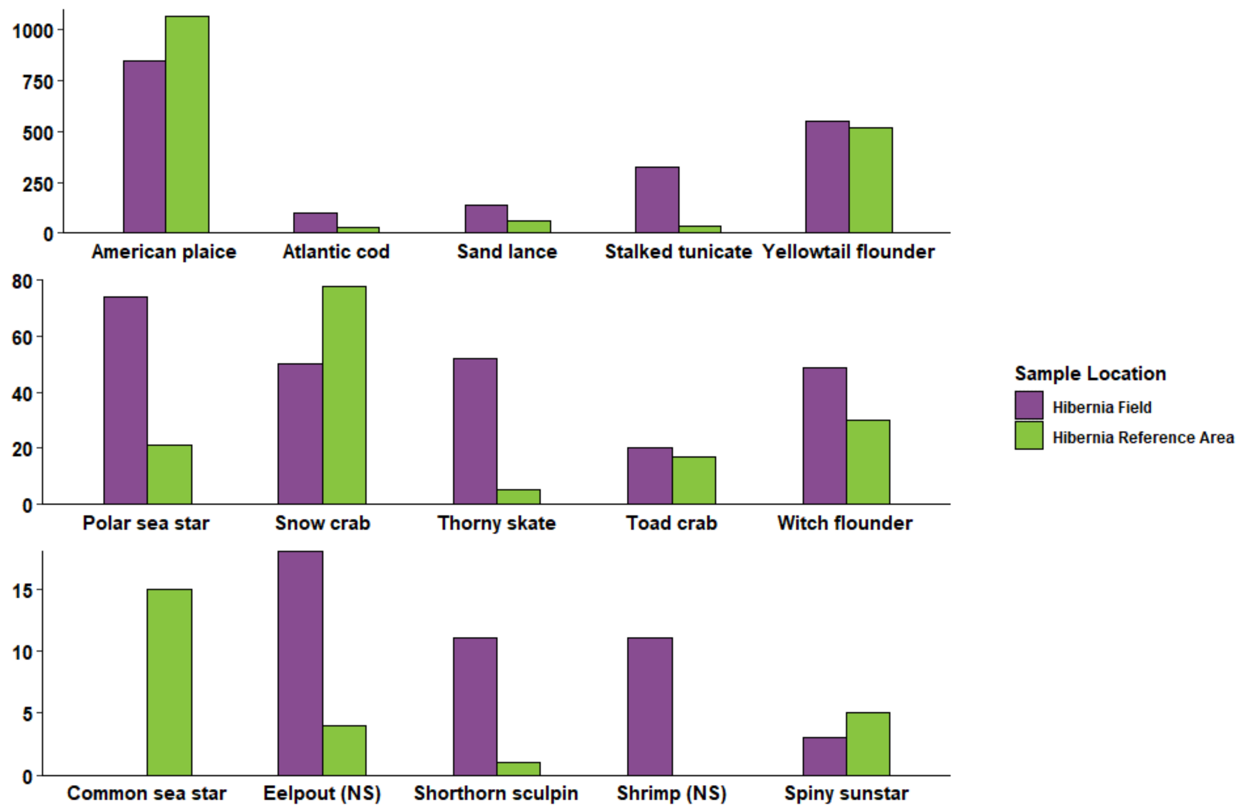


Figure 6-3: Catch at Hibernia Field and Reference Area during the 2020 EEM. Animals with four or fewer individuals are not included, see Table 6-3 for all fauna species caught.

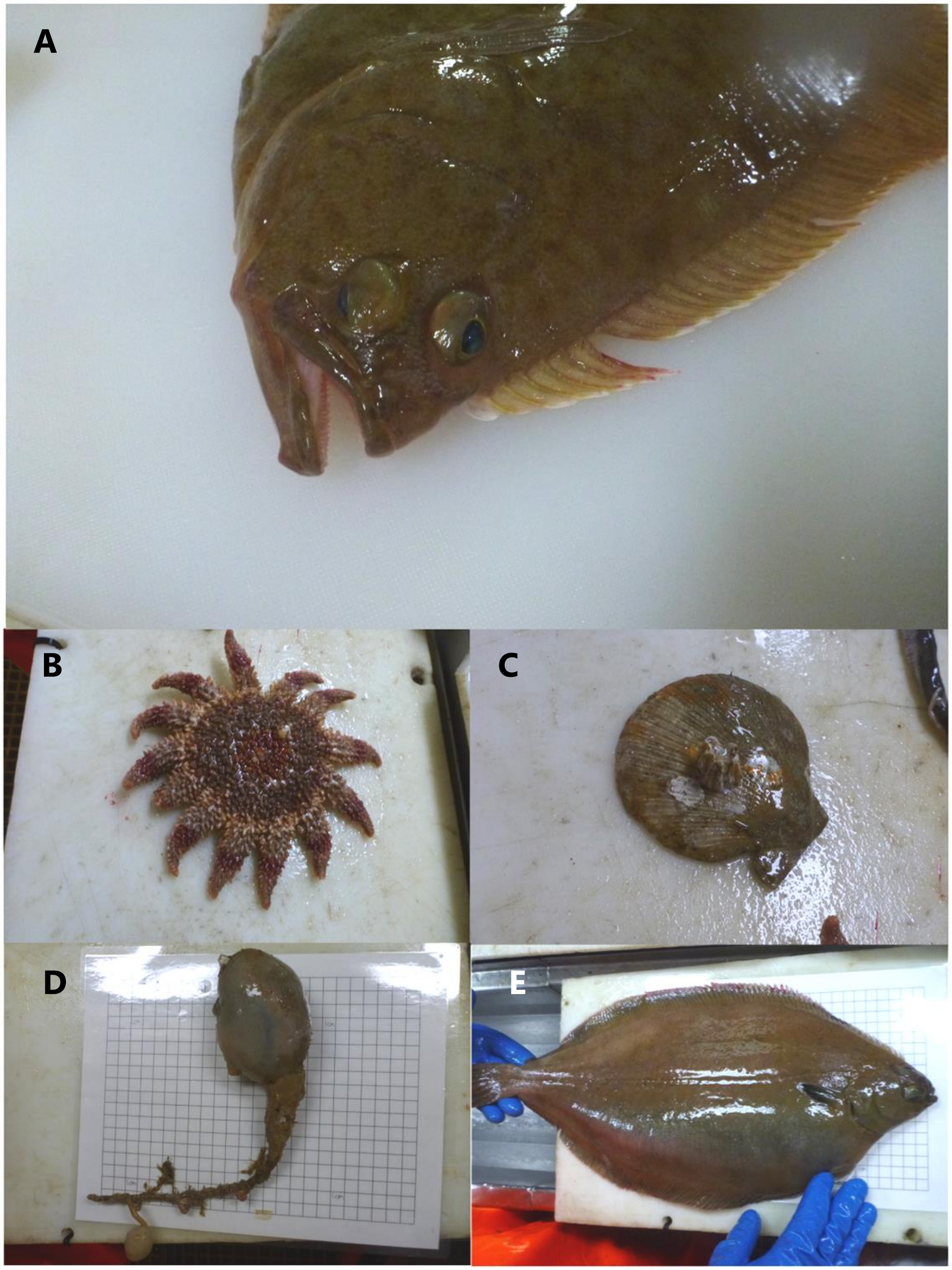


Figure 6-4: Representative catch species from the Hibernia 2020 EEM program: A) American plaice, B) spiny sunstar, C) Icelandic scallop, D) stalked tunicate, and E) witch flounder. See Table 7.1 for scientific names.

Table 6-3: Total catch per species and catch per unit effort (number per trawl) around the Hibernia Field and Reference Area, 2020.

Faunal Group	Species Name	Scientific Name	Hibernia Field		Reference Area	
			Total Catch	CPUE (n=12)	Total Catch	CPUE (n=12)
Fish	American plaice	*Hippoglossoides platessoides*	844	70.3	1068	89.0
Fish	Atlantic cod	*Gadus morhua*	98	8.2	29	2.4
Fish	Eelpout (NS)	Zoarcidae (F)	18	1.5	4	0.3
Fish	Laval's eelpout	*Lycodes lavalaei*	1	0.1	3	0.3
Fish	Longhorn sculpin	*Myoxocephalus octodecemspinosus*	1	0.1	3	0.3
Fish	Mailed sculpin	*Triglops* sp.	1	0.1	1	0.1
Fish	Sand lance	*Ammodytes dubius*	135	11.3	63	5.3
Fish	Sea raven	*Hemitripterus americanus*	0	0	2	0.2
Fish	Shorthorn sculpin	*Myoxocephalus scorpius*	11	0.9	1	0.1
Fish	Skate (NS)	Rajidae (F)	1	0.1	0	0
Fish	Snailfish	Liparidae (F)	1	0.1	0	0
Fish	Thorny skate	*Amblyraja radiata*	52	4.3	5	0.4
Fish	Witch flounder	*Glyptocephalus cynoglossus*	49	4.1	30	2.5
Fish	Yellowtail flounder	*Pleuronectes ferruginea*	550	45.8	519	43.3
Annelid	Polychaete (NS)	Polychaeta (C)	1	0.1	0	0
Ascidian	Stalked tunicate	*Boltenia ovifera*	325	27.1	31	2.6
Cnidarian	Soft coral	Capnellidae (F)	1	0.1	0	0
Cnidarian	Jellyfish (NS)	Medusozoa (SP)	2	0.2	4	0.3
Crustacean	Barnacle	Cirripedia (IC)	2	0.2	0	0
Crustacean	Northern shrimp	*Pandalus borealis*	2	0.2	3	0.3
Crustacean	Sculptured shrimp	*Sabinea* sp.	2	0.2	0	0
Crustacean	Shrimp (NS)	Decapoda (O)	11	0.9	0	0
Crustacean	Snow crab	*Chionoecetes opilio*	50	4.2	78	6.5
Crustacean	Toad crab	*Hyas* sp.	20	1.7	17	1.4
Echinoderm	Brittle star	Ophiuroidea (C)	0	0	3	0.3
Echinoderm	Common sea star	*Asterias rubens*	0	0	15	1.3
Echinoderm	Green sea urchin	*Strongylocentrotus droebachiensis*	3	0.3	0	0
Echinoderm	Spiny sunstar	*Crossaster papposus*	3	0.3	5	0.4
Echinoderm	Polar sea star	*Leptasterias polaris*	74	6.2	21	1.8
Mollusc	Bivalve (NS)	Bivalvia (C)	1	0.1	0	0
Mollusc	Icelandic scallop	*Chlamys islandica*	1	0.1	0	0

Notes:
Taxonomic Groups: SP – subphylum, C – Class, IC – Infraclass, O – Order, IO – Infraorder, F – Family

Table 6-4: Tows completed, and American plaice retained, for sampling and summary of samples taken for analysis.

Sampling area	Tow number	American plaice Retained	Liver samples collected	Fillet samples collected	Sensory analyses samples collected (g)
Hibernia Field	HIB-01	65	7	7	430.1
	HIB-02	62	7	7	326.6
	HIB-03	109	7	7	318.0
	HIB-04	169	7	7	676.3
	HIB-06	92	7	7	650.5
	HIB-08	25	7	7	769.3
	HIB-09	24	7	7	605.0
	HIB-10	99	7	7	474.8
	HIB-14	68	7	7	373.4
	HIB-16	41	7	7	376.7
	HIB-18	55	7	7	440.7
	HIB-19	24	7	7	323.7
	Total	**860**	**84**	**84**	**5765.1**
Reference Area	RAA-01	71	7	7	511.5
	RAA-02	86	7	7	556.5
	RAA-03	37	8	8	359.4
	RAA-04	150	7	7	313.0
	RAA-05	84	7	7	417.0
	RAA-06	85	7	7	634.6
	RAA-07	40	7	7	531.7
	RAA-08	67	7	7	675.4
	RAA-09	41	7	7	659.9
	RAA-10	85	7	7	611.0
	RAA-11	52	7	7	339.4
	RAA-12	144	7	7	326.0
	Total	**942**	**85**	**85**	**5935.4**

Table 6-5: Start and end coordinates for each trawl for the Hibernia Field 2020 commercial fish sampling.

Trawl ID	Depth (m)	Station Type	Start		End	
			Easting	Northing	Easting	Northing
HIB-01	77	Hibernia Field	665724.76	5184686.34	667088.22	5184540.69
HIB-02	79	Hibernia Field	666067.41	5184171.31	667504.94	5184022.25
HIB-03	77	Hibernia Field	667914.36	5184358.04	669296.70	5184226.40
HIB-04	78	Hibernia Field	668585.22	5184085.88	669833.24	5183620.67
HIB-06	81	Hibernia Field	671202.33	5183381.57	672377.57	5182803.58
HIB-08	80	Hibernia Field	673962.62	5182374.84	674782.31	5181340.30
HIB-09	75	Hibernia Field	662810.35	5181765.35	664189.19	5181682.45
HIB-10	78	Hibernia Field	666546.58	5181537.97	665177.21	5181689.17
HIB-14	79	Hibernia Field	668375.02	5180688.24	667537.98	5179645.46
HIB-16	75	Hibernia Field	668160.61	5175603.94	668795.16	5174342.88
HIB-18	75	Hibernia Field	670835.29	5172862.14	672152.98	5172276.93
HIB-19	78	Hibernia Field	672593.54	5172793.69	673595.88	5173728.86
RAA-01	82	Hibernia Reference Area	636597.00	5223534.18	636047.97	5220632.62
RAA-02	80	Hibernia Reference Area	637237.87	5219550.06	636453.29	5218462.74
RAA-03	77	Hibernia Reference Area	639074.81	5219759.63	639811.55	5220703.51
RAA-04	75	Hibernia Reference Area	639000.05	5218145.69	638133.16	5216956.15
RAA-05	77	Hibernia Reference Area	640335.97	5216926.30	641251.70	5218013.56
RAA-06	73	Hibernia Reference Area	639949.00	5214873.20	640837.84	5213908.36
RAA-07	80	Hibernia Reference Area	639908.90	5212274.22	640717.42	5211292.64
RAA-08	71	Hibernia Reference Area	638409.12	5212498.54	637475.01	5213458.98
RAA-09	79	Hibernia Reference Area	638007.55	5211028.99	638866.01	5209963.09
RAA-10	78	Hibernia Reference Area	636827.92	5209882.50	635863.30	5210898.08
RAA-11	75	Hibernia Reference Area	634462.38	5210610.52	633700.64	5209555.67
RAA-12	74	Hibernia Reference Area	631354.46	5209651.64	632168.06	5210670.26

Notes:
All coordinates are presented in UTM, Zone 22, NAD83

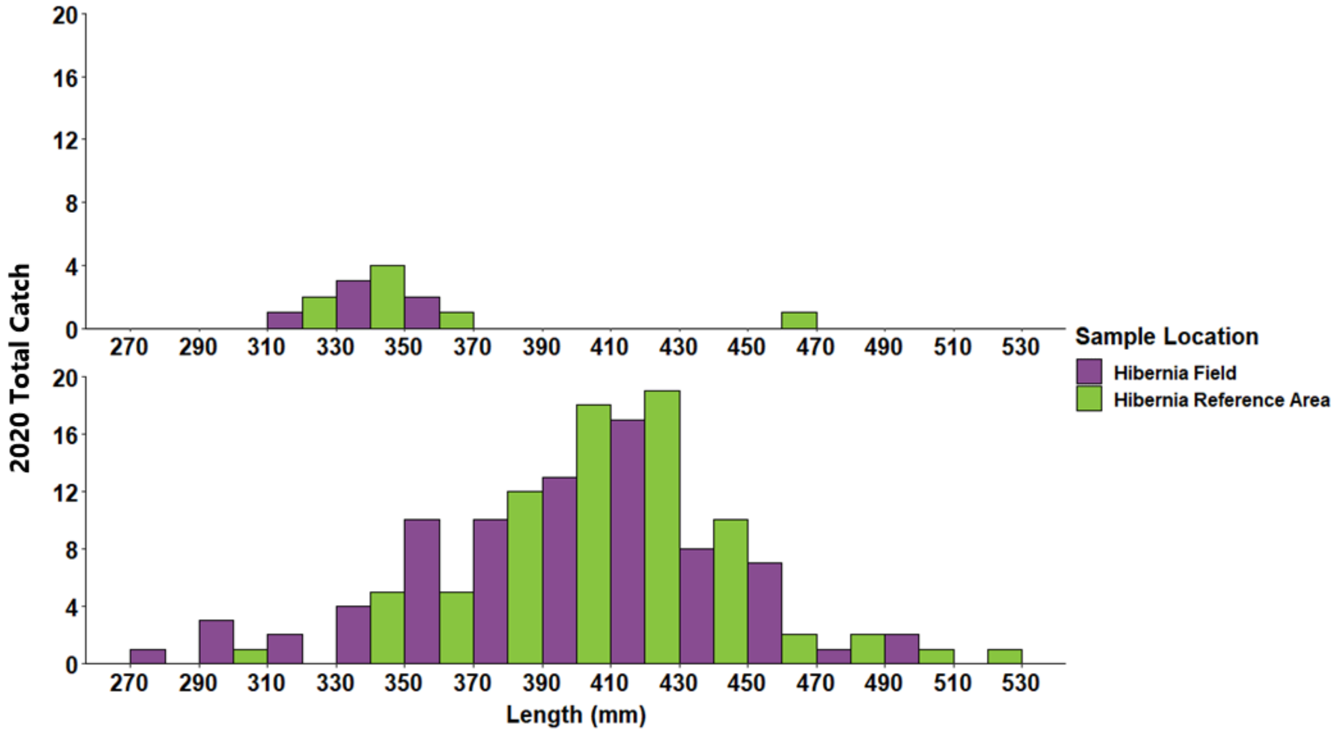
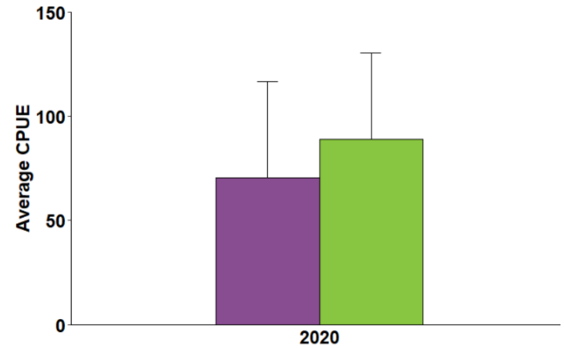
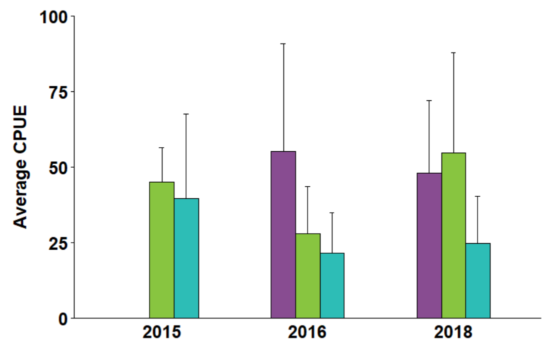
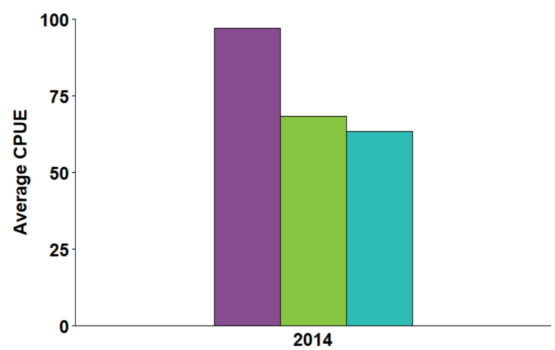


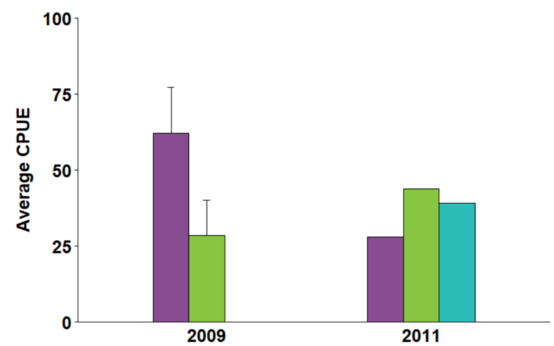
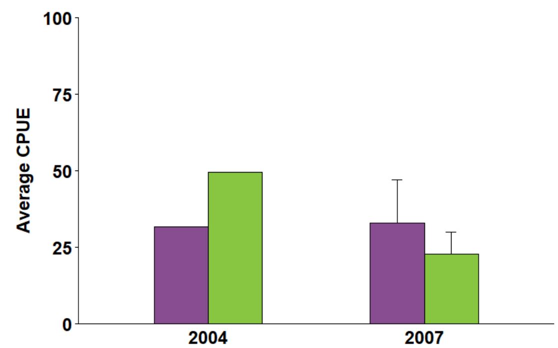
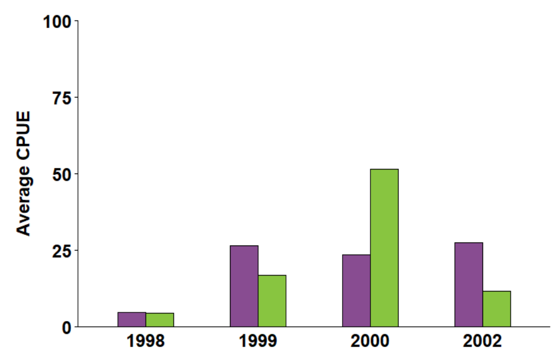
Figure 6-5: Length-frequency of male (A) and female (B) American plaice collected from the Hibernia Field and Reference Area in 2020.

6.2.1.1 Across-year Comparison

Fish in previous monitoring years for the Hibernia EEM were most recently collected aboard the Fisheries Research Vessel (FRV) *Nuliajuk* with a Campelen 1200 type trawl, while the 2020 EEM survey was aboard the OCI vessel *Aqviq* with a Goldentop 31 trawl (Table 6-6). As both trawls have different dimensions and differ in cod-end mesh size, catch per unit effort (CPUE) between these two time periods is not directly comparable, though generalizations can be made. In addition, HSE is no longer a separate trawling area and is included within the Hibernia Field. American plaice CPUE in 2020 was higher overall compared to 2015-2018, potentially as this cod-end mesh size is more effective for catching fish in the size class sampled as part of the EEM. Values between the Hibernia Field and Reference Area were similar in 2020 (Table 6-6).

Table 6-6: Catch per unit effort (CPUE) for American plaice from 1998-2020 across multiple sampling protocols

Trawl Details	Average Catch per Unit Effort
Monitoring Years: 2020 **Vessel**: OCI *Aqviq* **Gear Type**: Goldentop 31 trawl, with 145 mm cod-end **Tow Details**: 15-minute trawls at a speed of 3 knots **Legend:** **Sample Location** Hibernia Platform Hibernia Reference Area Hibernia Southern Extension	
Monitoring Years: 2015-2018 **Vessel:** *FRV Nuliajuk* **Gear type:** Campelen 1200 Trawl, with 44 mm cod-end **Tow details:** 15-minute tows at a speed of 3 knots.	
Monitoring Years: 2014 (HMDC 2017b) **Vessel:** *MV Kinguk* **Gear type**: Commercial Otter Trawl with 152 mm cod-end **Tow details:** 15-minute tows at a speed of 3 knots.	

Trawl Details	Average Catch per Unit Effort
Monitoring Years: 2009-2011 (HMDC 2012, 2014) **Vessel:** *MV Aqviq* **Gear type:** Commercial Otter Trawl with 154 mm cod-end **Tow details:** 15 minute tows at a speed of 3 knots	
Monitoring Years: 2004-2007 (HMDC 2005, 2009) **Vessel:** Canadian Coast Guard Vessels **Gear type:** Campelen 1800 Otter Trawl with cod-end liner removed. **Tow details:** 15 minute tows	
Monitoring Years: 1998-2002 (HMDC 1999, 2000, 2001, 2003) **Vessel:** Canadian Coast Guard Vessels **Gear type:** Campelen 1800 Otter Trawl with 44 mm cod-end **Tow details:** N/A	

6.2.2 Chemical Profiles of American Plaice Tissue

Twelve sets of tissue and composite liver samples were collected from American plaice from each of the two areas (Hibernia Field and Reference 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) at the Hibernia Field and Reference Area within fillets and liver composites is presented in Table 6-7 and Table 6-8.

For fillet tissue samples, both the Platform and Reference Area contained arsenic, mercury, and zinc above the detection limit in all twelve samples (Table 6-7). Only one other sample was above its RDL in 2020, with strontium detected at 2.0 mg/kg in one sample at the Hibernia Platform. No hydrocarbons were detected within the C_6-C_{32}

range in any sample, and no PAHs were among any sampled fillets (Table 6-7). One-way ANOVAs found no significant difference between the Hibernia Field and Reference Area for arsenic (p=0.842), mercury (p=0.277), or zinc (p=0.172) (Table 6-7).

For the liver composites, both the Platform and Reference Area samples contained arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc above the RDL in all twelve samples (Table 6-8). Two samples from the Reference Area (0.61 mg/kg and 0.14 mg/kg) and two from the Hibernia Field (0.13 mg/kg and 0.42 mg/kg) contained silver above RDL, and one sample from the Reference Area (1.6 mg/kg) and one sample from Hibernia Field (0.55 mg/kg) contained vanadium above RDL. Hydrocarbons from the $>C_{10}$-C_{16}, $>C_{16}$-C_{21}, and $>C_{21}$-C_{32} ranges were screened in, with six samples above RDL for $>C_{10}$-C_{16} hydrocarbons in the Reference Area, and four in the Hibernia Field (Table 6-8). No PAHs exceeded their RDL in any sample (Table 6-8). One-way ANOVAs found no significant difference between the Hibernia Field and Reference Area for arsenic, cadmium, copper, iron, mercury, selenium, or zinc (Table 6-8). Manganese was found to differ between the two sites (p=0.012) and was higher at the Reference Area (Table 6-8). Hydrocarbons in all three ranges did not significantly differ between sites (Table 6-8).

Table 6-7: Summary statistics of 2020 Hibernia Field and Reference Area fillet body burden data (mg/kg).

Parameter	RDL (mg/kg)	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	p-value
Hibernia Field Fillet composites (n=12)								**Reference Area Fillet composites (n=12)**						
Metals								**Metals**						
Arsenic	0.50	12	3.07	1.29	2.95	1.7	6.8	12	3.18	1.23	2.7	1.7	6.0	0.842
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Iron	15	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Mercury	0.01	12	0.062	0.027	0.052	0.032	0.110	12	0.076	0.034	0.071	0.027	0.160	0.277
Selenium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Zinc	1.5	12	4.18	0.38	4.15	3.6	4.9	12	4.43	0.45	4.4	3.8	5.5	0.172
Hydrocarbons								**Hydrocarbons**						
None detected, all samples <RDL (15 mg/kg)								None detected, all samples <RDL (15 mg/kg)						
PAHs								**PAHs**						
None detected, all samples <RDL (0.050 mg/kg) [a]								None detected, all samples <RDL (0.050 mg/kg)[a]						

Notes:
Bolded p-value denotes a significant result (α=0.05)
[a] RDL for Benzo(b/j)fluoranthene is 0.10 mg/kg

Table 6-8: Summary statistics of 2020 Hibernia Field and Reference Area liver composite body burden data (mg/kg).

Parameter	RDL (mg/kg)	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	p-value
Metals		**Hibernia Field Fillet (n=12)**						**Reference Area Fillet (n=12)**						
Arsenic	0.50	12	3.84	0.85	3.7	2.8	5.7	12	3.64	0.79	3.45	2.5	5.5	0.574
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	12	0.93	0.35	0.81	0.67	1.90	12	0.82	0.20	0.835	0.52	1.30	0.351
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	12	4.73	1.22	4.4	3.4	7.4	12	4.51	1.52	4.0	2.7	8.0	0.716
Iron	15	12	53.6	14.5	51	36	78	12	47.8	9.1	46.5	34	68	0.270
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	12	0.94	0.07	0.94	0.84	1.10	12	1.03	0.08	1.05	0.88	1.10	**0.012**
Mercury	0.01	12	0.050	0.015	0.050	0.023	0.074	12	0.053	0.018	0.048	0.033	0.097	0.697
Selenium	0.50	12	2.16	0.24	2.15	1.8	2.5	12	2.11	0.13	2.2	1.8	2.2	0.546
Zinc	1.5	12	31.1	3.5	30	27	37	12	30.1	2.8	31	25	35	0.466
Hydrocarbons								**Hydrocarbons**						
>C_{10}-C_{16}	15	4	18.1	5.5	15	<RDL	34	6	17.6	4.0	15.5	<RDL	28	0.824
>C_{16}-C_{21}	15	12	68.6	21.9	70	31	100	12	65.1	26.2	64	27	120	0.738
>C_{21}-C_{32}	15	12	170.2	77.8	165	70	300	12	158.9	42.2	155	97	240	0.678
PAHs								**PAHs**						
None detected, all samples <RDL (0.050 mg/kg) [a]								None detected, all samples <RDL (0.050 mg/kg) [a]						

Notes:
Bolded p-value denotes a significant result (α=0.05)
[a] RDL for Benzo(b/j)fluoranthene is 0.10 mg/kg

6.2.2.1 Across-Year Comparison of the Hibernia Field and Reference Area Tissue Data

Tissues collected in previous EEM years consisted of 10 fillets from individual fish and 10 liver composites, while 2020 EEM data now consists of 12 fillets from individuals and 12 liver composites. Consistent with the sediment chemistry analysis methodology, analytes having values below RDL in more than half of all samples tested were not subject to further analysis though values are mentioned in the text below.

Metals in Hibernia Field and Reference Area Fillets

Consistent with past EEM years, arsenic, mercury, and zinc were detected in all American Plaice fillets from both the Hibernia Field and Reference Area in 2020 (Table 6-7). No other metals, hydrocarbons, or PAHs were detected in fillet samples, with the exception of one detection of strontium at the Hibernia Field. Results from previous years have had sporadic samples above their RDL for aluminum, selenium, and strontium. The concentration of arsenic, mercury, and zinc in fish tissue from all EEM years is presented in Figure 6-6.

Separate two-way ANOVA results for arsenic, mercury, and zinc are given in Table 6-9. All three metals differed significantly between sampling years, and zinc also shows a significant interaction term (α=0.05). Figure 6-6 shows the concentration of each metal in all EEM sampling years, with large variations across time for each metal.

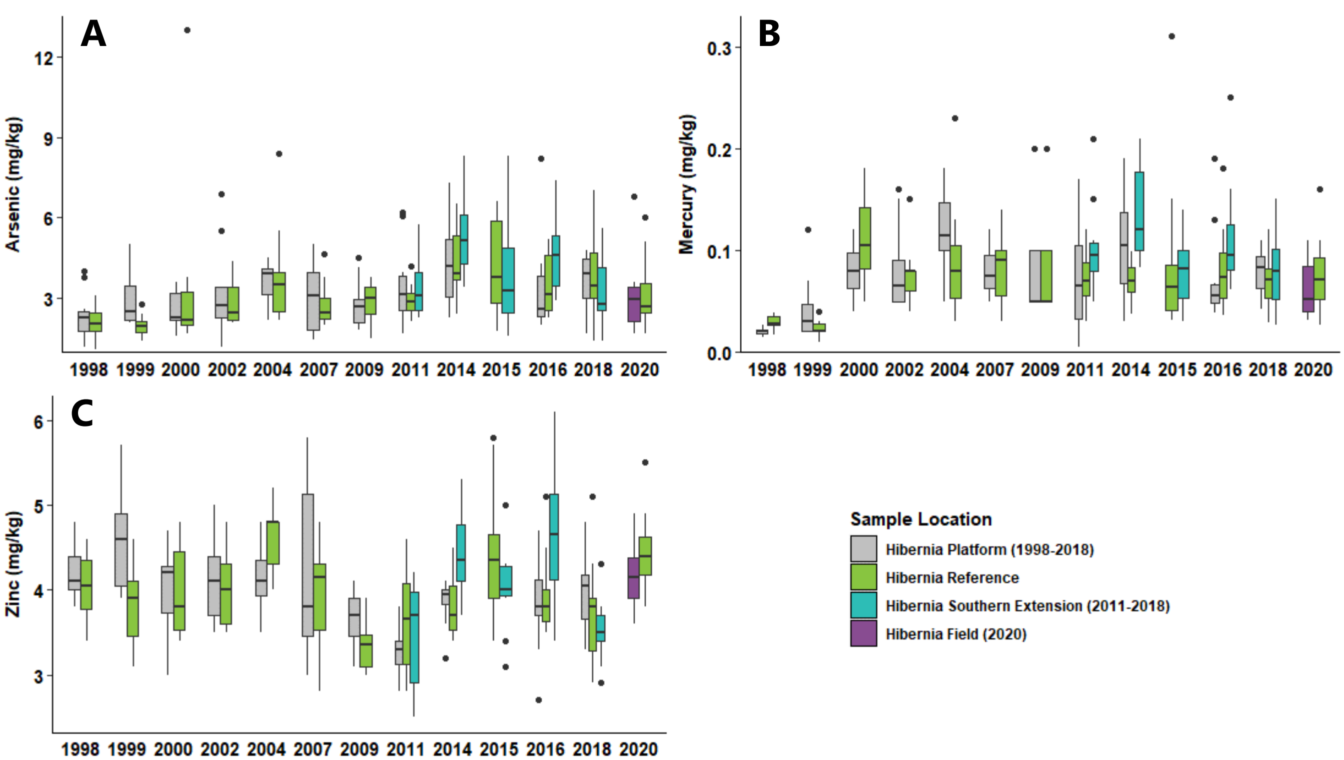


Figure 6-6: Boxplots of arsenic (A), mercury (B), and zinc (C) in American Plaice fillet tissue from the Hibernia Field and Reference Area from 1998-2020.

Table 6-9: Two-way ANOVAs for arsenic, mercury, and zinc concentration in fillet tissue from American Plaice collected from Hibernia Field and Reference Area from 1998 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	0.18	0.180	0.099	0.754
Year	11	74.41	6.764	3.701	**<0.001**
Site*Year	11	12.42	1.129	0.618	0.813
Residuals	243	444.19	1.828		
Mercury					
Site	1	8.0e-5	8.0e-5	0.062	0.804
Year	11	0.13	0.012	9.118	**<0.001**
Site*Year	11	0.021	1.9e-3	1.501	0.132
Residuals	243	0.313	1.3e-3		
Zinc					
Site	1	0.253	0.253	1.047	0.307
Year	11	18.641	1.695	7.018	**<0.001**
Site*Year	11	6.348	0.577	2.390	**0.008**
Residuals	243	58.673	0.241		
Notes: Bolded p-value denotes a significant result (α=0.05)					

Metals in Hibernia Field and Reference Area Livers

Consistent with past EEM years, arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in all liver composites for the Hibernia Field and Reference Area in 2020 (Table 6-8). Cobalt, silver, and vanadium have been inconsistently observed in samples from previous years. No samples were above RDL for cobalt in 2020, but two samples from both the Hibernia Field and Reference Area were above their RDL for silver, and one sample from both the Hibernia Field and Reference Area was above RDL for vanadium (see Section 6.2.2). These metals are not typically screened in for analysis, as greater than 50% of samples are not above RDL.

Comparisons across years (1998-2020) and across sites (Hibernia Field and Reference Area) for the eight metals listed above with greater than 50% of samples above RDL were compared using a two-way ANOVA. No difference between Years, Sites, or Site-Year interaction was observed for mercury (α=0.05; Table 6-10). Arsenic, cadmium, copper, iron, manganese, and selenium were significantly different between years (Table 6-10), with all metals but manganese lower in 2020 compared to 2018 (Figure 6-7, Figure 6-8). Zinc significantly differed between sites and years (Table 6-10) with higher values at the Reference Area compared to the Hibernia Field, and higher values in 1999 compared to other sampling years (Figure 6-8). No interaction terms were significant for any variable.

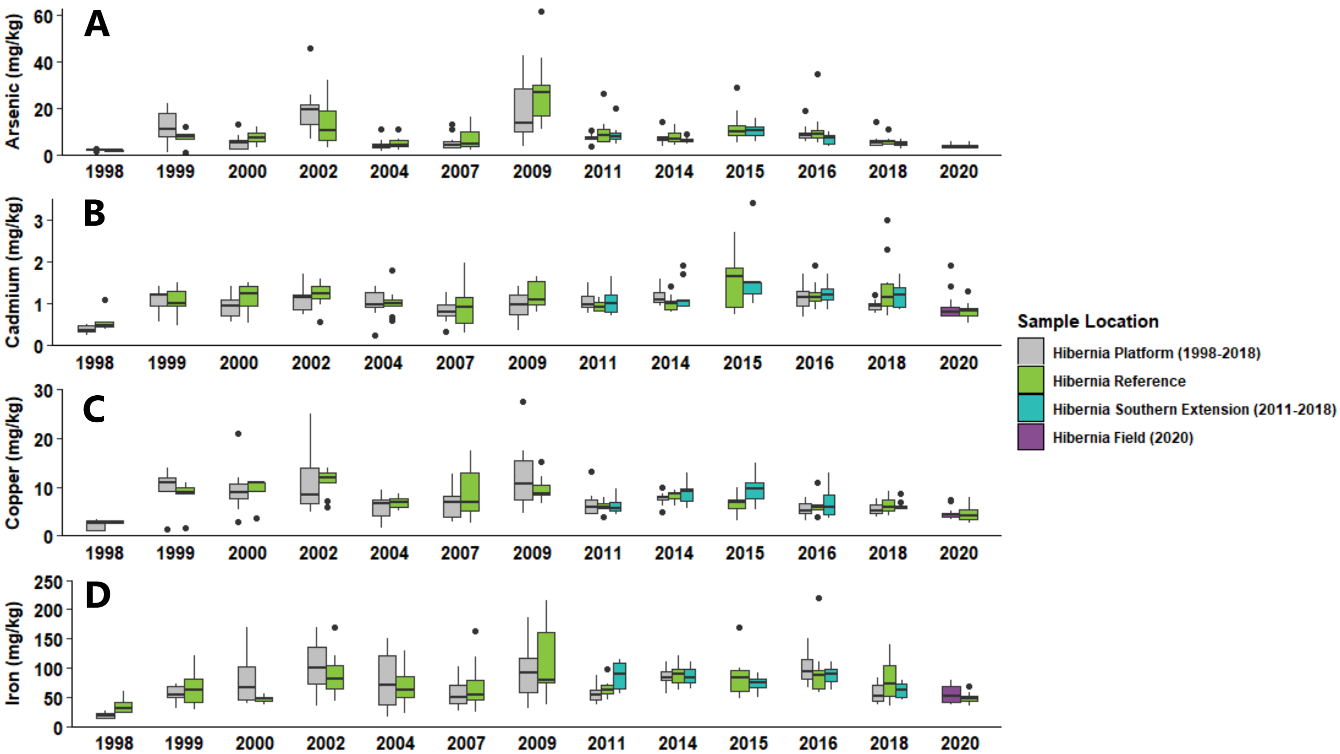


Figure 6-7: Boxplots of arsenic (A), cadmium (B), copper (C), and iron (D) in American Plaice liver composites from the Hibernia Field and Reference Area.

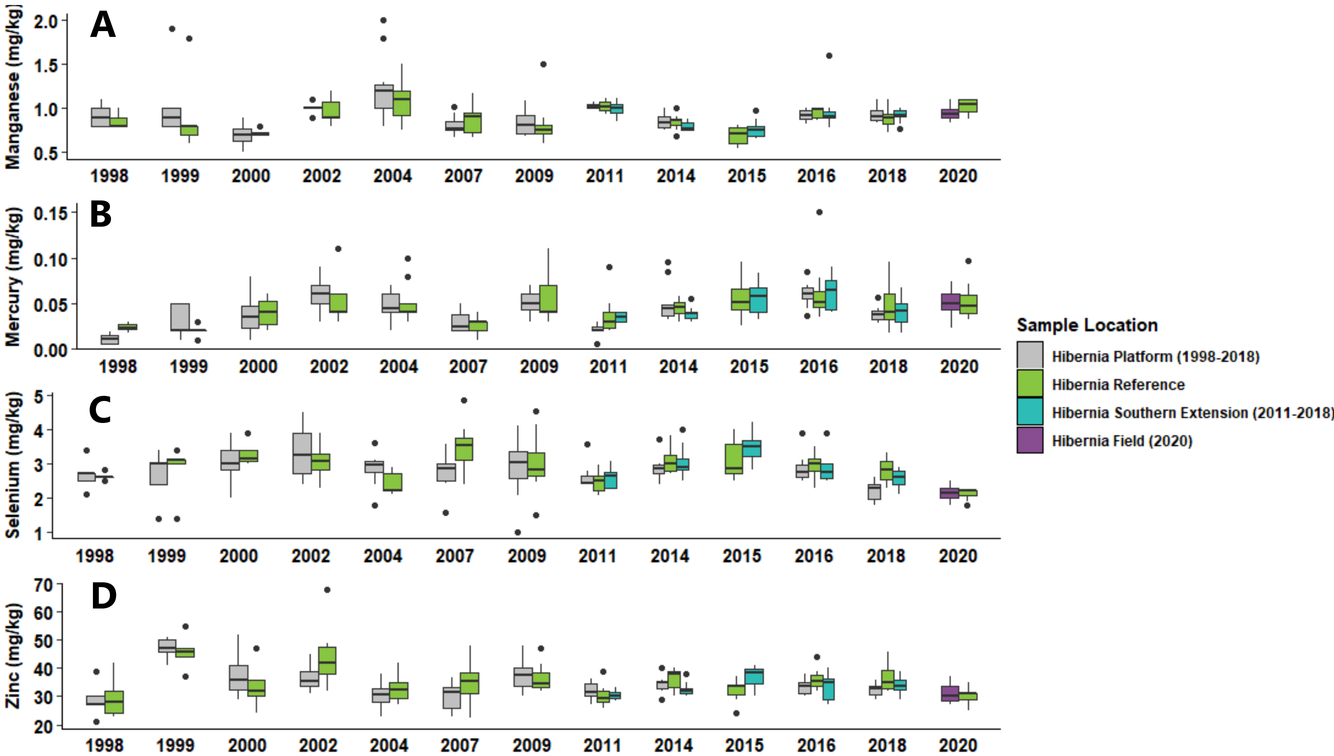


Figure 6-8: Boxplots of manganese (A), mercury (B), selenium (C), and zinc (D) in American Plaice liver composites from the Hibernia Field and Reference Area.

Table 6-10: Two-way ANOVAs for arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc concentration in liver composites from American plaice collected from Hibernia Field and Reference Area from 1998 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	18.9	18.9	0.439	0.509
Year	11	7389.2	671.8	15.586	**<0.001**
Site*Year	11	608.8	55.3	1.284	0.236
Residuals	188	8102.6	43.1		
Cadmium					
Site	1	0.283	0.283	2.599	0.109
Year	11	5.418	0.493	4.521	**<0.001**
Site*Year	11	1.576	0.143	1.315	0.219
Residuals	188	20.480	0.109		
Copper					
Site	1	0.03	0.029	0.003	0.958

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Year	11	1152.76	104.797	10.145	**<0.001**
Site*Year	11	72.13	6.558	0.635	0.798
Residuals	188	1942.10	10.330		
Iron					
Site	1	112	112.2	0.102	0.750
Year	11	80258	7296.2	6.629	**<0.001**
Site*Year	11	10639	967.2	0.879	0.562
Residuals	188	206938	1100.7		
Manganese					
Site	1	0.001	9.1e-4	0.031	0.861
Year	11	2.642	0.240	8.179	**<0.001**
Site*Year	11	0.281	0.026	0.869	0.572
Residuals	188	5.520	0.029		
Mercury					
Site	1	9.5e-3	9.5e-3	1.219	0.271
Year	11	0.133	0.012	1.555	0.115
Site*Year	11	0.061	5.6e-3	0.713	0.726
Residuals	188	1.464	7.8e-3		
Selenium					
Site	1	0.13	0.132	0.512	0.475
Year	11	22.35	2.032	7.858	**<0.001**
Site*Year	11	5.65	0.514	1.987	0.032
Residuals	188	48.61	0.259		
Zinc					
Site	1	120.7	120.73	4.435	**0.037**
Year	11	3336.7	303.34	11.142	**<0.001**
Site*Year	11	501.0	45.55	1.673	0.082
Residuals	188	5118.1	27.22		
Notes: Bolded p-value denotes a significant result (α=0.05)					

Hydrocarbons in Hibernia Field and Reference Area Tissues

No hydrocarbons were detected in fillets taken from the Hibernia Field or Reference Area in 2020 (Table 6-7). However, nearly all liver composites from both sites contained hydrocarbons in the $>C_{10}$-C_{16}, $>C_{16}$-C_{21} and $>C_{21}$-C_{32} range (only 6 samples at the Reference Area and 4 at the Hibernia Field in the $>C_{10}$-C_{16} range were above RDL; Table 6-8). Hydrocarbons in all three ranges did not differ between the Hibernia Field and Reference Area in 2020 (Table 6-8). All composites at both sites also contained unidentified compounds in the fuel/lube range (see Bureau Veritas report in Volume II).

The lower and upper fuel ranges were combined into $>C_{10}$-C_{21} to allow comparison to previous EEM years. Hydrocarbons in both the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} ranges are above RDL in the majority of EEM years. However,

>C_{10}-C_{16} hydrocarbons have not been screened in any previous EEM year since it has been analyzed separately, though two samples in 2015 at the Reference Area were above RDL. Comparisons across Sites and Years is presented in Figure 6-9. Hydrocarbons in both ranges significantly differed between years (Table 6-11), with values in 2020 for >C_{10}-C_{21} hydrocarbons higher than any other sampling year (Figure 6-9). Hydrocarbons in the >C_{21}-C_{32} range were higher in 2020 compared to 2016 or 2018, but lower than 2015 values which had the highest values of any EEM year.

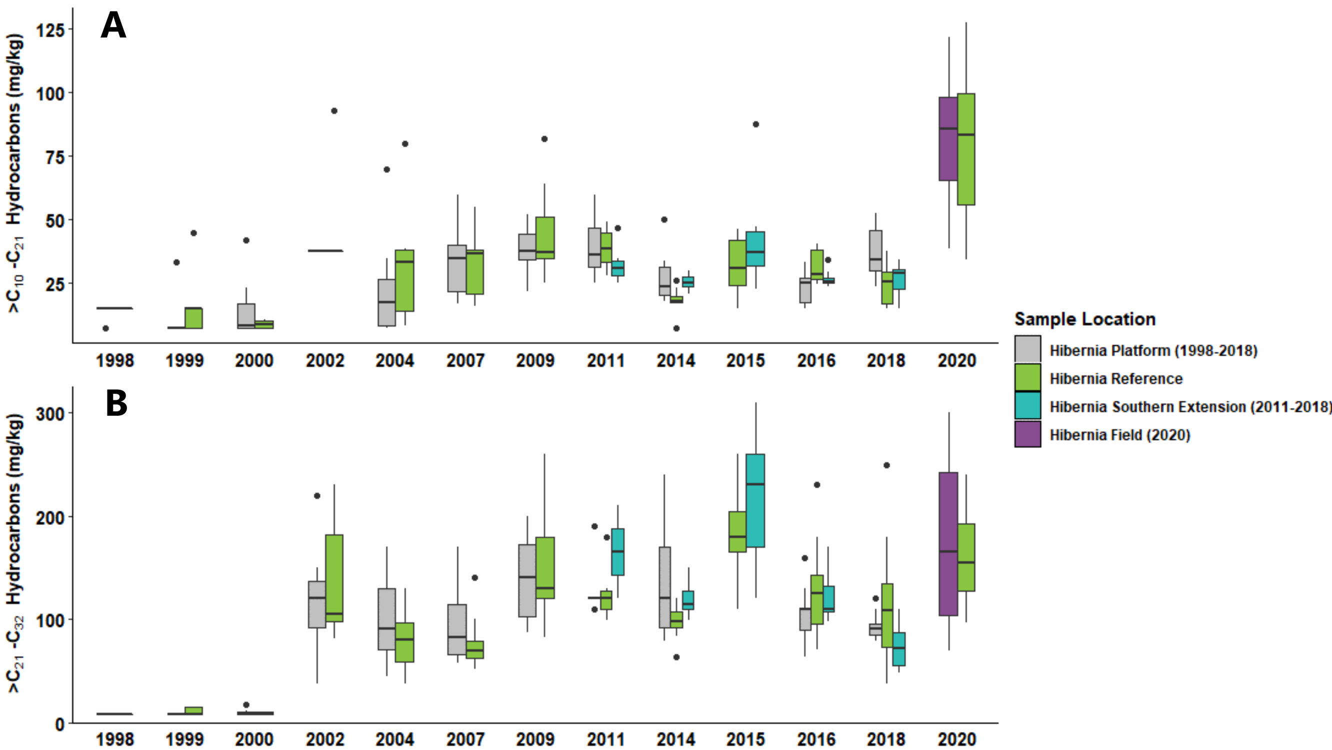


Figure 6-9: Boxplots of (A) >C_{10}-C_{21} hydrocarbons and (B) >C_{21}-C_{32} hydrocarbons in American plaice liver composites from the Hibernia Field and Reference Area from 1998-2020.

Table 6-11: Two-way ANOVAs for >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon concentrations in liver composites from American Plaice collected from Hibernia Field and Reference Area from 1998 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
>C_{10}-C_{21} Hydrocarbons					
Site	1	158	157.6	0.733	0.393
Year	11	72215	6565.0	30.559	**<0.001**
Site*Year	11	2431	221.0	1.029	0.423
Residuals	188	40389	214.8		
>C_{21}-C_{32} Hydrocarbons					
Site	1	648	648	0.368	0.545
Year	11	463160	42105	23.924	**<0.001**
Site*Year	11	19889	1808	1.027	0.424
Residuals	188	330879	1760		
Notes: Bolded p-value denotes a significant result (α=0.05)					

PAHs in Hibernia Field Tissues

No PAHs were detected in fillet or liver samples from either the Hibernia Field or the Reference Area in 2020 (Table 6-7). In past EEM years some PAHs have exceeded their RDLs, such as methylnaphthalene-2 and naphthalene in 2015, but have never been screened in for analysis because there was insufficient overall detection.

6.2.2.2 Taste Panels

For the 2020 Hibernia EEM program, 11 of 24 panelists were unable to successfully discriminate the odd sample in the triangle test which indicates panellists could not distinguish the unique sample (p=0.140). Comments from panelists for the triangle test are provided in Table 6-12. For the 2020 EEM, Hedonic taste tests showed no significant differences between the Hibernia Field and the Reference Area indicating no difference in sample preference (p=0.954; Table 6-13). Comments from panelists from the hedonic tests are provided in Table 6-14.

Past EEM programs at the Hibernia Platform have detected significant results for the triangle test, but never the hedonic taste test. Significant differences in the triangle test were seen in 2009 and 2011, with 14 out of 24 participants identifying the correct sample in both years (Table 6-15).

Table 6-12: Summary of comments from the triangle test for Hibernia Platform and Reference Area American plaice collected in 2020. Brackets are paraphrased text to clarify site.

Correctly guessed odd sample	Incorrectly guessed odd sample
Stronger flavour on (Hibernia Field).	I really didn't detect any difference in taste or odour. (Reference Area) was slightly better tasting.
(Reference Area) tastes sweeter.	(Hibernia Field) slightly more flavourful.
Found both the odour and taste was slightly different than other samples.	(Hibernia Field) was slightly more bland.
I think there was a distinct difference in the last (Hibernia Field).	(Hibernia Field) had a sweet taste.
No real discernable difference.	All taste identical. First had slight off odour.

Table 6-13: One-way ANOVA of Hedonic taste test preference evaluation of American plaice from Hibernia Platform and Reference Area in 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Between Groups	2	0.333	0.167	0.046	0.954
Within Groups	45	157.583	3.502		
Total	47	157.917			

Notes:
Bolded p-value denotes a significant result (α=0.05)

Table 6-14: Summary of comments from the Hedonic scaling test for Hibernia Platform and Reference Area American plaice collected in 2020. Brackets are paraphrased text to clarify site.

Preferred Reference Sample	Preferred Hibernia Field Sample
Can't say I like fish, tastes fine though.	(Hibernia Field) slightly sweet. (Reference Area) fishy flavour.
Sample (Hibernia Field) was more, bland taste. Both were good.	(Reference Area) taste had a strange aftertaste in my mouth, was not a fan. (Hibernia Field) tastes normal, like boiled fish.
(Hibernia Field) had a less desirable flavour.	Sample (Hibernia Field) was slightly less tasty to sample (Reference Area).
I preferred (Hibernia Field).	(Hibernia Field) had a lighter flavour.
(Hibernia Field) had an off taste.	(Hibernia Field) mild, sweeter.
	Sample (Hibernia Field) tasted nice. Sample (Reference Area) had a slight off flavour.
	(Reference Area) smelled old, tasted fishy, not pleasant, feed taste. (Hibernia Field) had off flavour like plastic.
	(Hibernia Field) has a prominent fishy aftertaste, more than would expect from a fish dish. (Reference Area) very fishy aftertaste.

Table 6-15: Summary of Hibernia Platform triangle and Hedonic taste test results across all EEM years.

Year	Triangle Test		Hedonic Taste Test
	# Correctly Identified	Significant Result	Significant Result
1995	8/24	No	No
1998	10/24	No	No
1999	5/24	No	No
2000	11/24	No	No
2002	11/24	No	No
2004	9/24	No	No
2007	9/24	No	No
2009	14/24	**Yes**	No
2011	14/24	**Yes**	No
2014	11/24	No	N/A*
2016	10/24	No	No
2018	10/24	No	No
2020	11/24	No	No

Notes:
*Hedonic taste test was not conducted for the 2014 EEM program.

6.2.3 Fish Health Program

6.2.3.1 Maturity Stages

Sexual maturity stages and the frequency (percentage) of fish presenting in each category at both locations is presented in Table 6-16. During the 2020 EEM program, six males and 78 females were collected at the Hibernia Field, and eight males and 76 females at the Reference Area. Fisher's exact test showed no difference in the ratio of male to female fish between Sites (p=0.78). No difference was found between maturity stage frequency for males or females between Sites (Table 6-16). As sample sizes for male fish are very low in 2020, statistical analyses have very little power for distinguishing differences between Sites.

Table 6-16: Frequencies (%) of maturity stages of male (top) and female (bottom) American plaice from the 2020 Hibernia Field EEM biological survey.

Male Maturity Stage (% of individuals)								
Area	**n**	**Immature (100)**	**Spent L (110)**	**Mat P (140)**	**Partly Spent (150)**	**Spent P (160)**	**Spent P (170)**	**Mat N (180 or 190)**
Hibernia Field	6	16.7	16.7	66.7	0	0	0	0
Reference Area	8	62.5	12.5	12.5	12.5	0	0	0
p-value		0.14	1.00	0.09	1.00	1.00	1.00	1.00

Female Maturity Stage (% of individuals)										
Area	**n**	**Immature (500)**	**Spent L (510)**	**Maturing A-P (520)**	**Mat B-P (530)**	**Maturing C-P (540)**	**Partly Spent P (550)**	**Spent P (560)**	**Spent P Mat N (570)**	**Mat N (580)**
Hibernia Field	78	25.6	5.1	32.1	12.8	3.8	2.6	16.7	1.3	0
Reference Area[1]	76	25.0	6.6	39.5	13.2	3.9	0	6.6	2.6	0
p-value		1.00	1.00	0.40	1.00	1.00	0.50	0.08	0.62	1.00

Notes:
[1] Two female fish from the Reference Area did not have maturity stages recorded
Maturity stages were defined according to DFO procedures (Templeman et al. 1978)
p-value obtained with the Fisher's Exact Test
Bolded p-value denotes a significant result (α=0.05)

6.2.3.2 Biological Characteristics

2020 Results

No significant variations between Sites existed for male and female American plaice sampled in 2020 (Table 6-17). Male gonad weight was near significance (p=0.059), with higher values at the Hibernia Field. Several parameters likely co-vary. For example, gutted weight is expected to increase with total fish length, and liver and gonad weights should increase with gutted weight (regardless of HSI and GSI values). This was controlled using analysis of co-variance (ANCOVA) with the regression of the variable of interest as the covariate, compared between Sites. Female fish gutted weight significantly differed between Sites after including total length as a covariate (Table 6-18)

Table 6-17: Averages and standard deviations of biological characteristics and condition indices of male (top) and female (bottom) American plaice from the Hibernia Field and Reference Area in 2020.

Parameter	Hibernia Field	Reference Area	p-value
Male			
No. of Fish	6	8	
Length (cm)	345.2 ± 16.1	350.3 ± 44.5	0.819
Total Body Weight (g)	360.2 ± 54.0	382.9 ± 184.3	0.791
Gutted Body Weight (g)	321.3 ± 51.3	332.5 ± 166.2	0.885
Liver Weight (g)	5.22 ± 0.99	6.70 ± 5.56	0.561
Gonad Weight (g)	3.75 ± 1.56	2.05 ± 1.26	0.059
Age (years) [a]	7.0 ± 1.2	8.0 ± 1.9	0.245
Fulton's Condition Index [b]	0.77 ± 0.03	0.73 ± 0.05	0.121
Hepatosomatic Index [c]	1.63 ± 0.20	1.83 ± 0.50	0.418
Gonadosomatic Index [d]	1.18 ± 0.51	0.77 ± 0.59	0.233
Female			
No. of Fish	78	76	
Length (cm)	400.2 ± 44.5	404.9 ± 37.4	0.476
Total Body Weight (g)	579.7 ± 188.4	571.7 ± 161.6	0.777
Gutted Body Weight (g)	478.9 ± 150.7	473.3 ± 132.2	0.810
Liver Weight (g)	10.09 ± 5.83	10.49 ± 3.79	0.610
Gonad Weight (g)	16.38 ± 9.38	18.41 ± 12.40	0.257
Age (years) [e]	10.0 ± 2.0	9.9 ± 1.4	0.372
Fulton's Condition Index [b]	0.71 ± 0.13	0.70 ± 0.07	0.651
Hepatosomatic Index [c]	2.16 ± 1.74	2.22 ± 0.54	0.174
Gonadosomatic Index [d]	3.23 ± 1.41	3.76 ± 2.31	0.245

Notes:
All data are expressed as average values ± standard deviation
[a] For male age calculations, n=6 for the Hibernia Field and n=8 for the Reference Area
[b] Calculated as 100 x gutted body weight (g) / length (cm)^3
[c] Calculated as 100 x liver weight (g) /gutted body weight (g)
[d] Calculated as 100 x gonad weight (g) /gutted body weight (g)
[e] For female age calculations, n=54 for the Hibernia Field and n=52 for the Reference Area
* Bolded p-value denotes significant results (α=0.05)

Table 6-18: Adjusted p-values from ANCOVA analysis of gutted, liver, and gonad weight for male (top) and female (bottom) American plaice from the Hibernia Field and Reference Area in 2020.

Variable	Covariate	Adjusted p-value [a]
Male		
Gutted weight (g)	Length (mm)	0.649
Liver Weight (g)	Gutted weight (g)	0.091
Gonad weight (g)	Gutted weight (g)	0.066
Female		
Gutted weight (g)	Length (mm)	**0.035**
Liver Weight (g)	Gutted weight (g)	0.447
Gonad weight (g)	Gutted weight (g)	0.097

Notes:
[a] p-value obtained after ANCOVA analysis of regression of variable on covariate.
Bolded p-value denotes significant results (α=0.05)

Across-year Comparison

The three indices (FCI, HSI, and GSI) were compared across years as they incorporate many biological factors (fish length and gutted, gonad, and liver weight). Two-way ANOVAs for both male and female American plaice for each index were used to compare changes (Table 6-19). For both male and female fish, Year was significantly different for every index with the exception of male HSI (Table 6-19, Figure 6-10). Additionally, male GSI also varied significantly between Sites, with higher values at Hibernia Field compared to the Reference Area (Table 6-19, Figure 6-10).

Table 6-19: Two-way ANOVA comparison of Fulton's condition index, hepatosomatic index, and gonadosomatic index for male (top) and female (bottom) American plaice sampled from the Hibernia Field and Reference Area from 2016 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male					
Fulton's Condition Index					
Site	1	0.001	0.001	0.087	0.769
Year	2	0.148	0.074	11.887	**<0.001**
Site*Year	2	0.021	0.011	1.707	0.185
Residuals	132	0.823	0.006		
Hepatosomatic Index					
Site	1	0.188	0.188	1.031	0.312
Year	2	0.533	0.266	1.464	0.235
Site*Year	2	0.633	0.317	1.740	0.180
Residuals	132	240.21	0.182		

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Gonadosomatic Index					
Site	1	7.295	7.295	5.047	**0.026**
Year	2	32.428	16.214	11.218	**<0.001**
Site*Year	2	0.073	0.037	0.025	0.975
Residuals	132	190.785	1.445		
Female					
Fulton's Condition Index					
Site	1	0.001	0.001	0.035	0.852
Year	2	0.207	0.104	5.488	**0.005**
Site*Year	2	0.013	0.006	0.344	0.709
Residuals	303	5.717	0.019		
Hepatosomatic Index					
Site	1	0.165	0.165	0.173	0.678
Year	2	21.959	10.980	11.520	**<0.001**
Site*Year	2	0.186	0.093	0.098	0.907
Residuals	303	288.775	0.953		
Gonadosomatic Index					
Site	1	0.5	0.53	0.024	0.878
Year	2	295.2	147.58	6.616	**0.002**
Site*Year	2	18.8	9.41	0.422	0.656
Residuals	302	6736.2	22.31		

Notes:
Bolded p-value denotes a significant result (α=0.05)

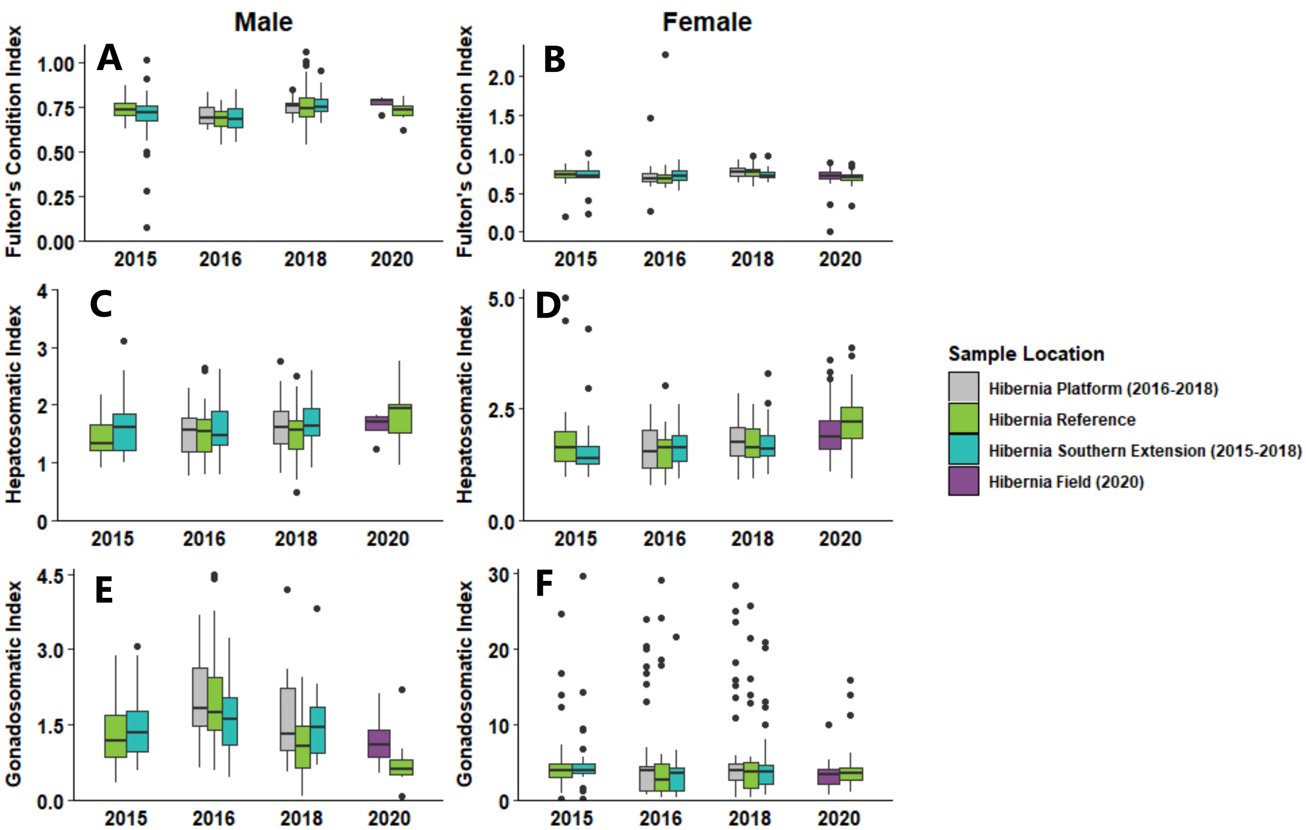


Figure 6-10: Boxplots of Fulton's condition index for male (A) and female (B) fish, hepatosomatic index for male (C) and female (D) fish, and gonadosomatic index for male (E) and female (F) American plaice sampled from the Hibernia Field and Reference Area from 2015 to 2020.

6.2.3.3 Gross Pathology

2020 Results

American plaice retained for fish health examination (≥250 mm) and tissue subsampling appeared overall in good condition at both the Hibernia Field and Reference Area. Example pathologies observed during the biological survey are presented in Figure 6-11. Several minor conditions were noted including localized discolouration on the liver (such as bile accumulation in the anterior region of the liver; Figure 6-11A), mild skin and fin abrasion (likely associated with trawl collection; Figure 6-11B), , and the presence of parasites in or on specimens (Figure 6-11A). These conditions and their prevalence at both sites are summarized in Table 6-20 for male and female plaice. There were no significant differences among any of the other parameters examined individually for males or females, aside from skin for female plaice differing between Sites (Table 6-20). The totals of fish health conditions were compiled and analyzed as the health assessment index (HAI; Table 6-20). No significant differences were found for either male or female fish in 2020.

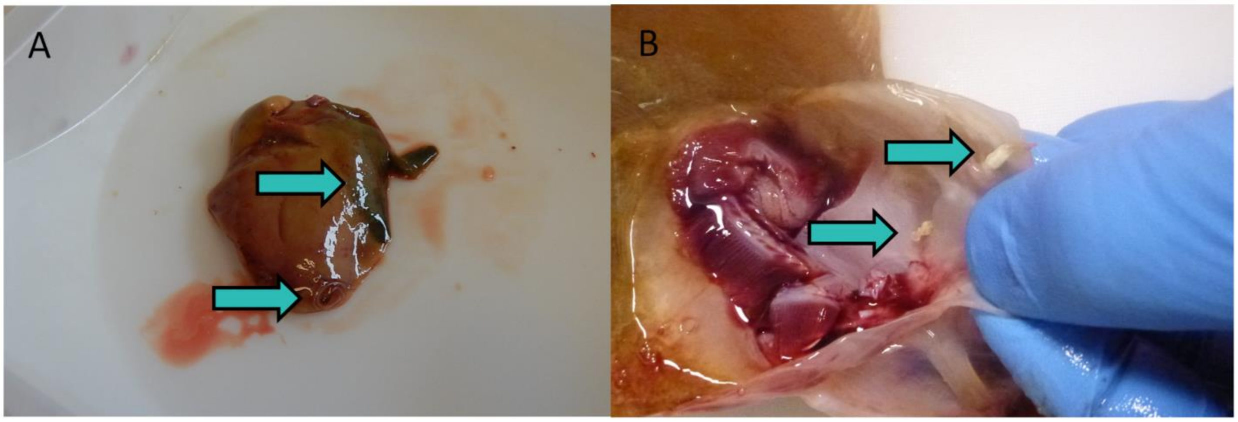


Figure 6-11: Examples of gross pathologies observed among American plaice from the Hibernia Field. A) nematode and green discolouration present on liver, B) parasitic copepod (*Acanthochondria* spp.).

Table 6-20: Pathologies and health assessment index of male (top) and female (bottom) American plaice from the Hibernia Field and Reference Area in 2020.

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Male	**Hibernia Field (n=6)**		**Reference Area (n=8)**			
Fins	0	0	0	0	1.000	Fisher's
Spleen	0	0	0	0	1.000	Fisher's
Hindgut	0	0	0	0	1.000	Fisher's
Kidney	0	0	0	0	1.000	Fisher's
Skin	0	0	0	0	1.000	Fisher's
Liver	6	100	8	100	1.000	Fisher's
Eyes	0	0	0	0	1.000	Fisher's
Gills	0	0	0	0	1.000	Fisher's
Parasites	1	16.7	2	25.0	1.000	Fisher's
Male	**Hibernia Field (n=6)**		**Reference Area (n=8)**		**p-value**	**Test used**
HAI	33.3 ± 8.2		32.5 ± 4.6		0.812	ANOVA
Modified.HAI.1	33.3 ± 8.2		32.5 ± 4.6		0.812	ANOVA
Modified.HAI.2	30.0 ± 0.0		30.0 ± 0.0		0.264	ANOVA
Female	**Hibernia Field (n=78)**		**Reference Area (n=76)**		**p-value**	**Test used**
Fins	0	0	0	0	1.000	Fisher's
Spleen	0	0	1	1.3	0.494	Fisher's
Hindgut	0	0	0	0	1.000	Fisher's
Kidney	0	0	0	0	1.000	Fisher's
Skin	3	3.8	10	13.2	**0.045**	Fisher's

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Liver	60	76.9	53	69.7	0.364	Fisher's
Eyes	0	0	0	0	1.000	Fisher's
Gills	0	0	0	0	1.000	Fisher's
Parasites	30	38.5	33	43.4	0.623	Fisher's
Female	**Hibernia Field (n=)**		**Reference Area (n=)**		**p-value**	**Test used**
HAI	30.0 ± 14.8		27.9 ± 14.6		0.376	ANOVA
Modified.HAI.1	29.6 ± 14.5		26.6 ± 14.4		0.195	ANOVA
Modified.HAI.2	23.1 ± 12.7		21.3 ± 13.7		0.410	ANOVA

Notes:
Bold p-value denotes significant result (α=0.05)
Health Assessment Index data is the average value ± standard deviation
Modified.HAI.1 - Removed Skin and Fins
Modified.HAI.1 - Removed Skin, Fins, and Parasites

Across-year Comparison

The three health assessment indices (HAI, mod. 1, and mod. 2) were compared between the Hibernia Field and Reference Area from 2016 and 2020 (no gross pathology data available for 2015). Significant differences were found for Site and Year for all HAI modifications for both male and female fish, with the exception of HAI mod. 2 for female fish which differed by year but not Site (Table 6-21, Figure 6-12, Figure 6-13). No HAI modification for either sex had significant interaction terms.

Table 6-21: Two-way ANOVA for male and female American plaice comparing the three HAI modifications (HAI, mod. 1, and mod. 2) at the Hibernia Field and Reference Area from 2016 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male					
Health Assessment Index (HAI)					
Site	1	8176	8176	27.396	**<0.001**
Year	2	2323	1162	3.893	**0.023**
Site*Year	2	1121	560	1.878	0.157
Residuals	132	39394	298		
HAI Modification 1 (Removed skin and fins)					
Site	1	7370	7370	24.936	**<0.001**
Year	2	3625	1813	6.133	**0.003**
Site*Year	2	1521	761	2.573	0.080
Residuals	132	39014	296		
HAI Modification 2 (Removed skin, fins, and parasites)					
Site	1	4530	4530	19.930	**<0.001**
Year	2	4092	2046	9.000	**<0.001**

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Site*Year	2	771	386	1.697	0.187
Residuals	132	30005	227		
Female					
Health Assessment Index (HAI)					
Site	1	1304	1304	4.401	**0.037**
Year	2	3968	1984	6.699	**0.001**
Site*Year	2	659	329	1.112	0.330
Residuals	303	89740	296		
HAI Modification 1 (Removed skin and fins)					
Site	1	1319	1319	4.677	**0.031**
Year	2	6883	3442	12.207	**<0.001**
Site*Year	2	241	120	0.427	0.653
Residuals	303	85432	282		
HAI Modification 2 (Removed skin, fins, and parasites)					
Site	1	201	201	0.919	0.338
Year	2	8291	4145	18.978	**<0.001**
Site*Year	2	155	78	0.355	0.702
Residuals	303	66185	218		
Notes: Bolded p-value denotes a significant result (α=0.05)					

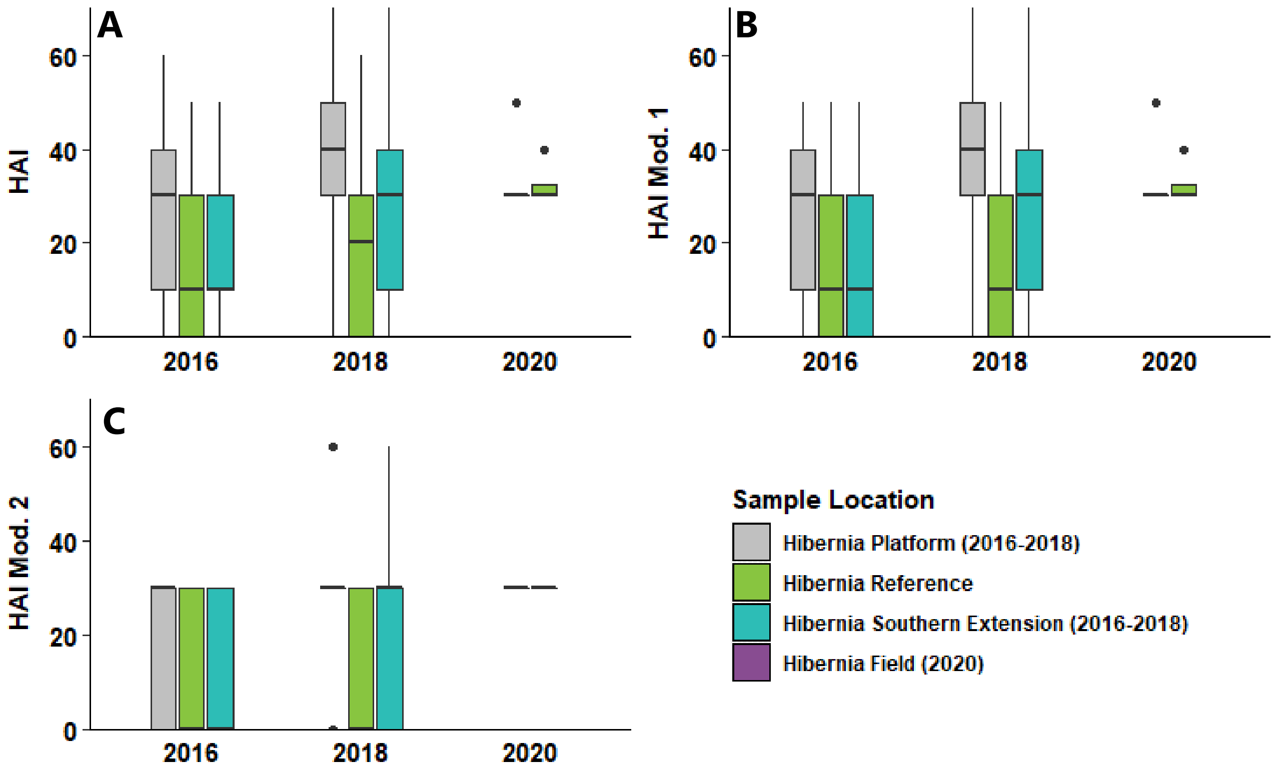


Figure 6-12: Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for male American plaice sampled at the Hibernia Field and Reference Area from 2016 to 2020.

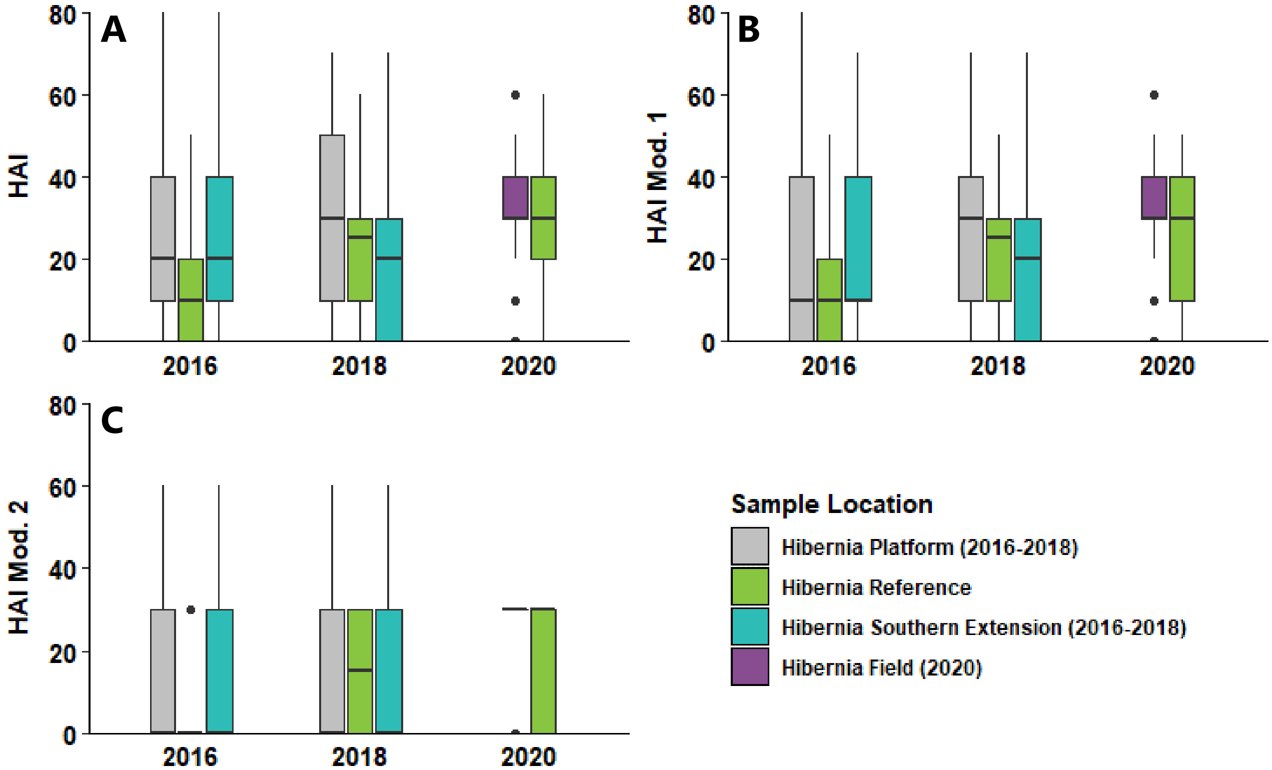


Figure 6-13: Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for female American plaice sampled at the Hibernia Field and Reference Area from 2016 to 2020.

6.2.3.4 Haematology

Blood smears were collected from 60 fish at both the Hibernia Field and Reference Area in 2020, and examples of each cell type can be found in Figure 6-14. These counts are used to prepare percentages of these cells in a minimum of 200 white blood cells.

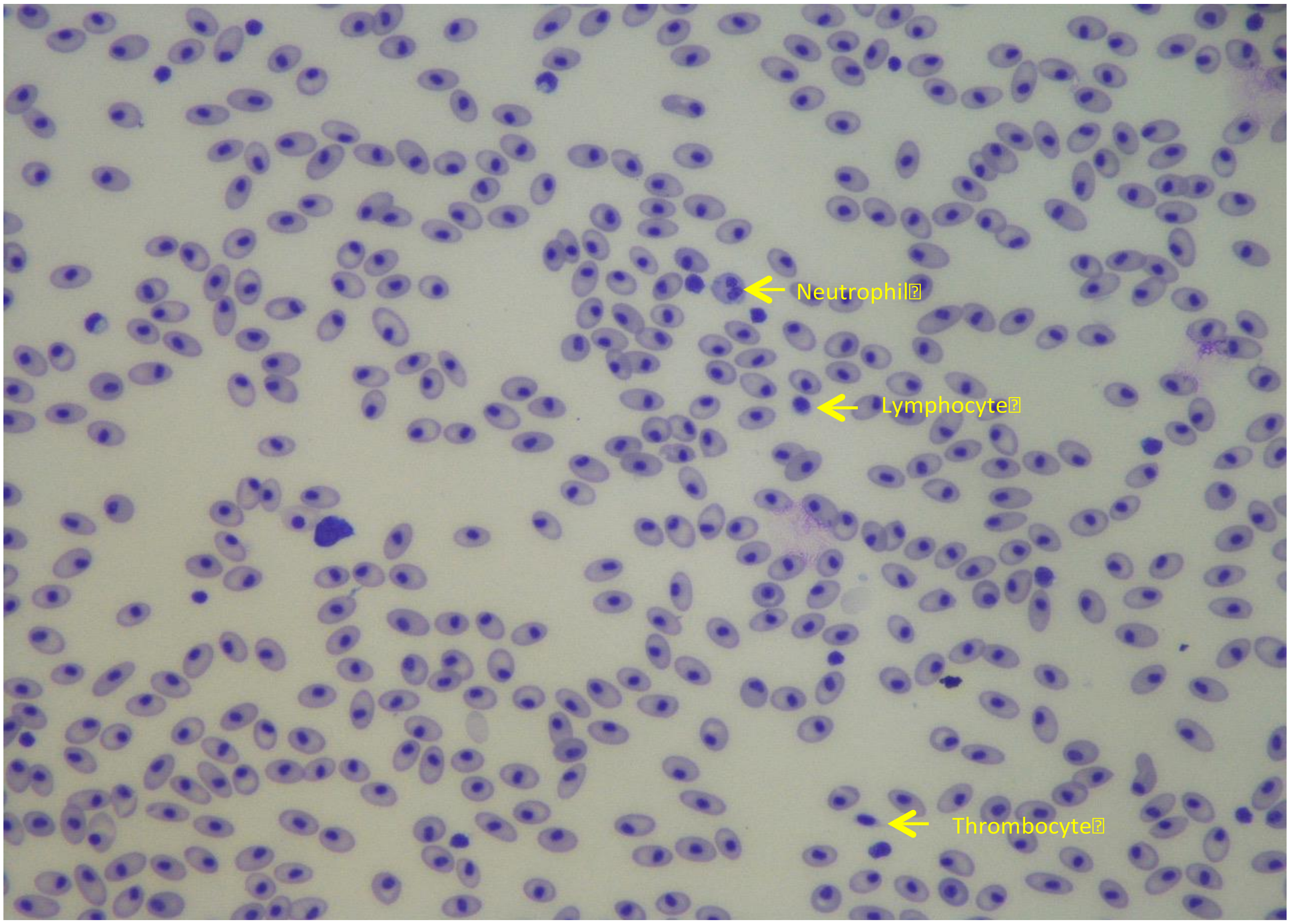


Figure 6-14: Example of cell types in blood smear from American plaice. Arrows indicate a neutrophil (top), lymphocyte (middle), and thrombocyte (bottom). Image provided by CDRF (MUN).

2020 Results

For 2020, no significant difference was found between Sites for neutrophils (Table 6-22), however lymphocytes and thrombocytes both significantly differed. Lymphocytes were higher at the Hibernia Field, while thrombocytes were higher at the Reference Area (Table 6-22).

Table 6-22: Frequencies of blood cell types in American plaice from the 2020 Hibernia biological survey.

Cell Type	Hibernia Field (n=60)	Reference Area (n=60)	p-value
Lymphocytes (%)	96.48 ± 3.75	94.55 ± 4.37	**0.011**
Neutrophils (%)	0.96 ± 0.85	0.79 ± 0.89	0.283
Thrombocytes (%)	2.56 ± 3.65	4.67 ± 4.34	**0.005**
Notes: All data expressed as mean percentage ± standard deviation of each type of cell on at least 200 white blood cells counted per fish.			

Across-year Comparison

Haematology results taken in 2015 were not suitable for analysis, and so results presented here are from 2016 to 2020. Results from before 2015 are not presented to ensure consistency, as different laboratories conducted the haematology counts. Significant differences were found between Years for all cell types (Table 6-23), with lower values in 2020 for neutrophils and thrombocytes, and higher in 2020 for lymphocytes (Figure 6-15). Site was also significantly different for lymphocytes and thrombocytes (Table 6-23), with lymphocytes higher at the Hibernia Platform and thrombocytes higher at the Reference Area (Figure 6-15).

Table 6-23: Two-way ANOVA of the percent of neutrophils, lymphocytes, and thrombocytes from the blood smears of American plaice collected from the Hibernia Field and Reference Area from 2016 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Neutrophils (%)					
Site	1	1.20	1.20	0.480	0.489
Year	2	342.63	171.32	68.443	**<0.001**
Site*Year	2	0.60	0.30	0.119	0.888
Residuals	307	768.43	2.50		
Lymphocytes (%)					
Site	1	258	257.6	8.287	**0.004**
Year	2	587	293.7	9.448	**<0.001**
Site*Year	2	1	0.5	0.017	0.983
Residuals	307	9544	31.1		
Thrombocytes (%)					
Site	1	294	294.0	9.912	**0.002**
Year	2	822	411.1	13.860	**<0.001**
Site*Year	2	2	1.0	0.033	0.967
Residuals	307	9106	29.7		
Notes: Bolded p-value denotes a significant result (α=0.05)					

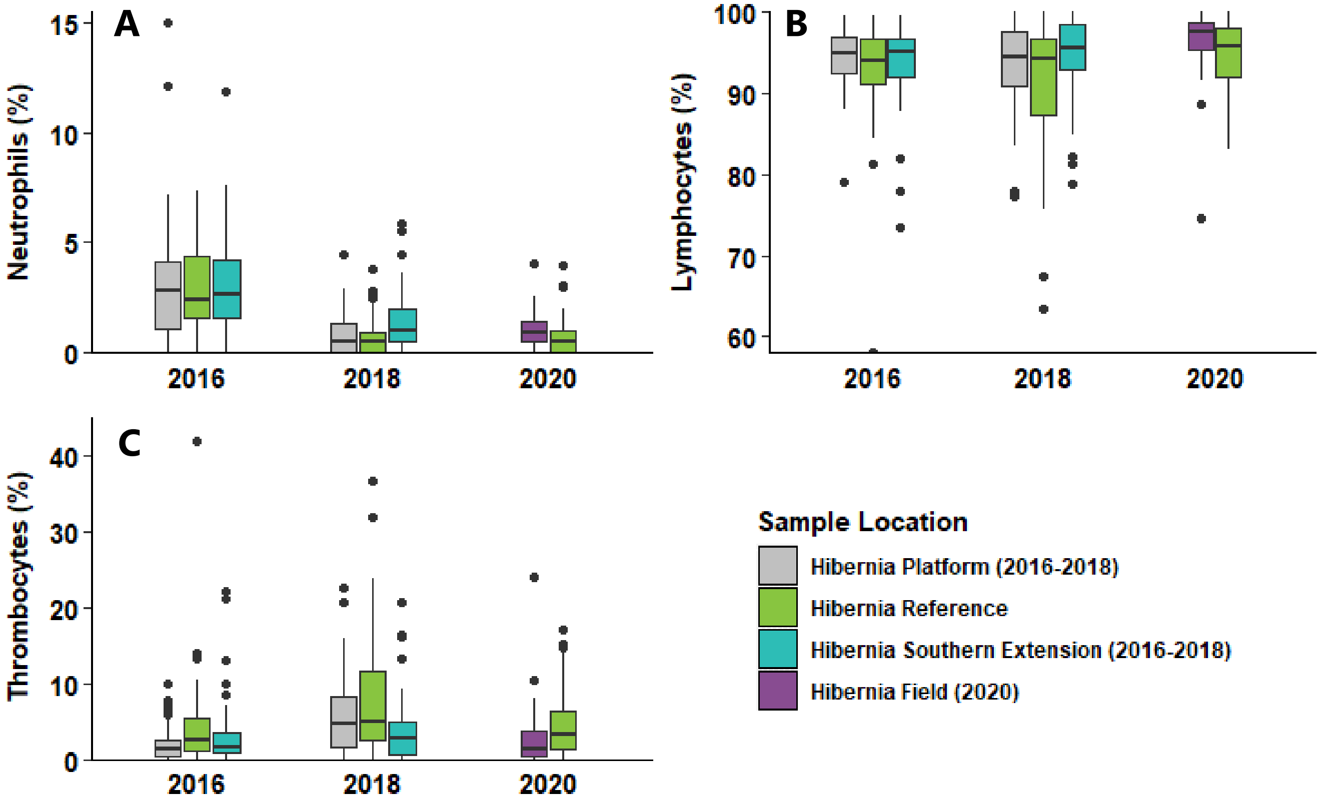


Figure 6-15: Boxplots of the percentage of neutrophils (A), lymphocytes (B), and thrombocytes (C) from blood smears of American Plaice taken from the Hibernia Field and Reference Area from 2016 to 2020.

6.2.3.5 Mixed Function Oxygenase Activity

2020 Results

A significant difference was found between female American plaice collected from the Hibernia Field and the Reference Area (p=0.09; Table 6-24). No difference was found for male fish between Sites (p=0.146; Table 6-24).

Table 6-24: Mixed function oxygenase activity (pmol resorufin / mg protein / min) from male (top) and female (bottom) American plaice sampled from the Hibernia Field and Reference Area in 2020.

Mixed Function Oxygenase (pmol resorufin / mg protein / min)			
Male	**Hibernia Field (n=6)**	**Reference Area (n=8)**	**p-value**
MFO (EROD)	25.8 ± 20.4	13.6 ± 7.9	0.146
Female	**Hibernia Field (n=78)**	**Reference Area (n=76)**	**p-value**
MFO (EROD)	13.3 ± 10.2	8.8 ± 6.8	**0.009**
Notes: All data expressed as mean percentage ± standard deviation Bolded p-value denotes significant result (α=0.05)			

Across-year Comparison

Two-way ANOVAs were used to compare MFO activity across both Sites (Hibernia Field and Reference Area) and years (2016 to 2020) for male and female American plaice. Both analyses had significant results in their interaction terms and between Years (Table 6-25). Figure 6-16 shows the cause of the significant interactions, with much higher results in 2018 compared to 2016 and 2020, and variation in whether the Hibernia Field or Reference Area fish have a higher mean in a given year.

Table 6-25: Two-way ANOVA of mixed function oxygenase (MFO) activity (pmol resorufin / mg protein / min) collected from American plaice at the Hibernia Field and Reference Area from 2016 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male					
Site	1	6.2	6.2	0.026	0.871
Year	2	4150.0	2075.0	8.839	**<0.001**
Site*Year	2	1531.2	765.6	3.261	**0.043**
Residuals	97	22772.2	234.8		
Female					
Site	1	113.1	113.1	0.848	0.358
Year	2	1137.3	568.7	4.262	**0.015**
Site*Year	2	2451.7	1225.9	9.189	**<0.001**
Residuals	210	28016.4	133.4		
Notes: Bolded p-value denotes a significant result (α=0.05)					

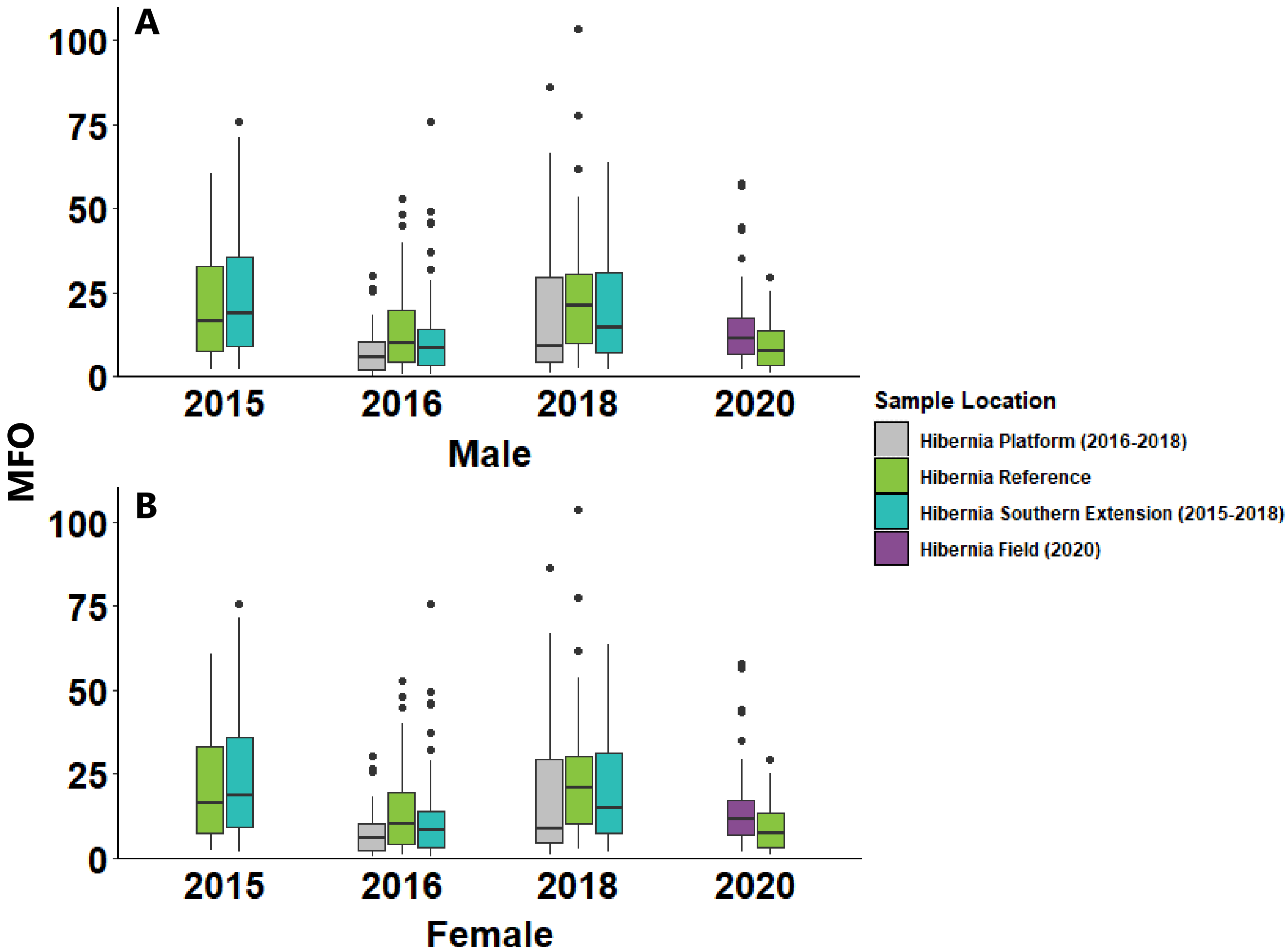


Figure 6-16: Boxplot of mixed function oxygenase (MFO) activity (pmol resorufin / mg protein / min) collected from male (A) and female (B) American plaice at the Hibernia Field and Reference Area from 2015 to 2020.

6.2.3.6 Histopathology

The histological parameters examined for American plaice tissue samples collected for the EEM program were assessed microscopically for the presence of different lesions summarized in the tables below and defined according to standard methods (Khan and Kiceniuk 1984, Khan 1990, 1995, Khan et al. 1994, Stentiford et al. 2003, Agamy 2012). Examples of liver pathologies is shown in Figure 6-17, and examples of gill pathologies in Figure 6-18.

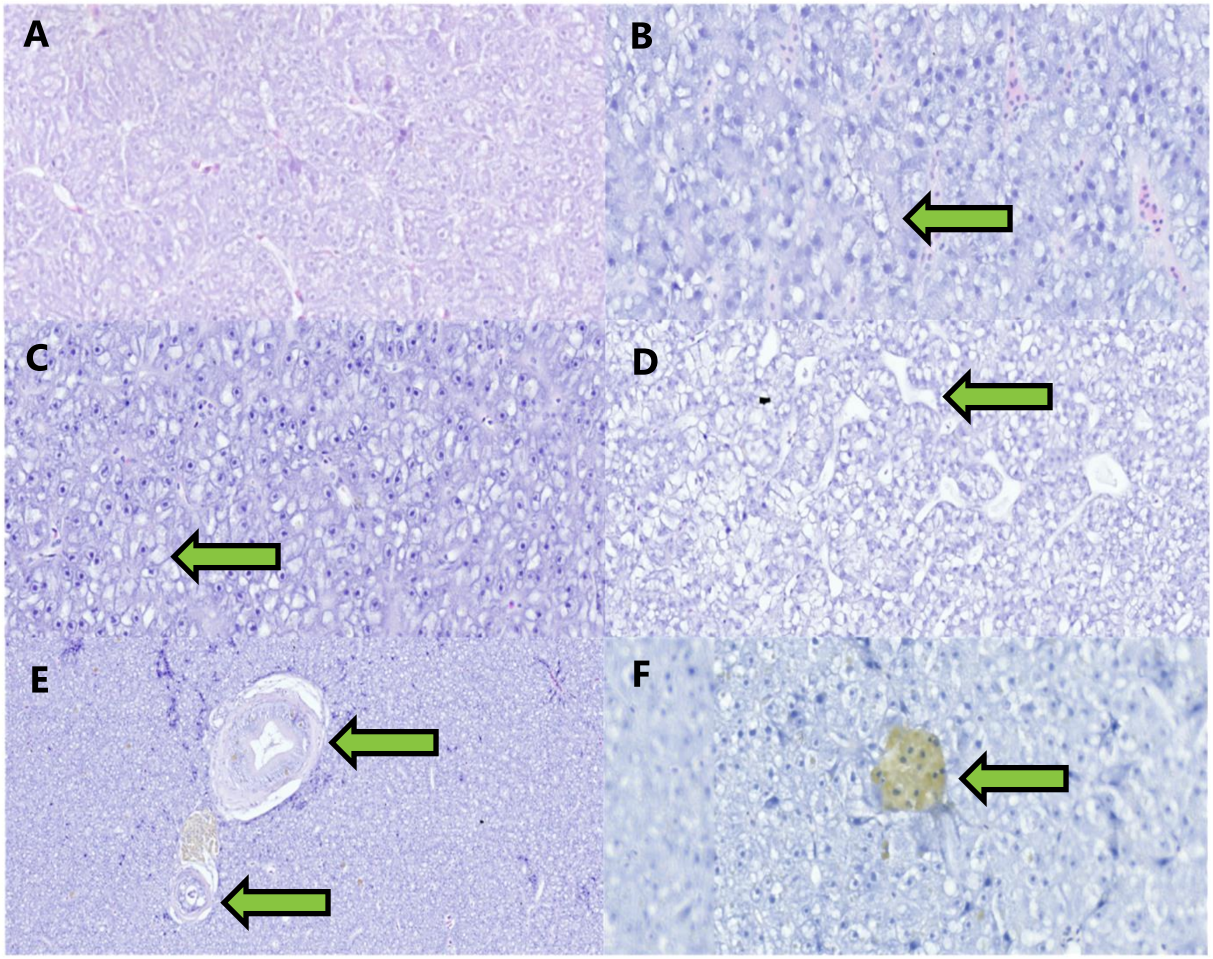


Figure 6-17: Examples of liver pathologies: A) normal liver tissue, B) small hepatocellular vacuoles, C) medium hepatocellular vacuoles, D) large hepatocellular vacuoles, E) bile duct hyperplasia, and F) macrophage aggregate. Images provided by the CDRF (MUN).

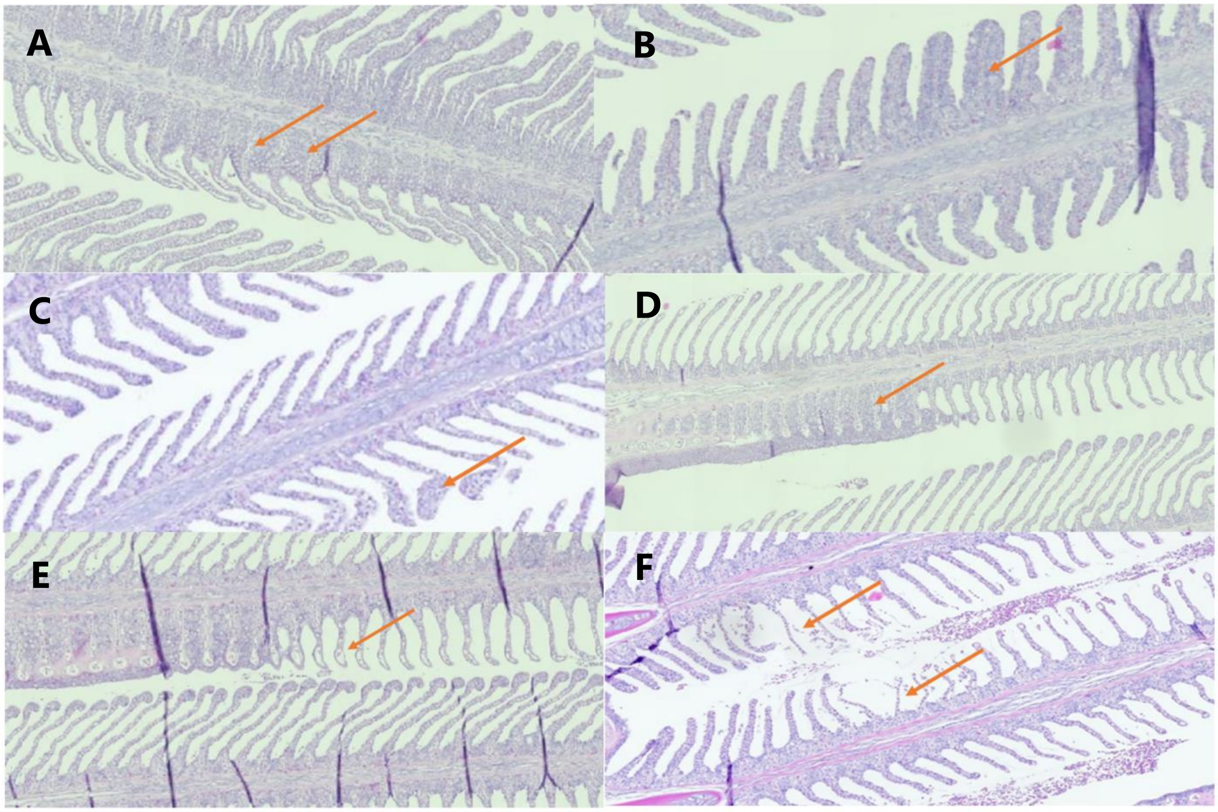


Figure 6-18: Examples of gill pathologies: A) basal hyperplasia, B) distal hyperplasia, C) tip hyperplasia, D) fusion, E) epithelial lifting, and F) thin filaments. Images provided by the CDRF (MUN).

2020 Liver Histopathology Results

Several hepatic lesions were observed in American plaice in 2020, including bile duct hyperplasia (Figure 6-17), hepatocellular carcinoma (not shown), macrophage aggregates (Figure 6-17), and hepatocellular vacuoles (Figure 6-17; Table 6-26). No liver histopathology lesions significantly differed between Sites in 2020 (Table 6-26).

Table 6-26: Number and frequency of American plaice with hepatic lesions from the Hibernia Field and Reference Area in 2020

Lesions	Hibernia Field (n=60)		Reference Area (n=60)		p-value
	Fish Affected	Prevalence (%)	Fish Affected	Prevalence (%)	
Normal	11	18.3	10	16.7	1.00
Nonspecific necrosis	0	0	0	0	1.00
Bile duct hyperplasia	21	35	20	33.3	1.00
Nuclear pleomorphism	0	0	0	0	1.00
Megalocytic hepatosis	0	0	0	0	1.00

Lesions	Hibernia Field (n=60)		Reference Area (n=60)		p-value
	Fish Affected	Prevalence (%)	Fish Affected	Prevalence (%)	
Eosinophilic foci	0	0	0	0	1.00
Basophilic foci	0	0	0	0	1.00
Clear cell foci	0	0	0	0	1.00
Hepatocellular carcinoma	25	41.7	24	40	1.00
Benign Tumours	0	0	0	0	1.00
Cholangioma	0	0	0	0	1.00
Cholangiofibrosis	0	0	0	0	1.00
Increase in mitotic activity	0	0	0	0	1.00
Macrophage aggregates[a]	3	5	6	10	0.49
Macrophage aggregates[b]	0	0	0	0	1.00
Hydropic vacuolation	0	0	0	0	1.00
Hepatocellular vacuoles S	11	18.3	11	18.3	1.00
Hepatocellular vacuoles M	13	21.7	13	21.7	1.00
Hepatocellular vacuoles L	0	0	2	3.3	0.50
Hepatocellular vacuoles A	24	40	26	43.3	0.85

Notes:
S – small, M – medium, L – large, A – all (small, medium, and large combined)
[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
Prevalence is the percentage of fish affected
Bolded p-values denotes significant result (α=0.05)

Liver Histopathology Across-year Comparison

A multivariate analysis of variance (MANOVA) was performed using the factors listed in Table 6-26 that were detected in fish (i.e., excluding those with 0 fish affected). This left six factors: bile duct hyperplasia, hepatocellular carcinoma, macrophage aggregates (0-3), hepatocellular vacuoles (small), hepatocellular vacuoles (medium), and hepatocellular vacuole (large). All hepatocellular vacuoles could not be included in the MANOVA due to autocorrelation with the other hepatocellular vacuole factors. Table 6-27 (top) presents the results of the MANOVA, with significant differences between year (p=<0.001) and the interaction term (p=0.031). Two-way ANOVAs were then run on each individual factor to determine which are contributing to the significance in the MANOVA. Table 6-27 (bottom) shows the individual ANOVAs, with four factors having significant results: hepatocellular carcinoma, macrophage aggregates (0-3), medium hepatocellular vacuoles, and large hepatocellular vacuoles. All four of these terms significantly differed between years, and macrophage aggregates (0-3) had a significant interaction term.

Figure 6-19 shows each of the four factors with significant results found in Table 6-27. Hepatocellular carcinoma significantly differed between years, with higher values in 2020 compared to the previous three EEM years. Macrophage aggregates (0-3) significantly differed between years and had a significant interaction term. Medium hepatocellular vacuoles varied by year, with values in 2020 lower than those in 2018. For large hepatocellular vacuoles, the significant difference between years was due to values in 2020 being lower than the previous three EEM years.

Table 6-27: MANOVA (six factor) and two-way ANOVAs of each factor of liver histopathologies from American plaice collected from Hibernia Field and Reference Area from 2015 to 2020.

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
MANOVA (6 factors)					
Site	1	6	0.020	1.055	0.390
Year	2	12	0.294	8.860	**<0.001**
Site*Year	2	12	0.071	1.907	**0.031**
Residuals	313				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Bile duct hyperplasia					
Site	1	0.296	0.296	1.488	0.223
Year	2	1.072	0.536	2.694	0.069
Site*Year	2	0.966	0.483	2.429	0.090
Residuals	313	62.274	0.199		
Hepatocellular carcinoma					
Site	1	<0.001	2.3e-4	0.001	0.972
Year	2	4.290	2.145	11.593	**<0.001**
Site*Year	2	0.608	0.304	1.642	0.195
Residuals	313	57.917	0.185		
Macrophage aggregates (0-3)					
Site	1	0.111	0.111	1.966	0.162
Year	2	0.471	0.236	4.185	**0.016**
Site*Year	2	0.772	0.386	6.854	**0.001**
Residuals	313	17.630	0.056		
Hepatocellular vacuoles (small)					
Site	1	0.004	0.004	0.030	0.863
Year	2	0.063	0.032	0.218	0.804
Site*Year	2	0.136	0.068	0.470	0.625
Residuals	313	45.314	0.145		
Hepatocellular vacuoles (medium)					
Site	1	0.104	0.104	0.567	0.452
Year	2	2.285	1.142	6.251	**0.002**
Site*Year	2	0.354	0.177	0.970	0.380
Residuals	313	57.195	0.183		
Hepatocellular vacuoles (large)					
Site	1	0.393	0.393	2.901	0.090
Year	2	7.692	3.846	28.388	**<0.001**
Site*Year	2	0.069	0.034	0.253	0.776
Residuals	313	42.404	0.136		
Notes: Bolded p-value denotes a significant result (α=0.05)					

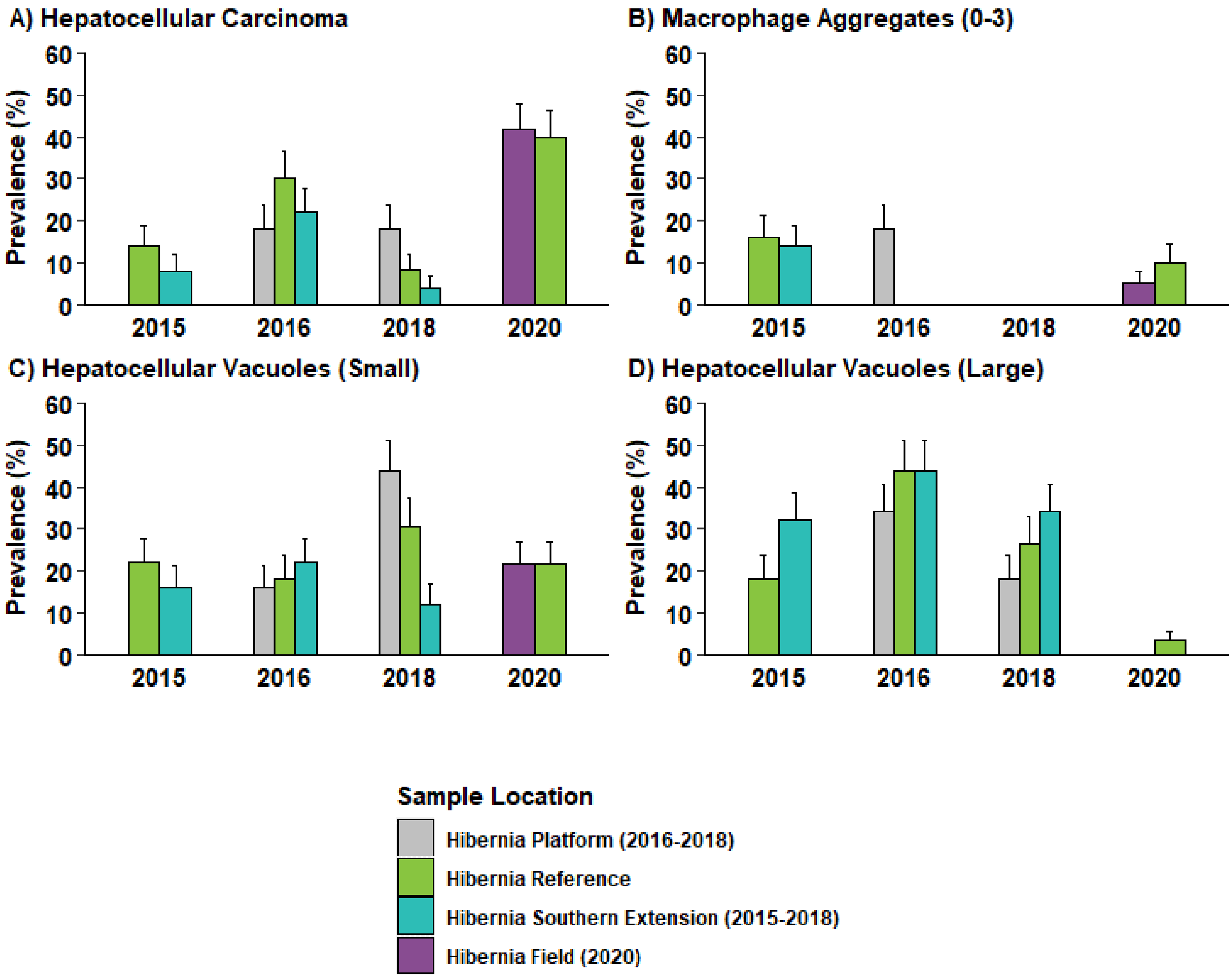


Figure 6-19: Bar graphs of the prevalence (%) of hepatocellular carcinoma (A), macrophage aggregates (0-3) (B), medium hepatocellular vacuoles (C), and large hepatocellular vacuoles (D) from livers of American Plaice taken from the Hibernia Field and Reference Area from 2015 to 2020. Bars indicate standard error.

2020 Gill Histopathology Results

Gills abnormalities were also observed in fish from both areas, though no significant differences were noted between the Hibernia Field and the Reference Area in 2020 (Table 6-28).

Table 6-28: Percentages of secondary lamellae affected by lesions, and scale of affected lesions in the gill tissues of American plaice from the Hibernia Field and Reference Area in 2019.

Lesion Type	Hibernia Field (n=60)	Reference Area (n=60)	p-value
Percentage of Secondary Lamellae Affected by Lesions			
Normal	99.4 ± 1.46	99.2 ± 1.88	0.519
Tip Hyperplasia [a]	0.03 ± 0.12	0.02 ± 0.08	0.494
Basal Hyperplasia [b]	0.07 ± 0.32	0.08 ± 0.28	0.857
Distal Hyperplasia [c]	0.04 ± 0.22	0.05 ± 0.19	0.750
Fusion	0.29 ± 1.02	0.44 ± 1.63	0.560
Telangiectasia	0.02 ± 0.17	0.01 ± 0.03	0.455
Thin Lamellae	0 ± 0	0 ± 0	1.000
Epithelial Lifting	0.10 ± 0.50	0.16 ± 0.70	0.584
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.23 ± 0.53	0.10 ± 0.35	0.109

Notes:
All data are mean percentage of lamellae presenting the lesion ± standard deviation.
[a] Tip hyperplasia was recorded when there were more than three cell layers at least 2/3 around the secondary lamellae tip.
[b] Basal hyperplasia: increase in thickness of the epithelium
[c] Distal hyperplasia was recorded when there were more than two cell layers all around the two sides of the secondary lamellae.
Bolded p-values denote a significant result (α=0.05)

Gill Histopathology Across-year Comparison

Due to the large number of gill histology factors, a MANOVA was performed using the factors listed in Table 6-28 excluding oedema as it is a measure of the scale of affected lesions. This left seven factors: hyperplasia (tip, basal, and distal), fusion, telangiectasia, and epithelial lifting. Though no thin lamellae were observed in 2020, it was included as part of the MANOVA as it is present in previous EEM years. Table 6-29 (top) shows the results of the MANOVA, with significant differences between Sites (p=<0.001), years (p=<0.001) and the interaction term (p=<0.001). Two-way ANOVAs were then run on each individual factor to determine which are driving the significance in the MANOVA. Table 6-29 (bottom) shows the individual ANOVAs, with all seven factors having significant results.

Figure 6-20 shows each of the seven factors with significant results found in Table 6-29. Tip hyperplasia had a significant Site and Year term, with incidence being higher at the Reference Area compared to the Hibernia Field, with lower values in 2020 compared to all other years. Basal and distal hyperplasia, as well as fusion, significantly differed between years and had significant interaction terms which may be indicative of potential project induced changes or natural variation. Telangiectasia and epithelial lifting significantly differed between Years and was highest in 2016 and have similar values in other EEM years. Thin lamellae had significant Site, Year, and interaction term, likely due to low incidence in most EEM years.

Table 6-29: MANOVA (seven factor) and individual two-way ANOVAs of each factor of detected gill histopathologies from American plaice collected at the Hibernia Field and Reference Area from 2016 to 2020.

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
MANOVA (7 factors)					
Site	1	7	0.103	4.456	**<0.001**
Year	2	14	0.561	15.269	**<0.001**
Site*Year	2	14	0.292	6.703	**<0.001**
Residuals	279				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Hyperplasia (tip)					
Site	1	5.727	5.727	5.056	**0.025**
Year	2	75.890	37.945	33.498	**<0.001**
Site*Year	2	5.221	2.610	2.305	0.102
Residuals	279	316.043	1.133		
Hyperplasia (basal)					
Site	1	2.578	2.578	3.162	0.076
Year	2	30.103	15.051	18.463	**<0.001**
Site*Year	2	6.112	3.056	3.749	**0.025**
Residuals	279	227.445	0.815		
Hyperplasia (distal)					
Site	1	3.230	3.232	2.482	0.116
Year	2	110	55	42.238	**<0.001**
Site*Year	2	14.540	7.269	5.582	**0.004**
Residuals	279	363.290	1.302		
Fusion					
Site	1	13.89	13.893	1.733	0.189
Year	2	169.31	84.655	10.559	**<0.001**
Site*Year	2	78.2	39.102	4.877	**0.008**
Residuals	279	2236.88	8.018		
Telangiectasia					
Site	1	0.090	0.090	0.495	0.482
Year	2	2.202	1.101	6.040	**0.003**
Site*Year	2	0.306	0.153	0.840	0.433
Residuals	279	50.854	0.182		
Thin lamellae					
Site	1	6.787	6.787	19.85	**<0.001**
Year	2	16.522	8.261	24.16	**<0.001**
Site*Year	2	21.86	10.930	31.966	**<0.001**

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Residuals	279	95.396	0.342		
Epithelial lifting					
Site	1	0.079	0.079	0.255	0.614
Year	2	1.956	0.978	3.171	**0.044**
Site*Year	2	0.690	0.345	1.119	0.328
Residuals	279	86.048	0.308		
Notes: Bolded p-value denotes a significant result (α=0.05)					

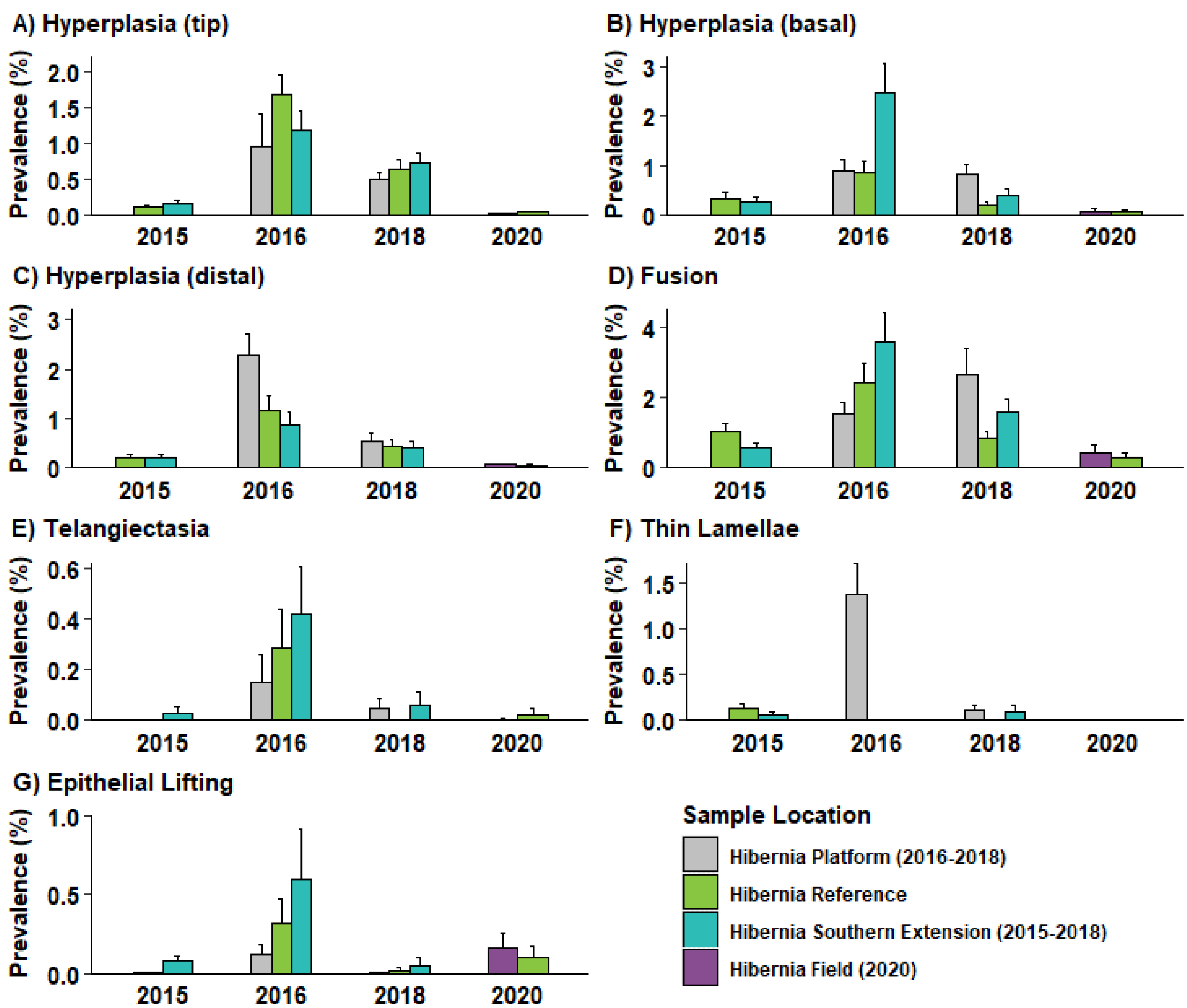


Figure 6-20: Bar graphs of the prevalence (%) of hyperplasia - tip (A), basal (B), and distal (C), fusion (D), telangiectasia (E), thin lamellae (F), and epithelial lifting (G) from livers of American Plaice taken from the Hibernia Field and Reference Area from 2015 to 2020. Bars are standard error.

6.3 Summary of Results

6.3.1 Summary of Chemical Profiles of American Plaice

Consistent with past EEM years, American plaice tissue sampled at the Hibernia Field and Reference Area in 2020 had arsenic, mercury, and zinc above their RDLs in all samples. Other metals have occasionally exceeded their RDLs in past EEM years, and in 2020 strontium was above RDL in one sample at the Hibernia Platform. No significant differences between the Hibernia Platform and Reference Area were noted in 2020. Comparison across EEM years found a significant difference between years for all three metals, and zinc had a significant interaction term indicating a potential project induced change.

For liver composites, eight metals have been consistently detected in all EEM years (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc), with other metals occasionally above their RDLs but not screened in for analysis (silver and vanadium in 2020). In 2020, only manganese was found to differ between areas and was higher at the Reference Area. No difference between Years, Sites, or Site-Year interaction was observed for mercury. Arsenic, cadmium, copper, iron, manganese, and selenium were significantly different between years, with all metals but manganese lower in 2020 compared to 2018. Zinc significantly differed between Sites and Years with higher values at the Reference Area compared to the Hibernia Field, and higher values in 1999 compared to other sampling years. No interaction terms were significant for any variable.

Hydrocarbons in all three ranges ($>C_{10}$-C_{16}, $>C_{16}$-C_{21}, and $>C_{21}$-C_{32}) were screened in for 2020, and no significant differences were detected between the Hibernia Field and Reference Area. The lower and upper fuel ranges were combined into $>C_{10}$-C_{21} to allow comparison to previous EEM years. Hydrocarbons in both the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} ranges are above RDL in the majority of EEM years. However, $>C_{10}$-C_{16} hydrocarbons have not been screened in any previous EEM sample year. No difference between Sites was found for the 2020 EEM. Hydrocarbons in both ranges significantly differed between years, with values in 2020 for $>C_{10}$-C_{21} hydrocarbons higher than any other sampling year. Hydrocarbons in the $>C_{21}$-C_{32} range were higher in 2020 compared to 2016 or 2018, but lower than 2015 values which had the highest values of any EEM year. No PAHs were detected in any liver composites in 2020, though some samples have exceeded RDLs in past years.

6.3.2 Summary of Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2020. Fisher's exact test showed no difference in the ratio of male to female fish between Sites. No difference was found between maturity stage frequency for males or females between Sites. As sample sizes for male fish are very low in 2020, statistical analyses have very little power for distinguishing differences between Sites.

For biological characteristics, no significant variations between Sites existed for male and female American plaice sampled in 2020. After accounting for covarying factors using ANCOVAs, female fish gutted weight significantly differed between Sites. Cross-year comparisons for both male and female fish, year was significantly different for every index with the exception of male HSI. While across year differences have been noted, no consistent trend suggests that differences may be due to natural variation. Additionally, male GSI also varied significantly between Sites, with higher values at Hibernia Field compared to the Reference Area.

For gross pathology, there were no significant differences among any of the parameters examined individually for males or females, aside from skin for female plaice being higher at the Reference Area. The three health assessment indices (HAI, mod. 1, and mod. 2) were compared between the Hibernia Field and Reference Area from 2016 and 2020. Significant differences were found for Site and year for all HAI modifications for both male and female fish, with the exception of HAI mod. 2 for female fish which differed by year but not Site. No HAI modification for either sex had significant interaction terms.

For haematology, no significant difference was found between Sites for neutrophils, however lymphocytes and thrombocytes both significantly differed. Lymphocytes were higher at the Hibernia Field, while thrombocytes were higher at the Reference Area. For the cross-year comparison, significant differences were found between years for all cell types, with lower values in 2020 for neutrophils and thrombocytes, and higher in 2020 for lymphocytes. Site was also significantly different for lymphocytes and thrombocytes, with lymphocytes higher at the Hibernia Platform and thrombocytes higher at the Reference Area.

For MFO, female fish significantly differed between the Hibernia Field and Reference Area in 2020. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, no significant differences between Sites existed for 2020. A MANOVA with six liver histology factors showed significant differences between Years and in the interaction term. Hepatocellular carcinoma, macrophage aggregates (0-3), medium hepatocellular vacuoles, and large hepatocellular vacuoles all significantly differed between years, and macrophage aggregates (0-3) had a significant interaction term.

For gill histopathology, no significant differences were detected between Sites in 2020. However, a MANOVA for seven gill histology factors detected significant results across Site, Year, with a significant interaction term. Significant differences between Sites were largely due to tip hyperplasia (higher at the Reference Area) and thin lamellae (higher at the Hibernia Field). All seven gill histologies significantly differed between Years, with generally lower values in 2020 and high values in 2016. Basal and distal hyperplasia, fusion, and thin lamellae had significant interaction terms.

Table 6-30: Summary of potential project related effects (significant results within each year) from the Hibernia Platform EEM fish health indicators in American plaice compared to the Reference Area.

Indicators	2002	2004	2007	2009	2011	2014	2016	2018	2020
Fulton's Condition Factor	No	No	No	Yes	No	No	No	No	No
Hepatosomatic Index (HSI)	Yes	No	No	Yes	No	Yes	No	No	No
Gonadosomatic Index (GSI)	Yes	No	Yes	No	No	Yes	No	Yes	No
Gross Pathology	No	No	No	No	No	No	Yes	Yes	No
Hematology	No	-	Yes	No	No	-	Yes	No	Yes
Mixed Function Oxygenase (MFO)	Yes	No	No	Yes	No	No	Yes	Yes	Yes
Liver Histopathology	No	No	Yes	Yes	No	No	Yes	No	No
Gill Histopathology	Yes	No	No	No	No	No	Yes	Yes	No

Table 6-31: Comments on statistically significant results for Hibernia Platform EEM fish health indicators in American plaice.

Monitoring Year	Comment on Statistically Significant Fish Health Indicator*
2002	**Hepatosomatic Index:** Males only. Higher HSI in fish from the Hibernia Platform Area. Likely natural variation. **Gonadosomatic Index:** Males only. Lower GSI in fish from the Hibernia Platform Area. Likely natural variation. **Mixed Function Oxygenase:** Females only. Slightly lower activity in fish from the Hibernia Platform Area. Likely natural variation **Gill Histopathology:** Distal hyperplasia slightly lower in fish from the Hibernia Platform Area. Likely natural variation
2004	No statistically significant results. Note: no haematology data collected
2007	**Gonadosomatic Index:** Females only. Higher GSI in fish from the Hibernia Platform Area. Likely natural variation. **Hematology:** Fewer lymphocytes and more thrombocytes in fish from the Hibernia Platform Area. Likely natural variation. **Liver Histopathology:** Fibrillar inclusions in a single fish from the Hibernia Platform Area. Very Low prevalence, likely natural.
2009	**Fulton's Condition Factor:** Females only. Higher Fulton's condition factor in fish from Hibernia Platform Area, likely natural variation. **Hepatosomatic Index:** Females only. Higher HSI in fish from Hibernia Platform Area, likely natural variation. **Mixed Function Oxygenase:** Marginally significant in females only. Higher activity in Hibernia Platform Area, likely natural variation. **Liver Histopathology:** Incidence of parasitic infestation was marginally significant. Higher in Hibernia Platform Area, likely natural variation.
2011	No statistically significant results.
2014	**Hepatosomatic Index:** Higher in F510 females from Reference Area. **Gonadosomatic Index:** Gonad weight on gutted weight covariate significantly higher by ANCOVA analysis only in females from Reference Area. Note: no haematology data collected
2016	**Gross Pathology:** Higher HAI score in males and females, and higher gill aberrations in males from Hibernia Platform Area. **Hematology:** Lower thrombocytes in fish from the Hibernia Platform Area. **Mixed Function Oxygenase:** Lower activity in males from the Hibernia Platform than the Reference Area. **Liver Histopathology:** Prevalence of bile duct hyperplasia and Macrophage aggregates are higher among fish from the Hibernia Platform Area. **Gill Histopathology:** Basal Hyperplasia is higher in fish from Hibernia Platform Area.
2018	**Gonadosomatic Index:** Higher in males from the Hibernia Platform Area. **Gross Pathology:** Higher incidence of liver, gill, and parasite pathologies at the Hibernia Platform, and all three Health Assessment Indexes higher at Hibernia Platform Area. **Mixed Function Oxygenase:** Female fish only, higher EROD results from the Reference Area. **Gill Histopathology:** Higher incidence of basal hyperplasia and fusion at the Hibernia Platform Area.
2020	**Haematology:** Lymphocytes higher in fish at Hibernia Field, and thrombocytes higher at Reference Area **Mixed Function Oxygenase:** Higher EROD values at Hibernia Field compared to Reference Area for female fish
Notes: * Summary information for 2014 and prior is from the 2014 Hibernia EEM Report (HMDC 2017a)	

7.0 DISCUSSION AND INTERPRETATION

The EEM program is designed to monitor the receiving marine environment to provide timely and beneficial information to detect any potential deleterious effects (HMDC 2019). Both Hibernia and HSE have the same three hypotheses to determine if any significant adverse effect has taken place due to Operations. This section will evaluate the results and assess the hypothesis statements and determine if they should be rejected.

7.1 Sediment Quality

7.1.1 Physical and Chemical Characteristics

7.1.1.1 Hibernia Platform

Based on the data screening criteria, no sediment fractions met the requirements for further analysis. In general, sediment samples collected from the Hibernia Platform study area consisted mainly of sand. Analytes that were screened-in for further analysis included, barium and WAM barium, fuel and lube range hydrocarbons, and total carbon.

Barium

Barium is an established marker for drill cuttings and is used to determine the extent of distribution (Trefry et al. 2013, DeBlois et al. 2014a, Whiteway et al. 2014). The observed range of barium and WAM barium concentrations for Hibernia Platform EEM programs since the 1994 program (baseline) have mainly been on a downward trend since 2000 (Table 7-1). From 1994 to 2000, the highest total barium concentrations have generally occurred at stations within 500 m from the platform. Concentrations reported in 2020 continue the mostly downward trend from peak concentrations reported in 2000. Barium concentrations in Hibernia Platform sediment have been correlated to drilling activities in previous EEM years. Results from the 2020 EEM are consistent with the downward trend and decreasing barium concentrations observed over time at all distances. While barium concentration distribution could be used to delineate the extent of contamination, it does not necessarily support a Project-related environmental effect.

Table 7-1: Summary comparison of barium concentrations in Hibernia Platform sediment samples all fields combined.

Year	Concentration Range (mg/kg)	
	Barium	WAM Barium
1994 (Baseline)	60-3,000*	**
1998	<5-1,400	<5-18
1999	<5-1,000	<5-42
2000	<5-3,100	<5-92
2002	56-1,400	<5-56
2004	57-780	<5-82
2007	56-600	<5-39
2009	60-1,400	<5-47
2011	62-870	<0.3-5
2014	45-450	<5-26
2016	<5-1,100	<5-26
2018	53-420	<5-36

Year	Concentration Range (mg/kg)	
	Barium	WAM Barium
2020	56-700	<5-33

Notes:
*One sample located where the Hibernia Platform is currently located. Next highest value was 450 mg/kg.
** Not conducted in 1994 during baseline EEM program.

Hydrocarbons

Fuel range hydrocarbon (>C_{10}-C_{21}) concentrations and lube range hydrocarbons (>C_{21}-C_{32}) have notably decreased since 2000 levels and continue a downward trend. The mean concentration of both ranges in 2020 were below the detection limit used during the baseline survey. The downward trend across years and fields/distances was statistically significant for both fuel and lube range hydrocarbons. The Petrotox model has been used to assess the ecologically relevant concentrations of PureDrill IA 35-LV below which effects would not be expected. The threshold concentration for Petrotox is 150 mg/kg. All concentrations since 2004 have been below this threshold (Table 7-2).

Table 7-2: Summary comparison of hydrocarbon concentrations in Hibernia Platform sediments in all distances.

Year	Concentration Range (mg/kg)	
	Fuel Range (>C_{10}-C_{21}) *	Lube Range (>C_{21}-C_{32})
1994 (Baseline)	<10	<10
1998	<0.25-341	<0.25-24.1
1999	<0.25-454	<0.25-30.5
2000	<0.25-4100	<0.25-69.5
2002	<0.25-793	<0.25-6.43
2004**	<0.25-131	<0.25-4.2
2007	<3-78	<3-7.1
2009	<0.3-58	<0.3-3.0
2011	<0.3-27	<0.3-5.0
2014	<0.25-17	<0.25-2.2
2016	<0.25-12	<0.25-4.5
2018	<0.25-5.5	<0.25-2.8
2020	<0.25-6.8	<0.25-3.7

Notes:
*Fuel range hydrocarbons were reported as >C_{11}-C_{21} until 2000 and >C_{10}-C_{21} starting in 2002
** There were two active drill sites during the 2004 sampling season

7.1.1.2 Hibernia Southern Extension

As observed at the Hibernia Platform, sediment collected around the HSE primarily consisted of sand particle sizes. However, HSE sediments have been observed to have higher concentrations of clay particles. Discharges from normal production activities (e.g., drill cuttings and muds) mainly consist of small particle sizes (e.g., clay and silt) and could explain the difference in percentage clay at HSE compared to the Hibernia Platform area. However, the percentage of clay in HSE sediments is exhibiting a downward trend. This difference in percent clay was statistically significant between Years and Fields. A notable trend was the chemical composition of station S-250 which had the highest reported percent clay and other screened-in analytes. 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 (Horowitz 1985, Herut and Sandler 2006). Smaller fractions in particular, such as clay, have higher concentrations of phyllosilicates and organic matter which have affinity for organic pollutants and trace elements (Herut and Sandler 2006). Results from the sediment chemical analysis are discussed below.

Barium

Barium and WAM barium concentrations appeared to be on an upward trend since baseline based on reported ranges (Table 7-3); however, analysis in 2020 shows that overall concentrations may have peaked and are beginning a downward trend (except for station S-250). These decreases were statistically significant, and differences were noted across all years, fields, and distances. Barium concentrations reported in 2020 were the highest of all EEM years and WAM barium concentrations reported in 2018 were the highest of all EEM years (Table 7-3). The highest concentration of both barium and WAM barium concentrations reported in 2020 was at station S-250, which also had the highest percentage of clay reported for HSE sampling stations. Concentrations of barium at the site have increased since this cessation of drilling in 2017. This could be due to several factors including spatial (i.e. the variation of the site location as sites vary can move several metres for each EEM program), physical (current may move the sediments and expose the higher concentrations of barium), biological (bioturbation by the benthic infauna can rework the sediment bringing the higher barium concentrations to the surface), or a combination of these factors (Cochrane et al. 2017).

Table 7-3: Summary comparison of barium concentrations in HSE sediment in all distances.

Year	Concentration Range (mg/kg)	
	Barium	Weak-acid Extractable Barium
2011 (Baseline)	84-300	<5-6
2014	70-460	<5-8.6
2015	93-2,900	<5-35
2016	85-6,200	<5-39
2018	78-16,000	<5-99
2020	84-28,000	<5-93

Hydrocarbons

As with other analytes previously discussed for HSE, fuel and lube range hydrocarbons exhibited a downward trend from concentrations reported in the 2018 EEM monitoring year. Hydrocarbon concentrations had been increasing since 2011 (Baseline) but appear to have peaked in 2018 (Table 7-4). Four stations within 500 m from the EDC have reported lube range hydrocarbon concentrations at or below baseline levels. Using the Petrotox threshold of 150 mg/kg, two stations were above the threshold, all within 250 m from the HSE. This is a decrease from the seven stations in 2018 and five stations reported in 2016. This downward trend across years, fields, and distances for both hydrocarbon ranges was statistically significant.

Table 7-4: Summary comparison of hydrocarbon concentrations in HSE sediment in all distances.

Year	Concentration Range (mg/kg)	
	Fuel Range (>C_{10}-C_{21})	Lube Range (>C_{21}-C_{32})
2011 (Baseline)	<0.3-4.3	<0.3-2
2014	<0.25-35	<0.25-1.2
2015	<0.25-510	<0.25-2.6
2016	<0.25-1390	<0.25-11
2018	<0.25-5200	<0.25-54
2020	<0.25-2890	<0.25-17

7.1.2 Sediment Toxicity

Based on the Petrotox screening (150 mg/kg no-effects threshold), only two stations within 250 m from the HSE (E-250 and S-250) were screened in for further testing. Station E-250 was screened-in but was deemed non-toxic by both assays (amphipod and polychaete). Station E-250 exceeded Petrotox threshold in the 2014, 2016, and 2018 EEMs and was deemed toxic in two (2016 and 2018) of those EEM monitoring years. This marks an improvement in survivorship and growth at this station. Station S-250 was deemed toxic by both amphipod and polychaete bioassays. Reduced amphipod and polychaete survivability is likely due to elevated metals and fuel range hydrocarbons (>C_{10}-C_{21}) in sediments collected at S-250. However, the percent survivorship of amphipods increased from the previous EEMs (2016 and 2018). Notably, S-250 had an 80% survivorship of polychaetes but was deemed toxic due to a 20% reduction compared to the control samples.

7.1.3 Combined Field Comparison

From the 2020 combined field analysis, overall, several chemical analytes were exhibiting a downward trend. Particularly a decrease in concentrations of certain analytes within 500 m from the HSE. These results continue the downward trend from peak values reported in the 2000 EEM survey.

Figure 7-1 illustrates the downward trend of hydrocarbons over time by comparing the TPH concentrations at 250 m distances with SBM cutting discharges over time (stations at 250 m typically have the highest concentrations of hydrocarbons). SBM cuttings re-injection was initiated in 2002 which has resulted in a decrease in Hibernia Platform sediment contaminant concentrations. Limited SBM cutting discharges were initiated in 2015 with the approval from C-NLOPB to ensure the integrity of the CRI system in certain drill situations (e.g., drilling through cement plugs). The majority of the SBM cuttings were re-injected via the CRI systems and 2020 discharges levels are lower than those reported in 2016 and 2018.

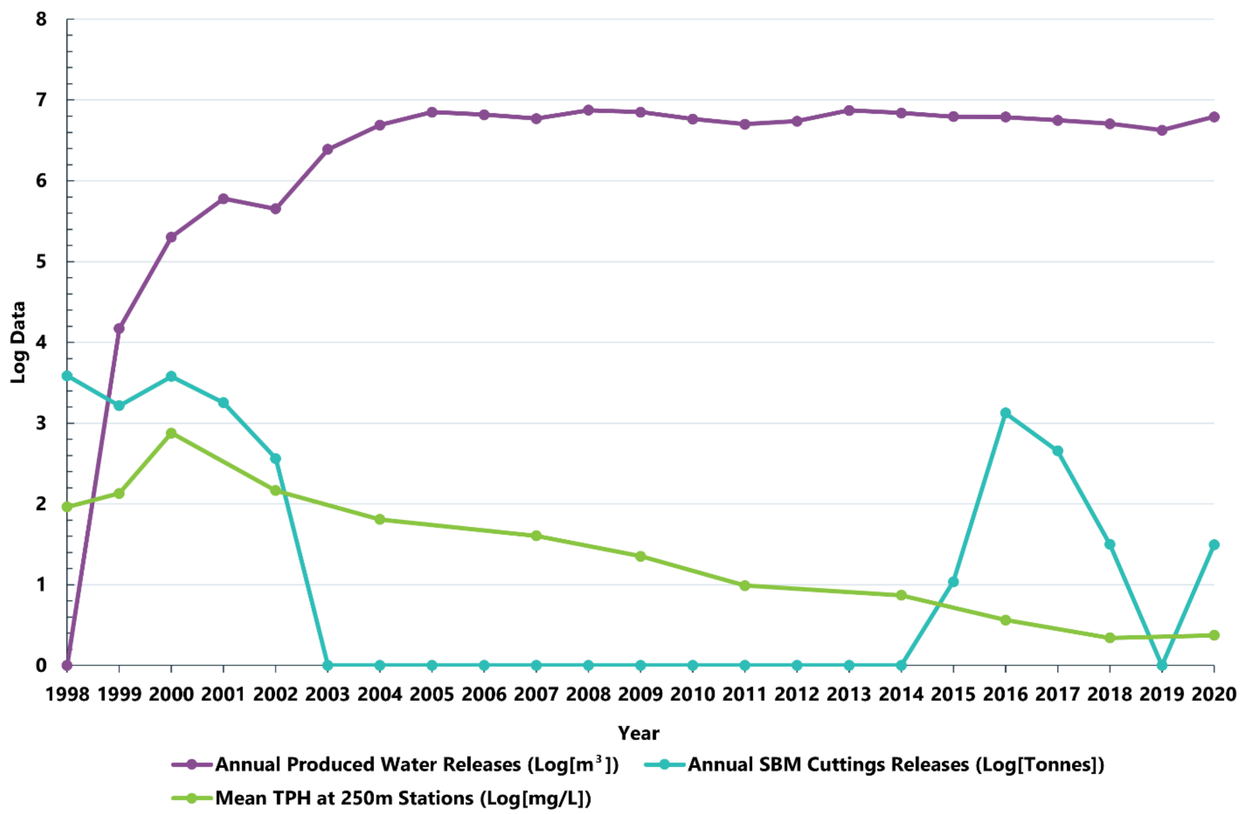


Figure 7-1: Comparison of Hibernia Platform discharges (annual SBM cuttings releases, annual produced water releases) to measured sediment hydrocarbon concentrations at 250 m stations (mean TPH). Data is Log_{10} transformed.

7.2 Water Quality

The water sampling/monitoring program at Hibernia is designed to assess the potential effects of produced water and other liquid discharges discussed in Chapter Section 2.0. As HSE has no produced water discharge, there is no water sampling program for this location.

Water samples were tested for metals, nutrients, hydrocarbon and pigments. None of the metal analyte concentrations detected at either sampling area exceeded CCME marine water guidelines (CCME 2021) with the exception of mercury, at a single station (50-3 mid depth). Hydrocarbons were detected in the fuel oil range ($>C_{10}$-C_{16}) and lube oil range ($>C_{16}$-C_{21}) at single station (again 50-3 mid depth). There was, also a detection of benzene and toluene at the 50-m distance (surface sample at 50-2 and 50-3 and mid depths at station 50-3) but were both below CCME marine water quality guidelines (CCME 2021). In addition, 20 PAH's and Alkylated PAHs showed a similar trend being detected at all three 50 m stations (50-1, 50-2, and 50-3) mostly at the surface and mid depths. Five PAHs were detected at the 150 m stations (150-2 mid depth and 150-3 surface). Based on the concentrations in the receiving environment compared to the produced water concentrations and the toxicity testing of the produced water, the concentrations in the water column were likely below the levels to elicit a sublethal response. Only a single station (50-3 mid depth, closest station samples) with a single analyte (>C_{16}-C_{21}) show a percent concentration (2.03%) high enough to potentially show a toxic response in sea urchin fertilization (<1.56%). In addition, based on the Environmental Assessment of the produced Water (HMDC 2011), the dilution ratio of the produced water into the receiving environment were projected to have a near-field dilution ratio of 10:1 to 60:1 (depending on the scenario) with a produced water concentration of 1-0.03% between 0-50m, less than 0.11% at 50 to 100 m, less than 0.004% at 100-250 m, and less than 0.01% at 250-1250 m. Analysis of those analytes that are more likely project-related (i.e., have higher concentrations within 50 m of the platform) show dispersion rates within those predicted in the model with the lowest dilution ratio (worst-case) of 49:1 and the highest percent concentration (worst-case) of 2% (both for >C_{16}-C_{21} Hydrocarbons at 50-3 Mid).

In summary, based on water monitoring results, the produced water appears to dilute rapidly once discharged, as analytes detected in seawater in the vicinity of the Hibernia Platform were rarely detected beyond 50 m from the produced water discharge point. Moreover, the most volatile and abundant hydrocarbons in produced water from the Hibernia Platform are BTEX (present study, and Yeung et al. 2015) and those BTEX analytes have estimated concentrations not exceeding 0.03% of undiluted produced water concentrations approximately 50 m from the platform, indicating that their potential for affecting a deleterious biological effect is likely minimal. Consistent with this, in a recent study characterizing the physical, chemical and microbial properties of produced water and seawater from the Hibernia Platform, all analyses revealed that the discharge of produced water did not have a detectable effect on the surrounding seawater (Yeung et al. 2015).

7.3 Commercial Fish

American plaice is a species of commercial importance in the Newfoundland offshore region that are monitored in all EEM programs in the area. This section describes potential project effects on body burden of metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAH), as well as reporting catch numbers and species caught, taint / taste testing, and several components of fish health. Several statistically significant differences were found in the 2020 data, and in comparisons to past EEM years. Past Hibernia EEM years had several methodological differences compared to the 2020 EEM program, though the differences in sample sizes should have minimal effect on cross-year results.

7.3.1 Catch Data

Twenty-one different taxa were caught as part of the 2020 Hibernia EEM program. The most commonly caught fish species was American plaice followed by yellowtail flounder, and the most common invertebrate was the stalked tunicate (Figure 6-3). These results are similar to those in previous years, but the trawl type and cod end mesh size used in 2020 led to fewer small bodied species (e.g., capelin, sand lance) being caught, and greater numbers of American plaice and similar sized fish (HMDC 2019b). Sampling methods for the Hibernia EEM have changed many times over the 22 years of sampling, with new gear used in 2020 making statistical comparisons of catch per unit effort (CPUE) to previous years inappropriate. In general, CPUE in 2020 was comparable to past EEM years. Unlike the Hebron Project, no clear trend in CPUE is noted for Hibernia with regards to higher CPUE near the platform itself (EMCP 2021, unpublished 2019 and 2020 data). A prediction for the placement of a large concrete structure is that it would act as an artificial reef and food source, and attract fish due to a release from fishing pressure. Nogueira et al. (2016) surveyed American plaice biomass from 2002 to 2014 on the Grand Banks and reported high fluctuations between years. Catch data at the Hibernia Platform seems similar to these reported fluctuations and no evidence of a reef effect is noted for CPUE.

7.3.2 Body Burden

For American plaice fillets, three metals were detected above their RDLs in the 2020 EEM program: arsenic, mercury, and zinc (Table 6-7). No significant differences were noted in 2020 between Sites, and no hydrocarbons or PAHs were above their RDLs in fillets in 2020. This is consistent with past EEM results, with the same three metals detected. Cross-year comparison showed significant differences between years for all three metals, and zinc had a significant interaction term. Zinc in fillets was generally lower in 2018 and higher in 2020 and varies between being higher at the Hibernia Platform and the Reference Area. These analytes are also consistent with other platforms, including Terra Nova (DeBlois et al. 2014b) and Hebron (EMCP 2016, 2021). These values appear steady across years and sites and likely reflect natural variation.

In American plaice liver composites, eight metals and three hydrocarbon groups were detected above their RDLs in the 2020 program (Table 6-8). Within the 2020 program, only manganese significantly differed between the Hibernia Field and Reference Area and was higher at the Reference Area. Comparing across years, no difference between years, Sites, or Site-Year interaction was observed for mercury. All other metals significantly differed between years, though all were lower in 2020 compared to 2018 with the exception of manganese which was higher at both Sites. Zinc also significantly differed between Sites, with higher values at the Reference Area in most EEM years. No interaction terms were significant for any variable.

Hydrocarbons in livers for all three ranges ($>C_{10}$-C_{16}, $>C_{16}$-C_{21}, and $>C_{21}$-C_{32}) were screened in for 2020, with no significant differences between Sites in 2020. The lower and upper fuel ranges were combined into $>C_{10}$-C_{21} to allow comparison to previous EEM years. Comparing across years, hydrocarbons in both ranges significantly differed between years, with values in 2020 for $>C_{10}$-C_{21} hydrocarbons higher than any other sampling year. Hydrocarbons in the $>C_{21}$-C_{32} range are higher in 2020 compared to 2016 or 2018 for both Hibernia Field and Reference Area, but lower than 2015 values which had the highest values of any EEM year. No PAHs were above RDL in 2020, and generally aren't above RDL in most EEM years.

These results for American plaice livers closely match results from the 2018 EEM program. Selenium and fuel range hydrocarbons were indicated as potential project induced effects in the 2018 EEM, and neither significantly differed between Sites in the 2020 EEM program. In sediment results, manganese was not screened in for the 2020 EEM program (see Section 4.1.3.1).

Fuel and lube range hydrocarbons were screened in for the sediment program in 2020, with most detections near the Hibernia Platform (Figure 4-13 to Figure 4-18). Values have been decreasing steadily since baseline sampling, with values in 2020 being some of the lowest recorded at Hibernia (Figure 4-28). For liver composites, lube range hydrocarbons are similar to those in 2018, with fuel range hydrocarbons elevated at both Sites in 2020. Hydrocarbons in these ranges are consistently reported at other production operations and may also simply be natural hydrocarbon compounds (DeBlois et al. 2014b).

These findings for liver composites are in line with other platforms operating on the Grand Banks. The same eight metals (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc), as well as fuel and lube range hydrocarbons, have been detected in livers from Hebron, Terra Nova, and White Rose at similar concentrations (Mathieu et al. 2011, Husky Energy 2019, EMCP 2021). Overall, no potential project induced changes were noted for American plaice body burden in the 2020 EEM.

7.3.3 Sensory Evaluation

For the 2020 EEM program, no significant difference was detected between the Hibernia Field and the Reference Area in either the triangle test or the hedonic scaling. These results are consistent with findings in most EEM years, as significant differences have only been noted in two EEM years (2009 and 2011) for the Triangle test. No significant differences have ever been noted for the hedonic scaling.

7.3.4 Fish Health Program

A broad variety of biological factors were analyzed based on current literature revolving around the effects of oil on fish. Factors analyzed include general biological characteristics, gross pathology of organs, white blood cells counts, mixed-function oxygenase activity, and histopathology of the gill and liver.

No difference was found in the ratio of male and female fish between the Hibernia Platform and Reference Area in 2020. Male and female fish were assigned maturity codes based on their condition using the index provided in Templeman et al. (1978). Due to the small sample size of male fish in 2020, statistical tests have little power to distinguish differences. No significant differences were found between Sites for either male or female fish in 2020. The majority of EEM programs on the Grands Banks have heavily skewed sex ratios, with female fish predominant. American plaice are sexually dimorphic; therefore, males are likely screened out from most programs as they are typically smaller than minimum take sizes. Several programs are also forced to exclude male fish due to small samples sizes (e.g., Terra Nova, Suncor Energy 2017), including Hibernia in past EEM years.

No biological characteristics were found to differ between Sites in 2020. Adjustment of p-values for co-variates found gutted weight significantly varied between Sites after accounting for fish length. This may be weak evidence that the Hibernia Platform is acting as a reef or shelter for larger fish, due to the lack of fishing pressure and additional food sources. Many studies have shown both current and decommissioned oil platforms act as highly productive artificial reefs, mainly through the addition of hard substrate for attachment (Page et al. 1999, Macreadie et al. 2011, Claisse et al. 2014, Gates et al. 2019). A potential reef-like effect on fish CPUE has been observed in the last several Hebron EEM programs (EMCP 2021). While this has been noted in previous Hibernia EEMs, this effect does not appear consistent across years and is not supported for the 2020 EEM.

Comparisons across EEM years for the three indices (FCI, HSI, and GSI) had some significant results. For both male and female fish, year was significantly different for every index with the exception of male HSI. Additionally, male GSI also varied significantly between Sites, with higher values at Hibernia Field compared to the Reference Area. However, due to the small sample size in 2020, there is little statistical confidence in results for male fish. Similar results were found for the 2016 and 2018 EEM programs, with fluctuations between years but only small differences between Sites in most years. EEM results from Hebron occasionally find differences in biological characteristics, with 2020 EEM data being significant for all female fish characteristics aside from fish age (no male fish were assessed due to small sample sizes; unpublished Hebron 2020 EEM data). The Hebron EEM also had difficulties collecting enough male American plaice to analyse in 2020 and so no results were reported. Though HSI and GSI frequently differ in many EEM years, no consistent trend has presented itself over the 22 years of monitoring at Hibernia and natural variation is likely a key factor.

For gross pathology in 2020, only the incidence of skin lesions in female fish differed significantly between Sites and was higher at the Reference Area. The three HAI indices were compared across years (2016-2020, no gross pathology was completed in 2015), as they incorporate all gross pathologies with scores given for severity of various pathologies (Goede and Barton 1990, Adams et al. 1993). Significant differences were found for Site and Year for all HAI modifications for both male and female fish, with the exception of HAI mod. 2 for female fish which differed by Year but not Site. No HAI modification for either sex had significant interaction terms. Results for male fish in 2020 were driven by small samples sizes, and very consistent results among fish sampled (see Figure 6-12). The lack of variation was likely the cause of the significant results between Years and Sites. Similar results were found in 2018 for HAI values in female fish, though results were slightly higher in 2020. Mathieu et al. (2011) report very few, if any, gross pathologies in American plaice taken as part of the Terra Nova EEM program. Hebron reported similar pathologies, and incidence rates are also similar to those in this study, with parasites typically as the most common incidence (e.g., HMDC 2019b). Skin conditions in American plaice were generally a result of trawl damage and are not typically indicative of a project induced effect. While significant differences have been noted in the past for the Hibernia EEM, no consistent trend is visible over time and natural variation likely a key factor.

Blood haematology significantly differed between Sites in 2020 for the incidence of lymphocytes and thrombocytes. Lymphocytes were higher at the Hibernia Field, while thrombocytes were higher at the Reference Area. Cross-year comparisons were made using data from 2016 to 2020, as samples were discarded in 2015. Significant differences were found between years for all cell types, with lower values in 2020 for neutrophils and thrombocytes, and higher in 2020 for lymphocytes. Site was also significantly different for lymphocytes and thrombocytes, with lymphocytes higher at the Hibernia Platform and thrombocytes higher at the Reference Area. No interaction terms were significant for any parameter. Lymphocytes help fight infections, and a decrease in the number of lymphocytes is generally considered to be a stress response (Chen et al. 2002). As lymphocytes were higher at the Hibernia Field, this is likely not indicative of a project induced effect. Thrombocytes are used in blood clotting, and a decrease typically indicates poor fish health (Corrêa et al. 2016). A decrease in thrombocytes at the Hibernia Field may be indicative of an induced effect. Similar patterns are visible for 2016 and 2018 for both lymphocytes and thrombocytes. As these proportions are related to each other, teasing apart individual effects can be difficult. These ratios should be closely monitored in future EEM years.

Mixed function oxygenases (MFOs), in particular ethoxyresorufin-O-deethylase (EROD), was used to measure industrial contamination as it acts to detoxify the liver (Hodson et al. 1991, Van Der Oost et al. 2003). Specific contaminants stimulate the release of MFOs designed to increase the solubility, and therefore excretability, of a given substance (Hodson et al. 1991). In the 2020 EEM, female plaice had significantly higher EROD values at the Hibernia Platform compared to the Reference Area, while males did not (though small samples sizes led to little statistical power in 2020) (Table 6-24). Cross-year comparisons showed a significant difference between years, and a significant interaction term, for both sexes (Table 6-25). Both sexes had lower values in 2020 compared to 2016 and 2018, and the interaction term points to the trend changing as the higher MFO results varies from being at the Hibernia Platform or at the Reference Area in different years (Figure 6-16). Similar results were noted in the 2018 EEM, though values were higher at the Reference Area in that year. The changes in MFO activity at both the Hibernia Field and Reference Area across years may point to natural fluctuations in the area, though the Hibernia Field values being higher for females in 2020 may indicate a project related effect. Monitoring programs for both Terra Nova and Hebron have found differences in some years between their platform and reference sites, but there is no clear pattern as the reference site is as likely to be higher as the platform (Mathieu et al. 2011, HMDC 2017). Longer term monitoring at the Hibernia Field is needed to clarify if this is a project related trend.

Of the 19 different liver histopathology lesions tested for, no significant differences were detected in the 2020 EEM (Table 6-26). A MANOVA comparing across Sites and Years found a significant difference across years, with a significant interaction term (Table 6-27). Each term in the MANOVA was subjected to a two-way ANOVA, and four terms varied across years, and one also had a significant interaction term (Figure 6-19). Hepatocellular carcinoma significantly differed between years, with higher values in 2020 compared to the previous three EEM years, and macrophage aggregates significantly differed between years and had a significantly interaction term (Table 6-27, Figure 6-19). Hepatocellular carcinoma is a malignant neoplasm present in the liver, that can be caused by contaminants but are also present in older fish (Feist et al. 2004). Macrophage aggregates are accumulations of dark-pigmented macrophages in the liver of fish, typically in relation to inflammation (Wolke 1992, Khan 2010). An increase in these factors over time may be due to sampling bias towards older, larger fish or may be natural variation within the population as no corresponding increase at the Hibernia Field was observed. A longer time series will allow for better comparisons across years. The same laboratory does liver histopathology for the Hebron Platform EEM and very similar pathologies and incidence rates were observed in the 2016 to 2020 programs (EMCP 2016, 2021, unpublished 2019 and 2020 data). These incidence rates were elevated compared to past Hibernia EEM programs and Terra Nova but was likely due to observer bias (Mathieu et al. 2011, Wolf et al. 2015, HMDC 2017).

Seven gill histologies, as well as oedema, were observed in the 2020 EEM, with no significant differences between Sites (Table 6-28). A seven factor MANOVA was used to compare the Sites between Years, and a significant difference was found between Sites, Years, as well as the interaction term indicating a potential project effect (Table 6-29). Two-way ANOVAs for each factor were used to see which factors contribute to the differences. Significant differences between sites were largely due to tip hyperplasia (higher at the Reference Area) and thin lamellae (higher at the Hibernia Field). All seven gill histologies significantly differed between years, with generally lower values in 2020 and high values in 2016. Basal and distal hyperplasia, fusion, and thin lamellae had significant interaction terms. In fish, the gills are a major uptake site for contaminants present in water and gill histology can be an early warning before other organs show symptoms (Stentiford et al. 2003). While hyperplasia can be present due to metal contamination or hydrocarbons, it can also be present due to gill parasites and other stressors (Mallatt 1985). Fish at the Hibernia Field and Reference Area had 99.4% and 99.2% of fish present normal gill histologies, respectively, which is higher than the three previous EEM years (Table 6-28). Significant interaction terms in 2020 are likely due to the small number of fish presenting with gill abnormalities in 2020, especially with the high values recorded in 2016 (Figure 6-20). In particular, occurrences of thin lamellae are rare and can easily be confused with epithelial lifting (CDRF, pers. comm.). Longer term monitoring at the Hibernia Field is needed to clarify if these trends are project induced changes.

Histopathology results for the 2020 Hibernia EEM program for both liver and gill are similar to findings from the Hebron Platform EEM results from 2015 to 2020 (EMCP 2016, 2021). Both Hebron and Hibernia report much higher incidences of liver and gill histologies compared to the Terra Nova EEM program (e.g., Mathieu et al. 2011). Throughout the course of the Hibernia EEM program, large differences in reported histologies have been detected with different observers (Wolf et al. 2015, HMDC 2017, 2019b). Hebron and Hibernia have both used the same laboratory for gill and liver histopathology since 2015 and therefore have more comparable results.

7.4 Interpretation

The EEM program is designed to monitor the receiving marine environment to provide timely and beneficial information to detect any potential deleterious effects (HMDC 2019). Both Hibernia and HSE have the same three hypotheses to determine if any significant adverse effect has taken place due to Operations. For Hibernia Platform, Operations is both production and drilling discharges, and for HSE Operations is solely drilling discharges.

7.4.1 Marine Fish Health

The null and alternate hypotheses for marine fish health are as follows:

> H_0 = Approved releases of solids and liquids from 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 Operations will result in significant adverse environmental effects on marine fish (as assessed by fish health indicators and integrative assessment).

Though some significant variations were observed in the 2020 EEM program, none exemplified a consistent trend over years. Similar variations in health indices, sex ratios, MFO, and histopathology have been detected in past years and at other operating platforms on the Grand Banks. The marine fish health hypothesis is not rejected for the 2020 EEM.

7.4.2 Marine Fish Habitat

The null and alternate hypotheses for marine fish habitat (using sediment and water quality results) are as follows:

> H_0 = Approved releases of solids and liquids from 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 Operations will result in significant adverse environmental effects on marine fish habitat (as evaluated by sediment toxicity assays and integrative assessment).

For Hibernia Platform in 2020, there were no toxic responses observed from either the amphipod survival or polychaete survival assays and the null hypothesis is not rejected.

For HSE in 2020, sediment collected two stations within 250 m of the EDC were screened in for further toxicity assays. Only station S-250 sediment was deemed toxic from both amphipod survival and polychaete survival assays. There was an improvement in survivorship and growth at Station E-250 as it was deemed toxic (amphipod and/or polychaete assays) in 2014, 2016, and 2018 EEMs but not in the 2020 EEM. As observed since 2014, increases of analytes associated with drill cutting discharges have been localized to stations within 250 m of the EDC. The quality of the benthic substrate assessed in 2020 relative to those assessed in 2011 have mainly higher survivability rates of juvenile polychaetes and amphipods and thus can be interpreted that no significant adverse environmental effects on fish habitat have resulted. Therefore, the 2020 EEM data does not reject the null hypothesis for marine fish habitat.

The water quality results show that the changes in water quality are minimal (i.e., detections were mostly limited to the first 50 m from the produced water discharge) and dilute rapidly once discharged therefore having no significant adverse effect on the fish and fish habitat in terms of the water column.

7.4.3 Marine Fish Taint

The null and alternate hypotheses for marine fish taint (using sensory assays) are as follows:

> H_0 = Approved releases of solids and liquids from 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 Operations will result in the taint (as measured by organoleptic evaluations and integrative assessment) of fishery resources outside of the safety zone.

No significant differences were detected by panelists using either the triangle or Hedonic tests with fish taken from both Hibernia Field compared to the Reference Area. For both areas, zinc in fish tissue was the only parameter that significantly differed across sites and years, indicating a potential project related effect. Therefore, the marine fish taint hypothesis is not rejected for the 2020 EEM.

8.0 RECOMMENDATIONS

Suggested improvements to future iterations of the design plan or program methodologies are included here.

8.1 Water Quality

The water quality monitoring program was initiated in 2004 to validate the model predictions in the EIS (HMDC 2011). Similar to other years, the 2020 EEM water quality results were consistent with the model predictions. After nine separate monitoring years it is recommended that the water quality program be re-evaluated for its value and contribution to the EEM program as a whole.

8.2 Commercial Fish

It is recommended to continue monitoring of fish health parameters. However, some histopathologies, such as telangiectasia and epithelial lifting for gill histopathology are potentially related to fish sampling methods. Furthermore, occurrences of thin lamellae are rare and can easily be confused with epithelial lifting (CDRF, pers. comm.). These histopathologies likely have less significance than others for assessing fish health. Therefore, the parameters as part of fish histopathology should be revisited for appropriateness in the monitoring program. In addition, it is recommended that further investigations into the hydrocarbons in liver to assess if they are biogenic or petrogenic in nature.

9.0 CLOSURE

This report on the Hebron 2020 EEM has been prepared for the exclusive use by HMDC. The project was conducted using standard practices by qualified WSP staff and in accordance with verbal and written requests from the client.

Yours sincerely,

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10.0 REFERENCES

Adams, S. M., A. M. Brown, and R. W. Goede. 1993. A quantitative health assessment index for rapid evaluation of fish condition in the field. Transactions of the American Fisheries Society 122:63–73.

Agamy, E. 2012. Histopathological liver alterations in juvenile rabbit fish (*Siganus canaliculatus*) exposed to light Arabian crude oil, dispersed oil and dispersant. Ecotoxicology and Environmental Safety 75:171–179.

Anderson, M. J., R. N. Gorley, and K. R. Clarke. 2008. Permanova+ for PRIMER: Guide to software and statistical methods. PRIMER-E Plymouth,UK.

Bakhtyar, S., and M. M. Gagnon. 2012. Toxicity assessment of individual ingredients of synthetic-based drilling muds (SBMs). Environmental Monitoring and Assessment 184:5311–5325.

Brooks, S., D. Pampanin, C. Harman, and G. Merete. 2015. Water Column Monitoring 2014: Determining the biological effects of an offshore platform on local fish populations.

CAPP. 2001. Offshore Drilling Waste Management Review. Canadian Association of Petroleum Producers.

CCME (Canadian Council of Ministers of the Environment). 2021. Guidelines. https://ccme.ca/en/current-activities/canadian-environmental-quality-guidelines.

Chapman, P. M. 2007. Determining when contamination is pollution — Weight of evidence determinations for sediments and effluents. Environment International 33:492–501.

Chen, W.-H., L.-T. Sun, C.-L. Tsai, Y.-L. Song, and C.-F. Chang. 2002. Cold-Stress Induced the Modulation of Catecholamines, Cortisol, Immunoglobulin M, and Leukocyte Phagocytosis in Tilapia. General and Comparative Endocrinology 126:90–100.

Claisse, J. T., D. J. Pondella, M. Love, L. A. Zahn, C. M. Williams, J. P. Williams, and A. S. Bull. 2014. Oil platforms off California are among the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences 111:15462–15467.

Clarke, K. R., and R. M. Warwick. 2001. An Approach to Statistical Analysis and Interpretation. PRIMER-E Plymouth.

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2021. Cumulative Production - Offshore Newfoundland.

Cochrane, S.K.J., Ekehaug, S., Pettersen, R., Refit, E.C., Hansen, I.M. and Aas, L.M.S., 2019. Detection of deposited drill cuttings on the sea floor-A comparison between underwater hyperspectral imagery and the human eye. Marine Pollution Bulletin, 145, pp.67-80.

Corrêa, S. A. da S., D. M. de S. Abessa, L. G. dos Santos, E. B. da Silva, and R. Seriani. 2016. Differential blood counting in fish as a non-destructive biomarker of water contamination exposure. Toxicological & Environmental Chemistry 2248:1–10.

De Rosario-Martinez, H. 2015. phia: Post-Hoc Interaction Analysis. R package version 0.2-1. 1.

DeBlois, E. M., M. D. Paine, B. W. Kilgour, E. Tracy, R. D. Crowley, U. P. Williams, and G. G. Janes. 2014a. Alterations in bottom sediment physical and chemical characteristics at the Terra Nova offshore oil development over ten years of drilling on the grand banks of Newfoundland, Canada. Deep Sea Research Part II: Topical Studies in Oceanography 110:13–25.

DeBlois, E. M., M. D. Paine, B. W. Kilgour, E. Tracy, R. D. Crowley, U. P. Williams, and G. G. Janes. 2014b. Examination of body burden and taint for Iceland scallop (*Chlamys islandica*) and American plaice (*Hippoglossoides platessoides*) near the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada. Deep-Sea Research Part II: Topical Studies in Oceanography 110:65–83.

DeBlois, E. M., E. Tracy, G. G. Janes, R. D. Crowley, T. A. Wells, U. P. Williams, M. D. Paine, A. Mathieu, and B. W. Kilgour. 2014c. Environmental effects monitoring at the Terra Nova offshore oil development (Newfoundland, Canada): Program design and overview. Deep Sea Research Part II: Topical Studies in Oceanography 110:4–12.

EC (Environment Canada). 1992. Biological test method: acute test for sediment toxicity using marine or estuarine amphipods. Environment and Climate Change Canada, Ottawa, Ont., Canada.

EC (Environment Canada). 1998. Biological Test Method: Reference method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods. Environment Canada, Ottawa.

EC (Environment Canada). 2001. Biological Test Method: Test for Survival and Growth in Sediment Using Spionid Polychaete Worms (*Polydora cornuta*). EPS1/RM/41. Page 132.

EC (Environment Canada). 2011. Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars), 2nd Edition. EPS 1/RM/27.

EMCP (ExxonMobil Canada Properties). 2016. Hebron Environmental Characterization: 2015 Biological (commercial fish) Survey – Report to Inform EEM Plan Results and Analysis. Page 283. Document Control Number: CAHE-EC-OOREF-01-006-5014-000.

EMCP (ExxonMobil Canada Properties). 2017. Hebron Offshore Environmental Effects Monitoring (EEM) Plan. Page 61p. Document Control Number: CAHE-EC-OOREF-01-006-5010-000.

EMCP (ExxonMobil Canada Properties). 2021. Hebron Platform Environmental Effects Monitoring Program (2018) Volume I - Interpretation. Page 174. St. John’s, NL, Canada.

Feist, S. W., T. Lang, G. D. Stentiford, and A. Köhler. 2004. Biological effects of contaminants: Use of liver pathology of the European flatfish dab (*Limanda limanda* L.) and flounder (*Platichthys flesus* L.) for monitoring. ICES Techniques in Marine Environmental Sciences 38:42.

Gates, A. R., T. Horton, A. Serpell-Stevens, C. Chandler, L. J. Grange, K. Robert, A. Bevan, and D. O. Jones. 2019. Ecological role of an offshore industry artificial structure. Frontiers in Marine Science 6:675.

Goede, R. W., and B. A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. American Fisheries Society Symposium 83:93–108.

Government of Canada. 2014. Newfoundland Offshore Petroleum Drilling and Production Regulations. Last amended on December 31, 2014. Page 49 SOR/2009-316.

Gray, J. S., and M. Elliott. 2009. Ecology of marine sediments: from science to management. Oxford University Press.

Health Canada. 2020, July 3. List of Contaminants and other Adulterating Substances in Foods. https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/contaminants-adulterating-substances-foods.html.

Herut, B., and A. Sandler. 2006. Normalization methods for pollutants in marine sediments: review and recommendations for the Mediterranean. Israel Oceanographic and Limnological Research H18:23.

HMDC (Hibernia Management and Development Company Ltd.). 1999. Report on Hibernia Production Phase Environmental Effects Monitoring Program – Year One.

HMDC (Hibernia Management and Development Company Ltd.). 2000. Hibernia Production Phase Environmental Effects Monitoring Program – Year Two of Production (August 1999) Volumes I and II.

HMDC (Hibernia Management and Development Company Ltd.). 2001. Hibernia Production Phase Environmental Effects Monitoring Program – Year Three (2000).

HMDC (Hibernia Management and Development Company Ltd.). 2003. Hibernia Production Phase Environmental Effects Monitoring Program – Year Four (2002).

HMDC (Hibernia Management and Development Company Ltd.). 2005. Hibernia Production Phase Environmental Effects Monitoring Program – Year Five (2004).

HMDC (Hibernia Management and Development Company Ltd.). 2009. Hibernia Production Phase Environmental Effects Monitoring Program – Year Six (2007) Volume I - Interpretation. File No. 1014865.

HMDC (Hibernia Management and Development Company Ltd.). 2011. Increased Production and Discharge of Produced Water Environmental Assessment Report. File No. 1014865.

HMDC (Hibernia Management and Development Company Ltd.). 2012. Hibernia Production Phase Environmental Effects Monitoring Program – Year Seven (2009) Volume I - Interpretation. File No. 1051516.

HMDC (Hibernia Management and Development Company Ltd.). 2014. Hibernia Production Phase Environmental Effects Monitoring Program – Year Eight (2011) Volume I - Interpretation. File No. 121510634 / 121510831.

HMDC (Hibernia Management and Development Company Ltd.). 2017a. Hibernia Environmental Compliance Monitoring Plan, HMDC Document Control Number: HS-O-O-X-A00-XX-0605.012.

HMDC (Hibernia Management and Development Company Ltd.). 2017b. Hibernia Production Phase Environmental Effects Monitoring Program – Year Nine (2014) Volume I - Interpretation. Page 424. EEM Results, File No. 121511249.

HMDC (Hibernia Management and Development Company Ltd.). 2019a. Hibernia Oil and Gas Production and Development Drilling Project Environmental Effects Monitoring (EEM) Plan. HS-O-O-X-A00-XX-0605.020 Rev. D1:313.

HMDC (Hibernia Management and Development Company Ltd.). 2019b. Hibernia Platform (Year 10) and Hibernia Southern Extension (Year 3) Environmental Effects Monitoring Program (2016): Volume I - Interpretation. Page 399.

HMDC (Hibernia Management and Development Company Ltd.). 2021a. Hibernia. https://www.hibernia.ca/.

HMDC (Hibernia Management and Development Company Ltd.). 2021b. Hibernia Southern Extension. https://www.hibernia.ca/hse.html.

HMDC (Hibernia Management and Development Company Ltd.). 2021c. Hibernia 2018 EEM Report Volume 1:405.

Hodson, P. V., K. R. Munkittrick, P. L. Luxon, I. R. Smith, M. M. Gagnon, M. Servos, and C. S. Branch. 1991. Function Oxygenases of Fish Liver. Canadian Technical Report of Fisheries and Aquatic Sciences 1829:49p.

Holdway, D. 2002. The acute and chronic effects of wastes associated with offshore oil and gas production on temperate and tropical marine ecological processes. Marine Pollution Bulletin 44:185–203.

Horowitz, A. J. 1985. A Primer on Trace Metal Sediment Chemistry. United States Geological Survey 2277:72.

Husky Energy. 2019. White Rose Environmental Effects Monitoring Program 2016 (Volume 1 of 2):235.

Jan, M., and I. Ahmed. 2016. Assessment of fecundity, gonadosomatic index and hepatosomatic index of snow trout, *Schizothorax plagiostomus* in river Lidder, from Kashmir Himalaya, India. International Journal of Fisheries and Aquatic Studies 4:370–375.

Khan, R. A. 1990. Parasitism in Marine Fish after Chronic Exposure to Petroleum Hydrocarbons in the Laboratory and to the Exxon Valdez Oil Spill. Bulletin of Environmental Contamination and Toxicology 44:759–763.

Khan, R. A. 1995. Histopathology in winter flounder, Pleuronectes americanus, following chronic exposure to crude oil. Bulletin of Environmental Contamination and Toxicology 54:297–301.

Khan, R. A. 2010. Two Species of Commercial Flatfish, Winter Flounder, *Pleuronectes americanus*, and American Plaice, *Hippoglossoides platessoides*, as Sentinels of Environmental Pollution. Bulletin of Environmental Contamination and Toxicology 85:205–208.

Khan, R. A., D. E. Barker, R. Hooper, E. M. Lee, K. Ryan, and K. Nag. 1994. Histopathology in winter flounder (*Pleuronectes americanus*) living adjacent to a pulp and paper mill. Archives of Environmental Contamination and Toxicology 26:95–102.

Khan, R. A., and J. Kiceniuk. 1984. Histopathological effects of crude oil on Atlantic cod following chronic exposure. Canadian Journal of Zoology 62:2038–2043.

Kirby, M. F., P. Neall, and T. Tylor. 1999. EROD Activity Measured in Flatfish from the Area of the Sea Empress Oil Spill. Chemosphere 38:2929–2949.

Lenth, R. V. 2016. Least-squares means: the R package lsmeans. Journal of statistical software 69:1–33.

Libes, S. 1992. An Introduction to Marine Biogeochemistry. Wiley, New York, NY.

Macreadie, P. I., A. M. Fowler, and D. J. Booth. 2011. Rigs-to-reefs: will the deep sea benefit from artificial habitat? Frontiers in Ecology and the Environment 9:455–461.

Mallatt, J. 1985. Fish Gill Structural Changes Induced by Toxicants and Other Irritants: A Statistical Review. Canadian Journal of Fisheries and Aquatic Sciences 42:630–648.

Martinez-Haro, M., R. Beiras, J. Bellas, R. Capela, J. P. Coelho, I. Lopes, M. Moreira-Santos, A. M. Reis-Henriques, R. Ribeiro, M. M. Santos, and others. 2015. A review on the ecological quality status assessment in aquatic systems using community based indicators and ecotoxicological tools: what might be the added value of their combination? Ecological Indicators 48:8–16.

Mathieu, A., J. Hanlon, M. Myers, W. Melvin, B. French, E. M. DeBlois, and F. M. Wight. 2011. Studies on fish health around the Terra Nova oil development site on the grand banks before and after discharge of produced water. Pages 375–399 Produced Water.

NEB (National Energy Board), CNSOPB (Canada-Nova Scotia Offshore Petroleum Board), and C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2010. Offshore Waste Treatment Guidelines. Page 28.

Neff, J. M. 2008. Estimation of bioavailability of metals from drilling mud barite. Integrated Environmental Assessment and Management 4.

Nogueira, A., D. González-Troncoso, and N. Tolimieri. 2016. Changes and trends in the overexploited fish assemblages of two fishing grounds of the Northwest Atlantic. ICES Journal of Marine Science 73:345–358.

Page, H. M., J. E. Dugan, D. S. Dugan, J. B. Richards, and D. M. Hubbard. 1999. Effects of an offshore oil platform on the distribution and abundance of commercially important crab species. Marine Ecology Progress Series 185:47–57.

Peralba, M. do C. R., D. Pozebon, J. H. dos Santos, S. M. Maia, T. M. Pizzolato, G. Cioccari, and S. Barrionuevo. 2010. Metal and hydrocarbon behavior in sediments from Brazilian shallow waters drilling activities using nonaqueous drilling fluids (NAFs). Environmental monitoring and assessment 167:33–47.

PSEP (Puget Sound Estuary Program). 1995. Recommended guidelines for conducting laboratory bioassays on Puget Sound sediments. Prepared for U.S. EPA, Region 10, Office of Puget Sound, Seattle, WA. Page 85. Seattle, WA.

Quinn, G. P., and M. J. Keough. 2002. Experimental design and data analysis for biologists. Cambridge University Press, Cambridge.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Redman, A. D., T. F. Parkerton, J. A. McGrath, and D. M. D. Toro. 2012. PETROTOX: An aquatic toxicity model for petroleum substances. Environmental Toxicology and Chemistry 31:2498–2506.

Steichen, D. J., S. J. Holbrook, and C. W. Osenberg. 1996. Distribution and abundance of benthic and demersal macrofauna within a natural hydrocarbon seep. Marine Ecology Progress Series 138:71–82.

Stentiford, G. D., M. Longshaw, B. P. Lyons, G. Jones, M. Green, and S. W. Feist. 2003. Histopathological biomarkers in estuarine fish species for the assessment of biological effects of contaminants. Marine Environmental Research 55:137–159.

Stevenson, R. D., and W. A. Woods. 2006. Condition indices for conservation: new uses for evolving tools. Integrative and Comparative Biology 46:1169–1190.

Suncor Energy. 2017. Terra Nova 2014 Environmental Effects Monitoring Program Year 9 (Volume 1). Project No.: 121511246.

Swain, D. P., and M. J. Morgan. 2001. Sex-specific temperature distribution in four populations of American plaice *Hippoglossoides platessoides*. Marine Ecology Progress Series 212:233–246.

Talalay, P. G., and A. R. Pyne. 2017. Geological drilling in McMurdo Dry Valleys and McMurdo Sound, Antarctica: Historical development. Cold Regions Science and Technology 141:131–162.

Templeman, W., V. M. Hodder, and R. Wells. 1978. Sexual maturity and spawning in haddock, *Melanogrammus aeglefinus*, of the southern Grand Bank. International Commission for the Northwest Atlantic Fisheries Research Bulletin 13:53–65.

Trefry, J. H., K. H. Dunton, R. P. Trocine, S. V. Schonberg, N. D. McTigue, E. S. Hersh, and T. J. McDonald. 2013. Chemical and biological assessment of two offshore drilling sites in the Alaskan Arctic. Marine Environmental Research 86:35–45.

US EPA (United States Environmental Protection Agency). 2002. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Marine and Estuarine Organisms. 3rd Edition. EPA-821-R-02-014. Page 464. Washington, DC.

van Der Oost, R., J. Beyer, and N. P. E. Vermeulen. 2003. Fish bioaccumulation and biomarkers in environmental risk assessment: a review. Environmental Toxicology and Pharmacology 13:57–149.

Whiteway, S. A., M. D. Paine, T. A. Wells, E. M. DeBlois, B. W. Kilgour, E. Tracy, R. D. Crowley, U. P. Williams, and G. G. Janes. 2014. Toxicity assessment in marine sediment for the Terra Nova environmental effects monitoring program (1997–2010). Deep Sea Research Part II: Topical Studies in Oceanography 110:26–37.

Wolf, J. C., W. A. Baumgartner, V. S. Blazer, A. C. Camus, J. A. Engelhardt, J. W. Fournie, S. Frasca, D. B. Groman, M. L. Kent, L. H. Khoo, J. M. Law, E. D. Lombardini, C. Ruehl-Fehlert, H. E. Segner, S. A. Smith, J. M. Spitsbergen, K. Weber, and M. J. Wolfe. 2015. Nonlesions, Misdiagnoses, Missed Diagnoses, and Other Interpretive Challenges in Fish Histopathology Studies: A Guide for Investigators, Authors, Reviewers, and Readers. Toxicologic Pathology 43:297–325.

Wolke, R. E. 1992. Piscine macrophage aggregates: A review. Annual Review of Fish Diseases 2:91–108.

Yang, M., F. I. Khan, and R. Sadiq. 2011. Prioritization of environmental issues in offshore oil and gas operations: A hybrid approach using fuzzy inference system and fuzzy analytic hierarchy process - ScienceDirect. Process Safety and Environmental protection 89:22–34.

Yeung, C. W., B. A. Law, T. G. Milligan, K. Lee, L. G. Whyte, and C. W. Greer. 2011. Analysis of bacterial diversity and metals in produced water, seawater and sediments from an offshore oil and gas production platform. Marine Pollution Bulletin 62:2095–2105.

Yeung, C. W., K. Lee, S. Cobanli, T. King, J. Bugden, L. G. Whyte, and C. W. Greer. 2015. Characterization of the microbial community structure and the physicochemical properties of produced water and seawater from the Hibernia oil production platform. Environmental Science and Pollution Research 22:17697–17715.