EXXONMOBIL CANADA PROPERTIES

HEBRON PLATFORM ENVIRONMENTAL EFFECTS MONITORING PROGRAM (2019)

VOLUME I -INTERPRETATION

MARCH 21, 2023

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EXECUTIVE SUMMARY

SEDIMENT COMPONENT

In 2019, a total of 36 stations were sampled for the sediment quality triad analyses. The Hebron Platform was the single point source for discharges. Sediment samples were collected using a boxcorer at predetermined stations at various distances on radii originating from the Hebron Platform. Sediment from these stations is sampled for particle size, total metals (including barium), hydrocarbons (total petroleum and polycyclic aromatic), total inorganic (TIC) and organic (TOC) carbon, sulphide, and ammonia as nitrogen. Sediment collected is also used to assess potential toxicity on amphipod survival, and benthic community assemblages. Data analysis and comparisons were made between distance from the GBS and between sampling years.

Physical and Chemical Characteristics

A total of 19 analytes were screened-in for further analysis. There was an increase in mean analyte concentration from 2018 levels. Station 8-250 sediment samples had the highest concentrations of barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons, moisture, sulphide, sulphur, and relatively higher concentrations of iron, lead, chromium, vanadium. Concentrations of barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons decreased with distance from the Hebron Platform. These results are expected as the sediment sampling station is near the point of discharge from the Hebron Platform and agree with the effects predicted in the CSR. The highest concentrations of uranium, strontium, vanadium, manganese, iron occurred at stations more than 6,000 m to the northeast of the Hebron Platform. Additionally, the first instance of negative redox potential values from any of the three survey years occurred. Of the eight negative readings, seven occurred in the northeast cluster and > 5 km from the GBS.

Toxicity

In 2019, all EEM sediment samples were below the no-effect Petrotox threshold. Of the obligatory sediment samples tested (<500 m), all were determined to be non-toxic from amphipod survival assays.

Benthic Community Structure

Overall, decreases were detected in all six of the community monitoring variables compared to baseline levels (except for biomass which was not recorded for baseline levels). The number and abundance of some taxa decreased from baseline 2014 levels at some stations within 1,000 m of the GBS. Effects were mainly observed within 2 km of the GBS and are consistent with EIS predictions. While species richness shows a decline over the three survey years with a mean there is an increase in 2019 from 2018 levels. Cluster analysis shows a distinction between stations within 3,000 m of the Hebron Platform and those more than 3,000 m towards the northeast.

Overall, polychaetes accounted for 50% of all taxa observed followed by Clitellata at 21% and Amphipoda at 10%. The Capitellidae, the most used indicator of marine pollution world-wide, were observed in 2014 within the northeast cluster stations (baseline year) and their abundance has decreased in both 2018 and 2019 (compared to baseline). Other widely used indicators of pollution (Spionidae and Clitellata) were observed in relatively high abundances at many of the northeast cluster stations (> 3,000 m from the GBS) and is likely not project-related effect. Transitional zone indicator species *Tharyx* sp. and *Exogone hebes* were observed throughout the survey area. After examining the faunal and environmental data through multivariate analysis, clustering is influenced by percent sand, total organic carbon, distance from the Hebron Platform.

WATER COMPONENT

Produced water modelling indicated under average low currents in August, dilution factors of 300 for oil to reach 0.1 ppm could be reached out to 352 m, however, hydrocarbons were not detected in any water samples. These results indicate that the produced water appears to dilute rapidly once discharged. Elevated barium in water samples collected near the bottom may be reflective of discharged cuttings near the seafloor. All these results indicate that their potential for the water columns discharges having a deleterious biological effect is likely minimal.

COMMERCIAL FISH COMPONENT

American plaice was chosen as the commercial fish of interest, as it is abundant near the Hebron Platform and is an important fishery species. Trawls are conducted within a 2 km radius from the Hebron Platform, as well as within a 2 km radius at a Reference Area roughly 87 km NNE away from the platform. These sites are compared to assess if the platform has any effect on American plaice. Since the 2015 Environmental Characterization (commercial fish), the Reference Area was changed to be shared with the Hibernia EEM Program. Chemical profiling is done using composites of 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

Composite American plaice tissue sampled at the Hebron Platform and Reference Area in 2019 consistently showed the presence of arsenic, mercury, and zinc. No hydrocarbons were detected in fillets. Zinc significantly differed between EEM years, consistent with the previous EEM. For liver composites, eight metals have been consistently detected in all EEM years, with three other metals occasionally above their RDLs. Metal concentrations were either similar across years, lower in 2019, or lower at the Hebron Platform, with the exception of manganese which was higher in 2019 and at the Hebron Platform. Hydrocarbons in all three ranges were screened in for 2019 liver samples, with significant differences between year due to higher values in 2019 compared to 2018. Significant differences between sites were not detected suggesting that the differences in liver hydrocarbon concentrations are not project-related. This represents the first EEM year that lower fuel range ($>C_{10}$-C_{16}) hydrocarbons have been screened in for analysis. No PAHs were above their RDL in 2019.

Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2019.

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2019 for the first and third of three maturing codes (Mat A-P code 520 and Mat C-P code 540) stage, both of which were higher at the Reference Area. For biological characteristics, male fish significantly differed for liver weight and the hepatosomatic index, and female fish differed in liver weight, age, the hepatosomatic index, and the gonadosomatic index between stations. Cross-year comparisons across all EEM years for three indices (Fulton's condition index (FCI), hepatosomatic index (HSI), and gonadosomatic index (GSI)) had significant results for male HSI (higher at the Hebron Platform compared to the Reference Area) and male GSI (higher in 2019 compared to 2015). Female plaice had significant interaction terms for both HSI and GSI.

For gross pathology, female American plaice had a higher incidence of parasites at the Hebron Platform compared to the Reference Area. Additionally, female fish had significantly higher health assessment index (HAI) values at the Hebron Platform for the original HAI and the first modification of the HAI (removal of skin and fins).

For haematology, no differences were detected in the 2019 EEM program. For the cross-year comparison, significant differences were found between stations for all three cell types, with the Hebron Platform having a greater percentage of neutrophils and thrombocytes, and the Reference Area having a higher percentage of lymphocytes. Year was significantly different for neutrophils and for thrombocytes, with 2015 having higher values for both cell types compared to 2018 and 2019.

For MFO, female fish significantly differed between the Hebron Platform and Reference Area in 2018. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, the Hebron platform and Reference Area significantly differed for hepatocellular carcinoma, large, and all hepatocellular vacuoles in 2019. A multivariate analysis of variance (MANOVA) showed significant differences between stations, years, and in the interaction term. Bile duct hyperplasia significantly varied by year, with a higher incidence in 2019 compared to 2015 or 2018. Hepatocellular carcinoma, macrophage aggregates, and small and large hepatocellular vacuoles all had significant interactions terms.

For gill histopathology, only the incidence of normal condition fish differed in 2019. However, a MANOVA for seven gill histology factors detected significant results across station, year, with a significant interaction term. Significant differences between stations was largely due to basal and distal hyperplasia (both higher at the Hebron platform), and telangiectasia (higher at Hebron platform). Significant differences between years was driven by distal and basal hyperplasia and fusion (higher in 2018 compared to 2015 or 2019), and tip hyperplasia (higher in 2018 and 2019 compared to 2015). Only tip hyperplasia had a significant interaction term.

CONCLUSION

Overall, project-related effects observed in the sediment monitoring program are consistent with results predicted in the Comprehensive Study Report (CSR; EMCP 2011), as well as results observed at other offshore oil and gas development installations that show localized changes among key sediment analytes. Specific analytes (TPH, barium, metals) were higher in the near-field, especially at the site closest to the drill cuttings deposition. The results of the commercial fish component found minor differences between the Hebron Platform and the Reference Area, including parasite incidence and higher MFO at the platform for female fish, and liver histopathology. Parasite incidence may be due to crowding near the platform, with the physical structures acting as an artificial reef. Higher MFO activity and liver histopathology traits have been noted across several years with no consistent trend, and is likely natural variation. Moreover, fish from either sampling area were indistinguishable in the taint (taste) test. Therefore, all three null hypotheses of the EEM Program will not result in significant adverse environmental effects on marine fish, fish habitat, or taint of fish and are not rejected based on the 2019 EEM survey.

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ACRONYMS, ABBREVIATIONS, AND UNITS

#	number
2D	Two-dimensional
AIC	Akaike Information Criterion
Alkyl PAH	Alkylated polycyclic aromatic hydrocarbons
ANCOVA	Analysis of Covariance
ANOVA	Analysis of variance
BTEX	Benzene, Toluene, Ethylene, Xylene
CCME	Canadian Council of Ministers of the Environment
CEAA	Canadian Environmental Assessment Act
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CRI	Cuttings re-injection
CSR	Comprehensive study report
CTD	Conductivity, temperature, depth
d	Species richness
dbRDA	Distance-based redundancy analysis
df	Degrees of freedom
DistLM	Distance-based linear modeling
E	Distance variable, east of the produced water outlet
ECCC	Environment and Climate Change Canada
EEM	Environmental Effects Monitoring
EMCP	ExxonMobil Canada Properties
EROD	ethoxyresorufin-O-deethylase
FCI	Fulton’s condition index
Fiber-op	Fiber optical
FPSO	Floating production storage and offloading
GBS	Gravity-based structure
GSI	Gonadosomatic index
H'	Shannon-Wiener Diversity Index
HEB	Hebron
HMDC	Hibernia Management and Development Company
HSE	Hibernia Southern Extension
HSI	Hepatosomatic index
ISQG	Interim Sediment Quality Guidelines
J'	Evenness
MANOVA	multivariate analysis of variance
MFO	Mixed function oxygenase
MinD	Minimum distance to active source
MS	Mean square
MUN	Memorial University
N	Distance variable, north of the produced water outlet
NAF	Non-aqueous fluids
N/n	Abundance/number

NB	New Brunswick
NL	Newfoundland and Labrador
nMDS	Non-metric multidimensional scaling
NS	Nova Scotia
OCNS	Offshore chemical notification scheme
OLS	Offshore loading system
OWTG	Offshore waste treatment guidelines
ρS	Spearman Rank Correlation
PAH	Polycyclic aromatic hydrocarbons
PEL	Probable effect levels
PERMANOVA	Permutational multivariate analysis of variance
QA/QC	Quality assurance / quality control
RDL	Reportable detection limit
S	Number of taxa
SBM	Synthetic based mud
SDL	Significant Discovery Licence
SIMPER	Similarity percentages
SS	Sum of squares
St. Dev.	Standard deviation
TIC	Total inorganic carbon
TN	Terra Nova FPSO
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
Tukey HSD	Tukey honest significant difference
USBL	Ultra-short base line
W	Distance variable, west of the produced water outlet
WBM	Water based mud
Y2	Year 2 (of the monitoring program)
Units	
%	Percent
% saturation	Percent saturation
^{0}C	Celsius
cm	Centimetre
Eh	Redox potential
g	Grams
kg	Kilograms
km	Kilometre
kts	Knots
m	Metre
mg	Milligrams
µg	Microgram
mg/L	Milligrams per litre
µg/L	Micrograms per litre

mm	Milometers
PSU	Practical salinity units
S/m	Siemens per metre

1.0 INTRODUCTION

ExxonMobil Canada Properties (EMCP) is committed to conducting an environmental effects monitoring (EEM) program to detect potential project-induced effects from the Hebron offshore platform. The results will enable an assessment of the need for additional mitigations (EMCP 2017). This report presents the results of the 2019 field program for the Hebron Platform based on the approved methods and plans from the Hebron Offshore EEM Plan (EMCP 2017). For the Hebron Platform, the 2019 program represents the 2nd Production-Phase EEM field program.

1.1 Report Structure

The Hebron 2019 EEM Program (Volume I) has been structured to provide a logical sequence of information including an EEM program overview, summary of project activities and discharges, and potential effects on the receiving environment. Due to the scope and complexities of the EEM program, the methods, results, and analysis are presented in individual component sections (sediment, water, commercial fish). The analysis provides statistical interpretation of the spatial and temporal trends that may occur in association with drilling and production activities at the Hebron Platform. Particular emphasis is given to parameters associated with drilling and production operations, such as barium, hydrocarbons and produced water analytes (EMCP 2011). As the data analysis is technical, a summary of results is presented at the end of individual component sections. The discussion section provides an overall assessment of the potential project effects relative to monitoring hypotheses. Additional detailed descriptions of sampling and handling methods, quality assurance and quality control (QA/QC), along with raw data and supporting information are provided in Volume II (Supporting Information).

1.2 Project Setting and Field Layout

The Hebron oil field is located offshore Newfoundland and Labrador, Canada in the Jeanne d'Arc Basin, approximately 350 kilometres southeast of St. John's in water depths of approximately 93 metres (mean sea level) (Figure 1-1). The Hebron oil field is in proximity to three other offshore oil and gas drilling operations and is approximately 9 km north of the Terra Nova development (operated by Suncor Energy), approximately 32 km southeast of the Hibernia development (operated by Hibernia Management and Development Company), and approximately 46 km southwest of the White Rose development (operated by Husky Energy). EMCP is leading the Hebron Project as Operator on behalf of itself and the other coventurers: Chevron Canada Limited; Petro-Canada Hebron Partnership through its managing partner Suncor Energy Inc.; Equinor; and Nalcor Energy – Oil and Gas Inc (EMCP 2011).

The oil field was first discovered in 1980 and is estimated to contain more than 700 million barrels of recoverable resources. The Hebron Unit currently contains three discovered fields (the Hebron Field; the West Ben Nevis Field and the Ben Nevis Field) and incorporates four Significant Discovery Licenses (SDLs) (SDL 1006, SDL 1007, SDL 1009 and SDL 1010), with ownership varying in each SDL. These four SDLs contain the most likely extent of the oil for the delineated pools within the Hebron Unit. The Hebron field is being developed using a stand-alone concrete gravity-based structure (GBS), a tall (120-130 m) cement column constructed to store approximately 1.2 million barrels of crude oil (Figure 1-1). The Hebron Platform is designed to produce approximately 150,000 barrels of crude oil per day (EMCP 2011). The Hebron Platform was towed out to the field in June of 2017 and began producing oil in November of 2017.

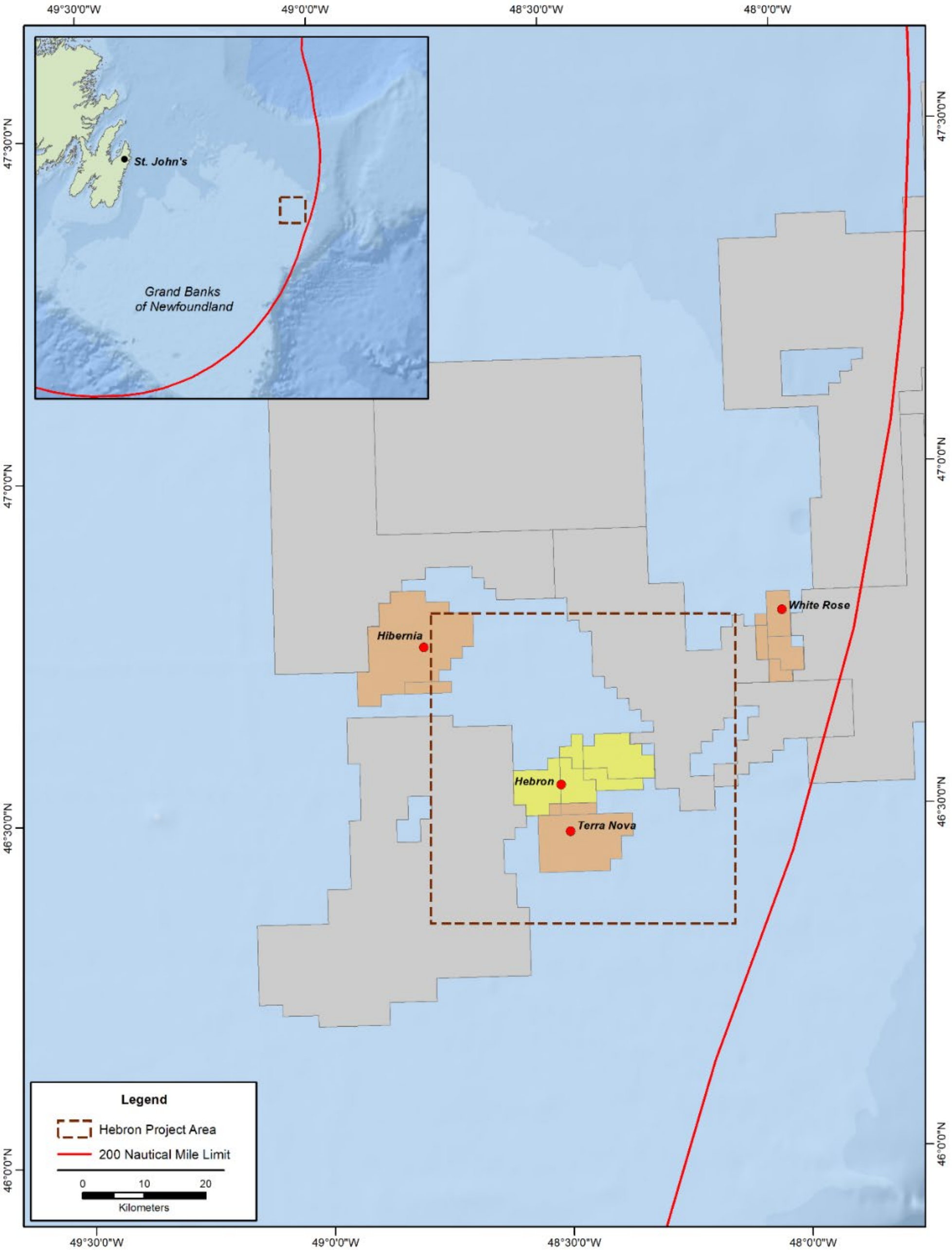


Figure 1-1 Location of the Hebron oil field in relation to St. John's, Newfoundland and Labrador, and proximity to other offshore production operations on the Grand Banks.

Figure 1-2 Hebron Platform in August 2019 with the MV Atlantic Griffon offshore supply vessel on the left.

1.3 Project Commitments

EMCP is committed to conducting an EEM program to detect potential changes in the surrounding environment that can be attributed to the project (EMCP 2017). 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 the Hebron Platform (EMCP 2017). The purpose of this EEM is to validate the Hebron Comprehensive Study (CSR) predictions that are relevant to effects related to marine discharges (EMCP 2017). Complementary to that purpose, the EEM Plan serves to fulfill regulatory information requirements associated with the Hebron Development Application Decision Report 2012.01 (C-NLOPB 2012) and to comply with any other federal environmental regulatory follow-up requirements.

Overall, the EEM program is one of a series of environmental protection initiatives outlined in Hebron's Basis of Safe Operations Plan which includes Emergency Response Management and Environmental Protection Planning (EMCP 2018). The EEM program serves two key functions; to detect changes in the receiving environment resulting from Hebron operational activities and to confirm the effectiveness of discharge limits put forth in the Environmental Compliance Monitoring Plans for the project (EMCP 2018).

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) (National Energy Board 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 are monitored according to Paragraph 9(j) of the Drilling and Production Regulations (National Energy Board et al. 2010). Operations at Hebron are required to comply with discharge levels and volumes on a continuous basis according to Operator's Environmental Compliance Monitoring Plan (a component of the Environmental Protection Plan). The discharge locations for the Hebron Platform are illustrated in Figure 2-1 and Figure 2-2. Discharges are separated into solid (muds and cuttings) and liquid discharges.

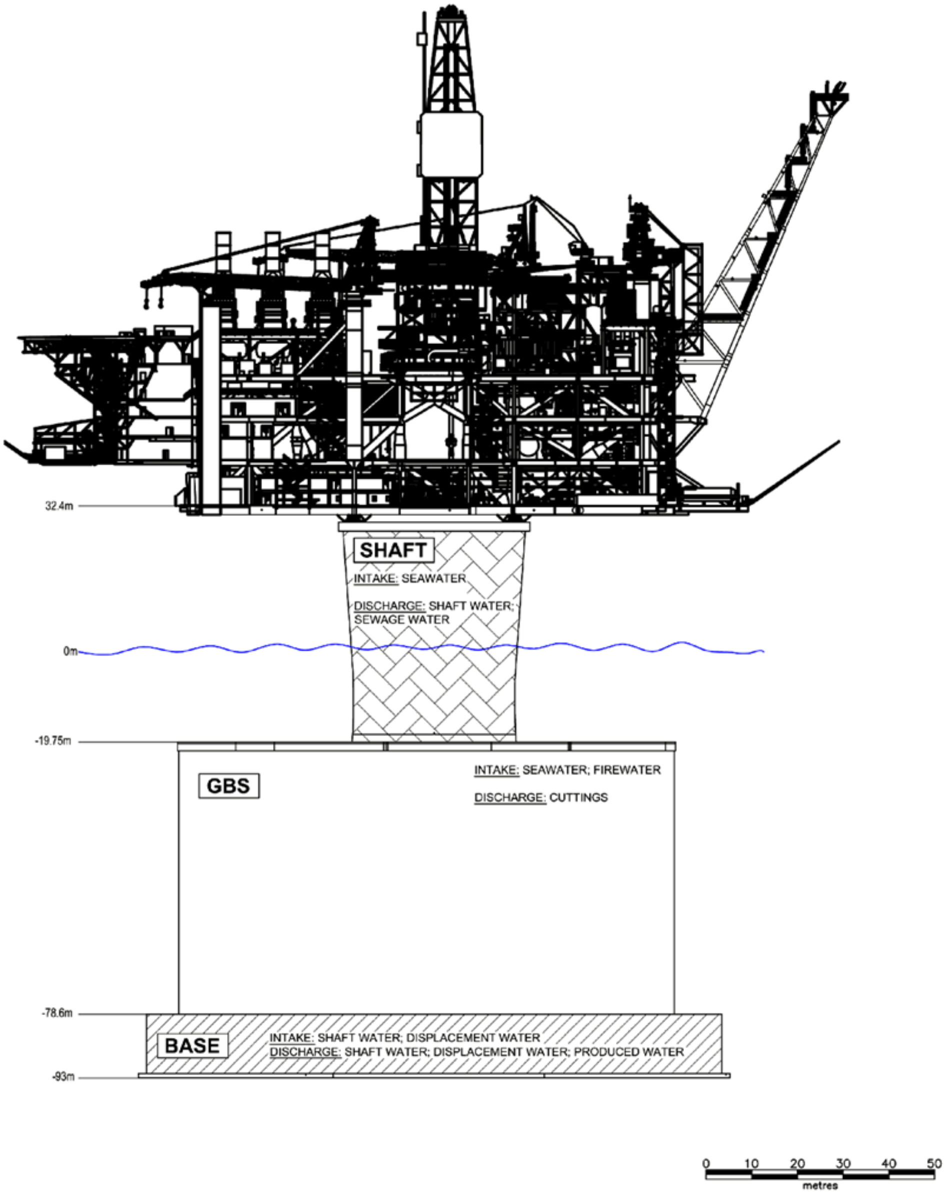


Figure 2-1 Discharges for the Hebron Platform; modified from EMCP (2017).

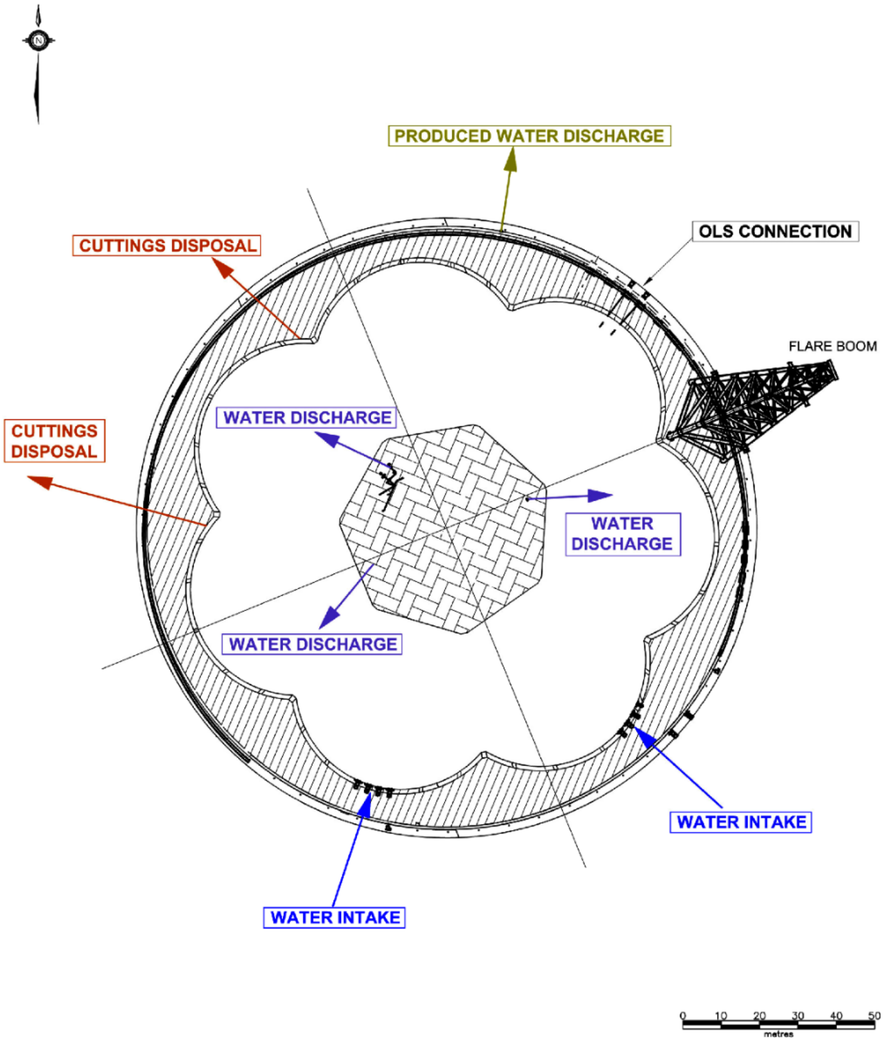


Figure 2-2 Discharge Orientations for the Hebron Platform. All discharges are below the water line. Purple discharges are from shaft and rest are from GBS itself or the base. Modified from EMCP (2017).

2.1 Construction and Operation 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 Schedule of construction and operation activities.

Activity	Date	Relevant Potential Discharges
Tow out	June, 2017	Seawater return, drainage water, sanitary and domestic wastes
Drilling Commenced	July, 2017	WBM cuttings, WBMs
1st SBM Discharge	September, 2017	SBM cuttings
OLS Hook Up	August 2017	Release of preservation materials (corrosion inhibitor, biocide)
Production Commenced	November, 2017	Storage displacement water, produced water*
Operations EEM	June/July 2018	
Operations EEM	July/August 2019	

Notes:
* Continuous Produced Water discharge commenced in 2019
OLS – Offshore Loading System
SBMs- Synthetic-based Muds
WBMs- Water-based muds

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, Paine et al. 2014). Drilling muds are circulated 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. There are two general types of drilling muds used: water-based muds (WBMs) and non-aqueous fluids (NAFs). NAFs are often referred to as Synthetic Based Muds (SBMs). WBMs are generally used only 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 (CAPP 2001, DeBlois et al. 2014c).

The primary constituents of WBMs are water, barium sulphate (a.k.a. barite or $BaSO_4$) as a weighting agent, and bentonite clay as a viscosifier (Trefry et al. 2013, DeBlois et al. 2014b). 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 percent of WBM) at the Terra Nova production field (DeBlois et al. 2014b). As WBMs are primarily water and barite, barium is the main contaminant of WBM-on-drill cuttings (Whiteway et al. 2014). For Hebron, WBM cuttings are separated from the drilling fluids and discharged overboard (EMCP 2017).

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

For Hebron Platform drilling, SBM cutting re-injection (CRI) equipment is currently operating with a majority of SBM drill cuttings and solids from the platform being reinjected into the formation. Limited discharges of SBM cuttings into the marine environment happens on occasion per approval from the C-NLOPB for certain situations (casing shoe tracks, cement plugs) to ensure the integrity of the CRI system. The majority of SBM cuttings, however, are reinjected via the CRI system. Table 2.2 lists the SBM discharges for 2018-2019 from the Hebron Platform.

Table 2.2 Synthetic-based mud drill cuttings discharges from the Hebron Platform (2018-2019).

Discharge Period		Oil on Cuttings Concentration (%)	Calculated Oil Released (m^3)	Discharged Wet Solids (tonne)	Total Injected Volume (m^3)
Dec 27, 2018	Mar 07, 2019	9.80	5.48	45.57	10,499
Mar 08, 2019	Apr 28, 2019	10.67	1.89	14.61	6,952
Apr 29, 2019	Jun 06, 2019	13.24	2.05	12.79	7,188
Jun 07, 2019	Jul 22, 2019	13.36	2.14	13.20	7,265
Jul 23, 2019	Sep 21, 2019	16.32	8.58	43.39	6,023
Sep 22, 2019	Nov 07, 2019	16.59	2.51	12.5	6,623
Nov 08, 2019	Dec 22, 2019	12.57	2.19	14.39	6,762
Project Total			24.84	156.5	51,312
Notes: 2019 EEM sampling was completed in July and August for fish and sediment cruise, respectively					

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 contained within the 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) (EMCP 2011). All chemical additives are screened for offshore use and discharge as per the Hebron Offshore Chemical Management

System. 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, Neff et al. 2013). Produced water discharges transitioned to a mostly continuous discharge in 2019 with some intermittent batch discharges and shutdowns due to maintenance turnarounds. For 2019, the information is as follows:

- January 1– February 28 – batch discharge
- September 2, 6-14, 27 – no overboard discharge due reduced rates and maintenance turnaround." (Table 2.3).

Figure 2-3 shows the produced water discharges for 2018-2019 for the Hebron Platform.

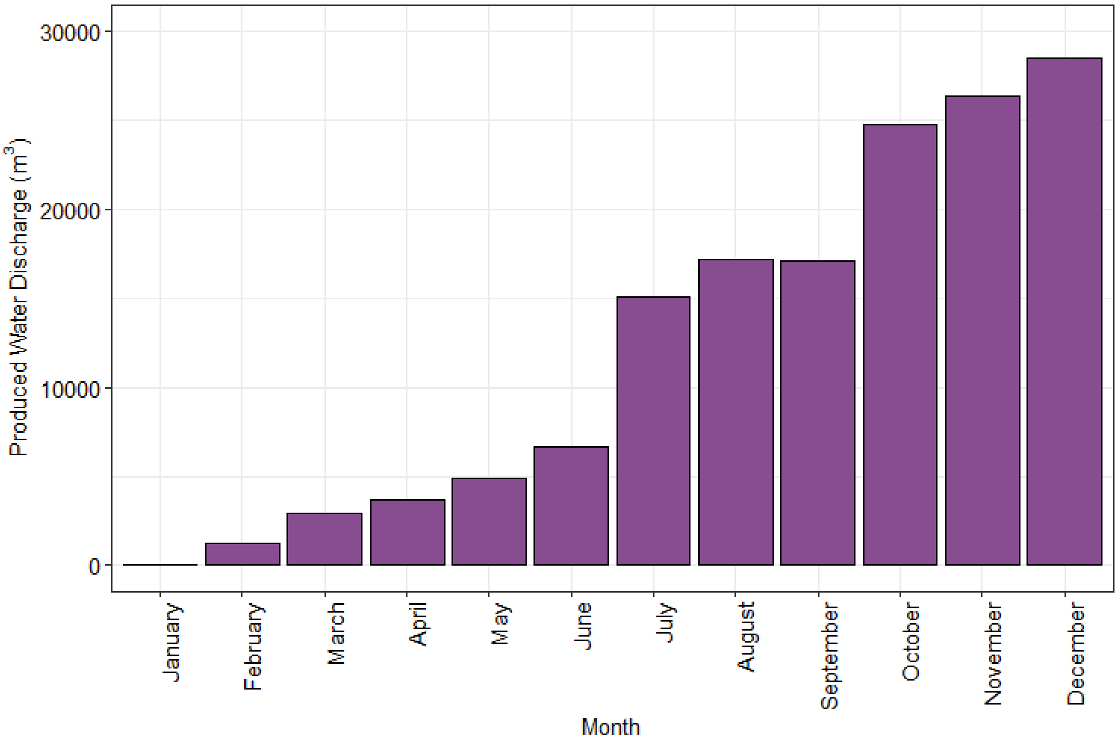


Figure 2-3 Monthly produced water discharges between January and December 2019.

Table 2.3 Summary of discharge oil concentrations within Hebron's produced water (2019).

Discharge Period	Monthly Mean 24-hour (0000-0000) Oil Concentrations* (mg/L)	Monthly Mean of 30-Day Rolling Average Oil Discharge** (mg/L)
January	-	-
February	-	4.5
March	4.2	5.5
April	3.4	3.8
May	5.3	4.3
June	5.7	6.0
July	5.0	5.8
August	6.5	5.1
September	8.6	5.0
October	7.9	9.2
November	8.5	7.5
December	9.1	8.9

Notes:
2019 EEM sampling was completed in July and August for fish and sediment cruise, respectively
* Regulatory Daily Limit is 44 mg/L
** Regulatory 30-day average Limit is 30 mg/L

2.4 Other Waste Discharges

2.4.1 Storage Displacement Water

The Displacement Seawater System is a liquid full, bidirectional system that facilitates the transfer of seawater from the open-sea into and out of the Crude Storage Cells allowing crude to flow in and out of the cells under hydrostatic pressure. When the crude is pumped, displacement seawater enters the connected storage cell via the displacement seawater system, and crude flows from the storage cell into the Crude Booster Pump Caisson. Water enters the two displacement seawater intakes and the Displacement Seawater Lower Ring Main, where it then flows into the seven Triangular Buffer Cells which work together as a common buffer. The flow of seawater entering the displacement seawater system occurs at the same net volumetric rates that the crude oil is pumped from the crude cell. During filling operations, as crude oil flows into the storage cells, the seawater is displaced out of the storage cells and returns back through the Upper Ring Main, through the Triangular Buffer Cells, through the Lower Ring Main, and ultimately back to the open sea (EMCP 2018).

The storage displacement water is tested to a regulatory limit of 15 mg/L residual average daily oil concentration. As part of environmental compliance monitoring, displacement water is collected at the outlet from the platform for analysis (Figure 2-2). Table 2.3 shows the 2019 oil concentration and flow rates for Hebron Storage Displacement Water Discharges.

Table 2.4 Storage displacement water discharges (2019).

Month (2019)	Oil Concentration (mg/L)*		Daily Average Effluent Flow (m^3/day)	
	Average	Range	Average	Range
January	0.3	0.0 – 2.1	13823	11343 – 14275
February	0.2	0.0 – 1.7	13154	6536 – 14228
March	0.4	0.0 – 1.6	15505	11678 – 18071
April	0.2	0.0 – 1.1	16520	12998 – 17225
May	0.5	0.0 – 1.8	19444	16596 – 20968
June	0.5	0.0 – 1.7	18718	9378 – 20375
July	0.5	0.0 – 1.8	18838	13985 – 19728
August	0.3	0.0 – 1.4	21214	18695 – 22532
September	0.4	0.0 – 1.8	14352	0.0 – 25150
October	0.4	0.0 – 1.9	22287	16094 – 24174
November	0.1	0.0 – 0.7	22388	17103 – 25861
December	0.2	0.0 – 1.5	20738	10736 – 25685

Notes:
2019 EEM sampling was completed in July and August for fish and sediment cruise, respectively
* 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 washdown and fire drills (National Energy Board 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 Hebron Platform, deck drain effluent is segregated, collected and treated by two separate systems: the Process Area and Drilling Area drains.

The Process Area drains collect all drainage 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 partial oil recovery. The Process Area Hazardous drains collect effluent including oily water from processing equipment, pig launchers as well as 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 so no standing pool of hydrocarbon if there was a spill in the area (EMCP 2018).

Drilling Area drains manage both hazardous and non-hazardous effluent that is directly related to drilling. The Drilling Area hazardous drain effluent may contain sea water, rainwater, chemical and mud components, cuttings, weighing agents, lubricants, and crude hydrocarbons (EMCP 2017). The Drilling Area non-hazardous drain effluent consists of sea water, minimal hydrocarbons, and mud components (EMCP 2017). The daily mean oil concentrations for process and area drain water are presented in Table 2.5; note that there was no Drilling Area drain discharges in 2019.

Table 2.5 Process Area Drainage water discharges (2019). There were no Drilling Area drain discharges in 2019.

Month (2019)	Oil Concentration (mg/L)*		Daily Average Effluent Flow (m^3/day)	
	Average	Range	Average	Range
January	6.5	2.0 – 12.0	190.6	106.9 – 335.9
February	4.9	1.4 – 11	123.1	35.5 – 280.9
March	4.0	1.2 – 8.7	161.6	84.0 – 338.1
April	4.7	0.8 – 12.0	159.0	85.4 – 281.5
May	4.2	1.6 – 7.8	167.2	95.7 – 350.4
June	4.8	0.9 – 7.7	182.4	99.5 – 292.4
July [a]	6.5	1.8 – 21.6	193.7	120.0 – 363.5
August [b]	5.3	1.7 – 10.4	190.3	48.8 – 320.1
September	4.6	0.5 – 10.7	154.5	0.0 – 296.4
October	4.2	0.65 – 8.05	168.7	87.7 – 348.1
November	4.3	0.9 – 11.3	181.0	107.2 – 249.9
December	3.6	1.0 – 8.0	155.7	91.8 – 301.5

Notes:
[a] 2019 EEM sampling for fish was completed in July
[b] 2019 EEM sampling for sediment was completed in August
* Regulatory Daily Limit is 15 mg/L

2.4.3 Seawater Return

Cooling water consists of sea water that has been chlorinated and pumped onto the platform and passed through heat exchangers 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 (EMCP 2017). Table 2.6 presents the mean residual chlorine concentrations of the seawater return discharge for 2019.

Table 2.6 Sea water return discharges (2019).

Month (2019)	Daily Free Chlorine Concentration (mg/L)*	
	Average	Range
January	1.58	1.42 – 1.72
February	1.51	0.02 – 1.83
March	1.49	1.28 – 1.62
April	1.55	1.44 – 1.71
May	1.62	0.61 – 1.77
June	1.62	1.45 – 1.83
July	1.58	1.32 – 1.75
August	1.59	1.37 – 1.80
September	1.51	1.15 – 1.88
October	1.54	1.32 – 1.77
November	1.63	1.30 – 1.80
December	1.59	1.40 – 1.80

Notes:
2019 EEM sampling was completed in July and August for fish and sediment cruise, respectively
* Regulatory Daily Limit is 2 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) and are not monitored directly. Sanitary and domestic wastes must be macerated to a particle size of six mm or less (National Energy Board et al. 2010). Domestic effluents are also treated to remove grease and screened to remove plastic and metals (EMCP 2017).

2.5 Contamination versus Pollution

Discharges resulting in the presence of a substance in the marine environment at concentrations greater than background levels or greater than a pre-determined approved concentration is characterized as contamination in the marine receiving environment (Chapman 2007). For a substance to be characterized as a 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 contaminant 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 discussed in later Sections.

3.0 ENVIRONMENTAL EFFECTS MONITORING SUMMARY

3.1 Program Objectives

The ultimate purpose of the EEM program is to validate the Hebron Comprehensive Study (CSR) predictions that are relevant to effects related to marine discharges. In addition, and complementary to that purpose, the Hebron EEM serves to:

- Fulfill Condition 2012.01.07 of the Hebron Development Application Decision Report 2012.01 (Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) 2012) (listed in Section 3.2);
- Fulfill the commitments regarding the offshore environmental effects monitoring plan made in Section 15 of the Hebron Comprehensive Study (CSR) report (EMCP 2011a); and
- Comply with any other federal environmental regulatory follow-up requirements.

3.2 Environmental Assessment Predictions

In 2009, the *Canadian Environmental Assessment Act (CEAA)* prescribed a comprehensive study-level environmental assessment for any offshore oil and gas development project. In addition, pursuant to the Development Plan Guidelines (C-NLOPB 2006), proponents of offshore oil development projects need to submit a Development Plan, which includes an Environmental Impact Statement. The Hebron Project CSR (EMCP 2011) fulfilled both the requirement of the *CEAA* and the Development Plan Guidelines. The CSR and subsequent EA Amendment included an environmental assessment of potential effects on valued ecosystem components. Valued ecosystem components addressed within the context of the Hebron EEM program were Fish and Fish Habitat and Commercial Fisheries (EMCP 2011). As such, predictions on alterations to physical and chemical characteristics of sediment and seawater (as components of fish habitat), and predictions on effects to benthos, fish and fisheries, apply to the EEM program.

In general, knowledge from other programs and modelling specific to Hebron indicate development operations at Hebron will alter near-field sediment physical and chemical characteristics and within the vicinity of drilling activities. Direct effects to fish populations as a result of drill cuttings discharge were expected to be unlikely, whereas effects most likely to occur would be to the benthic invertebrate communities (prey source for many species of fish).

Regular operations were expected to alter physical and chemical characteristics of seawater, through release of produced water in the immediate vicinity of the Hebron Platform (at Hibernia, produced water constituents are only detected within 0.5 km from the platform, Section 4.3). Alterations to the receiving environment from other liquid waste streams (e.g., cooling water and storage displacement water; see Section 2.4) on physical and chemical characteristics of sediment and seawater were considered small relative to drill cuttings and produced water discharges.

3.2.1 Sediment Quality Predictions and Assessment

The CSR and subsequent EA Amendments concluded that the potential geographical extent of effects for ‘operations and maintenance’ and ‘decommissioning and abandonment’ activities associated with sediment quality relating to Fish and Fish Habitat are in the 1- 10 km^2 category (CSR; Table 7-12 and Table

7-13) (EMCP 2011). This equates to a distance from the platform of <2 km where potential affects may occur.

It was further predicted, largely based on sediment dispersion modelling and review of drill cuttings effects from other projects, that the ~0.8 km^2 of seafloor area around the platform could be affected by project activities (pg. 7-100 of CSR) (EMCP 2011). This would translate to seafloor within ~500 m of the platform.

It is important to note that once planned mitigations were factored into the assessment, the actual effects (i.e., residual effects) were minimal and that 'No significant adverse environmental effects on Fish and Fish Habitat were predicted that could affect renewable resources' (CSR, Section 7.5.6) (EMCP 2011).

The EEM sampling plan has taken these conclusions and predictions into consideration by emphasizing sediment sampling within 2 km from the platform (primary) with some farther afield (>2km) stations included. The objective of the higher density sampling within the 2 km radius from the Hebron Platform is to validate the relevant CSR predictions as well as being robust enough to capture any potential effects outside the original predictions (i.e., >2km from the platform) (EMCP 2011).

3.2.2 Commercial Fisheries Prediction and Assessment

The CSR predicted that there will be no significant effect on commercial fisheries (Section 8.5.5). Reduced access (i.e., associated with the Safety Zone) is fixed and therefore requires no monitoring. Predictions related to catchability will be assessed using commercial trawls on index species (e.g., American plaice). Other aspects related to commercial fish, but not specifically identified in the CSR, such as taint of flesh, contaminant loads, and prevalence of disease are also included in this plan. All commercial fish elements of the program are based on comparisons to a reference area to identify effects that may be counter to the CSR prediction of no significant effect.

3.2.3 Water Quality Assessment and Conclusions

The CSR concluded that the potential geographical extent of effects for 'operations and maintenance' and 'decommissioning and abandonment' activities associated with water quality relating to Fish and Fish Habitat are in the 1-10 km^2 category (CSR; Table 7-12 and Table 7-13) (EMCP 2011). This equates to a distance from the platform of <2 km where potential effects may occur.

It was further predicted in the CSR, largely based on produced water modelling and review of effects from other projects (i.e., Hibernia, Terra Nova and White Rose) for other liquid discharges (see Section 2.3 and 2.4), that chemistry changes in the water column would take place up to 500 m from discharge (pg. 7-100 of CSR) (EMCP 2011). It is important to note that once planned mitigations were factored into the assessment, the actual effects (i.e., residual effects) were minimal and the CSR predicted that 'No significant adverse environmental effects on Fish and Fish Habitat are predicted that could affect renewable resources' (CSR, Section 7.5.6) (EMCP 2011).

3.3 Program Components

The program components for the Hebron EEM includes sediment quality, commercial fish assessment, and water quality.

3.4 Monitoring Hypotheses

As a central component of EEM programs, generic monitoring hypotheses are established to assess predictions made in the CSR. Null hypotheses, whether for generic monitoring or statistical applications, always state "no change", even if change has been predicted.

3.4.1 Sediment Quality Hypotheses

With respect to sediment quality, the generic monitoring hypothesis is:

H_0: Approved discharges from the Project will not induce changes in the receiving environment that may be distinguished statistically, as being more severe in outcome than predicted in the CSR.

3.4.2 Commercial Fish Hypotheses

Generic monitoring hypotheses for the commercial fish component are:

H_0: Approved solid and liquid project discharges from Hebron's production and drilling operations will not result in taint of American plaice resources at the Hebron Project area relative to Reference Area(s), as measured using taste panels.

H_0: Approved solid and liquid project discharges from Hebron's production and drilling operations will result in adverse effects to American plaice health at the Hebron Project area relative to Reference Area(s), as measured through assessment of biomarkers and general health indices.

3.4.3 Water Quality Hypotheses

As outlined in the Hebron EEM Plan, water sampling will commence when the produced water is continuous. The Hebron produced water transitioned to a continuous discharge in 2019. Predictive modelling of the produced water plume indicated that effects resulting from the discharge of produced water are expected to be undetectable further than 500 m from the Hebron Platform (EMCP 2011). Therefore, the monitoring hypotheses for the water quality component is:

H_0: Distribution of approved produced water discharges from the Project will not differ from the zone of influence as predicted in the CSR.

3.5 Sampling Design

3.5.1 Timing

Table 3.1 lists the schedule for all the EEM cruises for Hebron EEM Program. Initial baseline surveys were conducted prior to the initiation of drilling operations in 2017.

Table 3.1 Hebron EEM Timelines.

Phase	Year	Physical Cruise Dates	Biological Cruise Dates
Baseline (sediment)	2014	August 26 – September 04	-
Baseline (fish)	2015	-	June 3 – 27
Year 1	2018	July 26 – 30	June 27 – July 11
Year 2	2019	August 24 – 28	July 3 – 9
Year 3	2020	TBD	TBD

Notes:
Hebron began operations in June of 2017, began drilling in July of 2017, and started production in November of 2017.
Produced water was continuous in 2019.

3.5.2 Parameters

The EEM program consists of sediment, water and commercial fish sampling components (Table 3.2) to assess the chemistry and toxicity of sediment and water (Table 3.3, Table 3.4), and the health, size and body burden chemistry of fish (Table 3.5). The complete rationale for the selection of parameters as well as the various design changes are available within the EEM Design Plan (EMCP 2017).

Table 3.2 Hebron Platform Program sediment, water and biological sampling program component parameters and analysis.

Program Component	Parameters	Analysis
Sediment Quality Triad	Chemistry	Particle size, organic and inorganic carbon, metals, hydrocarbons, ammonia, and sulphide concentrations
	Toxicity	Amphipod survival
	Benthic Community	Benthic invertebrate community sampling
Water Quality	Chemistry	Metals, hydrocarbons
	CTD	Dissolved oxygen, temperature, salinity, and pH profiles
Commercial Fish (American plaice)	Tissue Chemical Profiles	Body burden (metals, hydrocarbons)
	Sensory Evaluation	Taint / taste testing (Triangle Test and Hedonic Scaling)
	Health Indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity

Table 3.3 Specific Constituents of the Sediment Quality Component for Hebron EEM.

Variable Type	Sediment Quality Component	Specific Constituents	
Physical/Chemical	General	Sediment Particle Size Sulphur/Sulphide Redox Ammonia	TIC/TOC
	Metals	Arsenic Barium Cadmium Chromium Copper	Iron Lead Manganese Mercury Selenium Zinc
	Hydrocarbons	Total Petroleum Hydrocarbons (C_6-C_{32}) BTEX C_6-C_{10} (less BTEX) C_{10}-C_{21} (Fuel Range) C_{21}-C_{32} (Lube Range)	
		Polycyclic Aromatic Hydrocarbons (PAHs)	
		1-Methylnaphthalene 2-Methylnaphthalene Acenaphthene Acenaphthylene Anthracene Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(j)fluoranthene	Benzo(k)fluoranthene Chrysene Dibenz(a,h)anthracene Fluoranthene Fluorene Indeno(1,2,3-cd)pyrene Naphthalene Perylene Phenanthrene Pyrene
Biological	Toxicity	Amphipod Toxicity for all stations <500m. reference stations, and any stations above PetroTox Sediment Quality Guideline (≥150 mg/kg)	
	Benthic Community	Benthic community analysis of invertebrate taxa at all sediment sampling stations	

Table 3.4 Specific Constituents of the Water Quality Component for Hebron EEM.

Variable Type	Water Quality Component	Specific Constituents	
Physical/Chemical	Metals	Arsenic Barium Cadmium Chromium Copper Iron	Lead Manganese Mercury Selenium Zinc
	Hydrocarbons	Total Petroleum Hydrocarbons (C_6-C_{32}) BTEX C_6-C_{10} (less BTEX) C_{10}-C_{21} (Fuel Range) C_{21}-C_{32} (Lube Range)	

Table 3.5 Specific Constituents of the Commercial Fish Component for Hebron EEM.

Variable Type	Commercial Fish Component	Specific Constituents	
Sensory Evaluation	Taste Tests	Triangle Test Hedonic Scaling Test	
Fish Health	General	Total body weight, Gutted body weight Length Liver weight Gonad weight Lipid/ Moisture Content	Age/sex Condition index (gutted weight) Hepatosomatic index Gonadosomatic index
	Stress Enzyme Activity	Mixed Function Oxidase (MFO)	
	Gill Histopathology	Epithelial lifting Hyperplasia (basal, distal, and tip) Telangiectasis Fusion	Thin lamellae Oedema condition
	Liver Histopathology	Nonspecific necrosis Nuclear pleomorphism Megalocytic hepatosis Eosinophilic foci Basophilic foci Clear cell foci Hepatocellular carcinoma	Cholangioma Cholangiofibrosis Mitotic activity increase Macrophage aggregates Hydropic vacuolation Hepatocellular vacuolation
	Haematology	Lymphocytes Neutrophils Thrombocytes	
Body Burden	Metals	Arsenic Barium Cadmium Chromium Copper Iron	Lead Manganese Mercury Selenium Zinc
	Hydrocarbons	Total Petroleum Hydrocarbons (C6-C32) C_6-C_{10} C_{10}-C_{21} (Fuel Range) C_{21}-C_{32} (Lube Range)	
		Polycyclic Aromatic Hydrocarbons 1-Methylnaphthalene 2-Methylnaphthalene Acenaphthene Acenaphthylene Anthracene	Benzo(k)fluoranthene Chrysene Dibenz(a,h)anthracene Fluoranthene Fluorene

Variable Type	Commercial Fish Component	Specific Constituents	
		Benz(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(j)fluoranthene	Indeno(1,2,3-cd) pyrene Naphthalene Perylene Phenanthrene Pyrene

3.5.3 Stations

The areas and sampling stations used for assessment of sediment and water quality, and commercial fish are illustrated in Figure 3-1, Figure 3-2, and Figure 3-3. Distance fields for statistical analyses for sediment quality are detailed in Table 3.6.

Table 3.6 Field distance definitions for sediment sampling.

Field Distance Descriptors	Distance from Hebron Platform	Prefixes	2019 EEM Program Stations
Near-field	≤1,000 m	4-, 6-, 8-, FL-	250, 500, 750, 1000
Mid-field	>1,000 m to ≤2,000 m	4-, 6-, 8-, FL-	1250, 1500, 2000
Far-field	>2,000 m	4-,6-, 8-, FL-	3000, 4000, 6000
		FL-	3,000
		2-, A-, B-, C-, D-, FL-	250, 500, 750, 1000, 1250, 1500, 2000, 3000, 6000
Total-field	All	All	All
Stations with a lettered prefix (A-,B-,C-, D-, FL-) were designed around a potential tieback that was never developed			

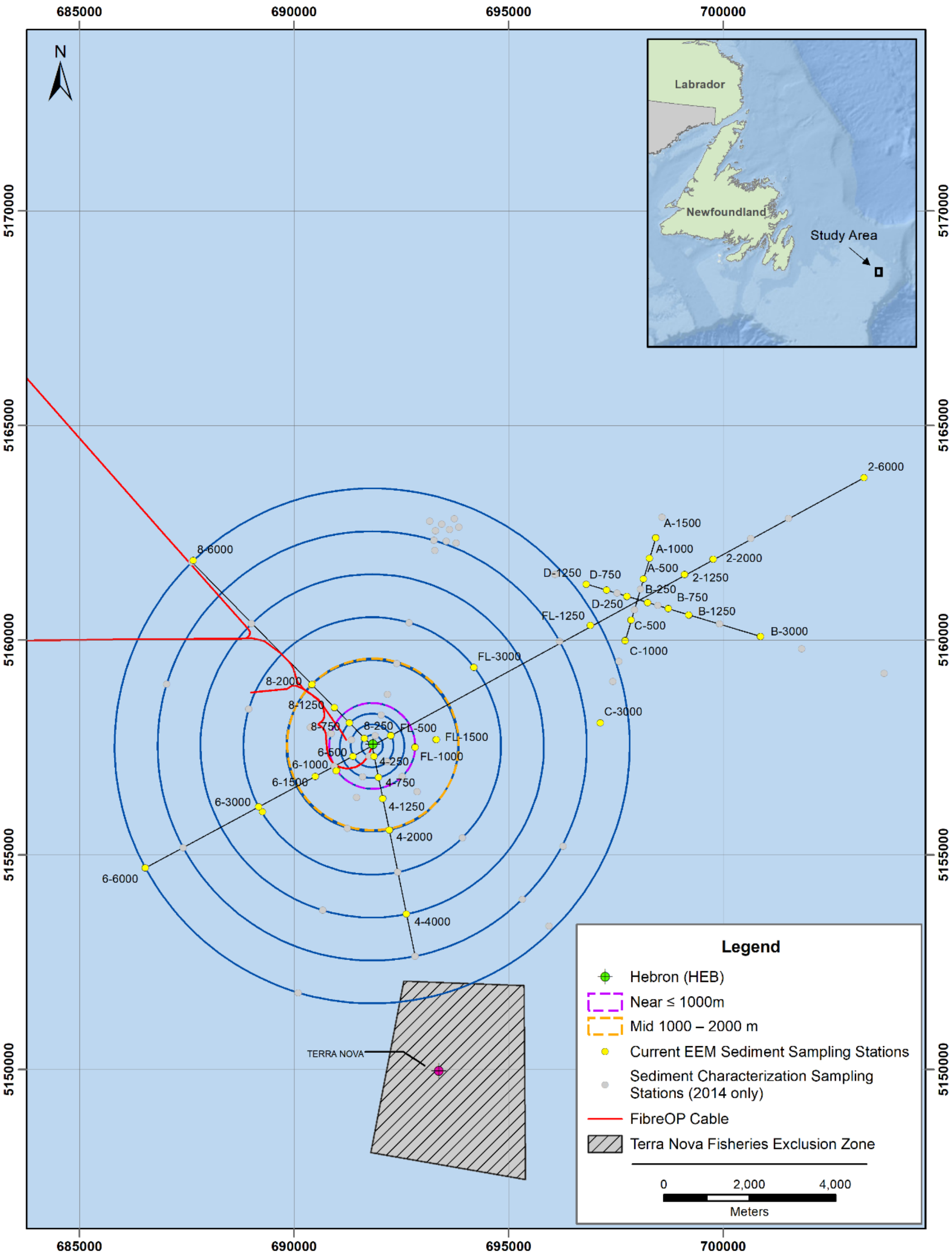


Figure 3-1 Sediment quality sampling stations for Hebron baseline and operational EEM.

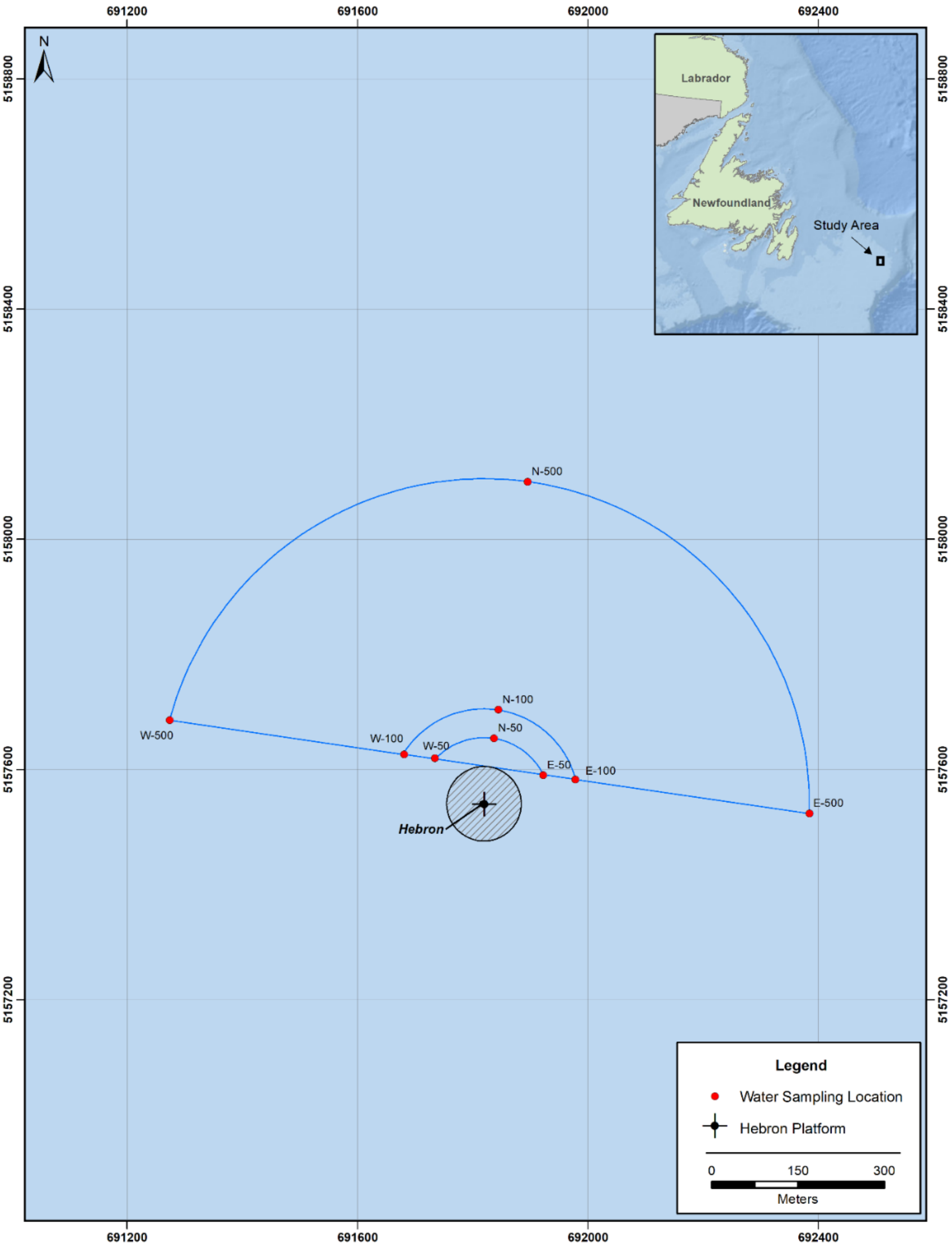


Figure 3-2 **Water quality sampling stations for Hebron 2019 EEM.**

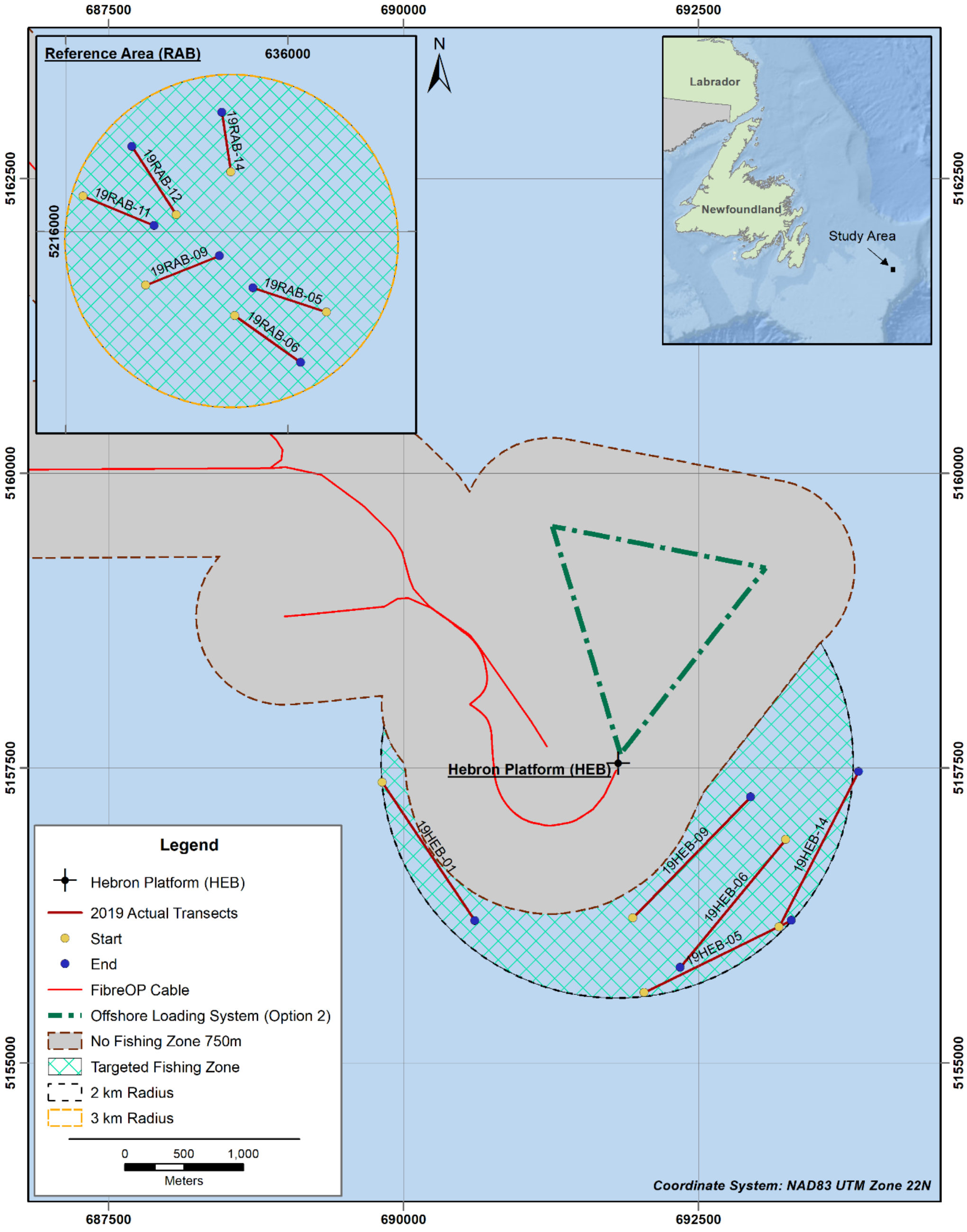


Figure 3-3 Commercial fishing area for Hebron 2019 EEM.

4.0 SEDIMENT COMPONENT

Below is a brief history of the Hebron EEM sediment program as of 2019. Sediment samples are collected in the Hebron Production Field every year for the first three years (2018, 2019, and 2020) . Below is a brief history of the Hebron EEM sediment program as of 2019.

Table 4.1 History of Hebron EEM sediment program stations per year.

Year	Hebron Stations (#)	Reference Area (#)	Northeast Cluster* (#)	Ocean Disposal Area (#)	Notes/Description
2014	47	8	31	9	Hebron Baseline
2018	18	-	18	-	Number of stations reduced to just around the active GBS
2019	18	-	18	-	First year of Produced Water sampling
*The Northeast Cluster was a serious of stations (FL-) around a potential tieback that was never developed					

4.1 Field Collection

The 2019 sediment sampling program is the second sediment operational sampling survey for the EEM program around the Hebron GBS and the first program for Produced Water sampling. Sediment sampling was conducted by WSP field staff from August 24th to August 28th aboard the supply vessel *Avalon Sea*, under contract to ExxonMobil Canada Properties (EMCP). Sediment sampling was completed in the Hebron field on August 28th, 2019.

Coordinates of the established sediment sampling stations are outlined in the Hebron EEM Design Plan (ECMP 2017). The Fugro offshore surveyors operated on the bridge and were responsible for logging the actual position and time of sediment sampling. The positioning of box corer deployment was coordinated through the team leader and a Fugro offshore surveyor.

As outlined in the Hebron EEM Design Plan (ECMP 2017), sediment sampling occurs at both primary and secondary sampling stations. The primary sampling stations (n=28) are arranged at varying distances on radii surrounding the Hebron GBS (GBS) for up to 2 km to assess any environmental effects from the platform. The secondary stations (n=8) occur at distances greater than 2 km from the platform and are used to assess any effects extending beyond 2 km and, interactions between the GBS and the Terra Nova production field.

Two samples are collected at each station, one for physical/chemical analysis and the other for benthic community analysis. An additional sample was collected at stations 4-750, 4-1250, 6-6000, 8-750, FL-1250 for QA/QC purposes. Three sample locations were revised compared to the original EEM plan per the following:

- 6-1000 and 8-6000 were moved 100 meters away from Fibre op cable prior to start of field program
- B-1250 was moved ~20 m at 180 degree heading from proposed position after initial insufficient

samples in the field.

For the 2019 sediment sampling program, an ultra-short baseline (USBL) device was added to track the positioning of the box corer on the seabed. Table 4.2 presents the coordinates (proposed and USBL actual) for 2019 Hebron sediment sampling locations. Actual sample locations were generally located within 10 m from the proposed sampling stations (except three stations noted above).

Sediment samples were collected using a large-volume box corer (Figure 4-1, A). Sediment samples were collected on a 24-hour basis when weather was suitable, and the vessel was not required for higher priority operations (e.g., spill or safety response), therefore, two complete (three-person) WSP teams were required. The vessel's deck hands, and the WSP team worked in a complimentary fashion with the ship's watch system. The deck hands worked 6-hour shifts; the WSP crews worked 12-hour shifts. Each 12-hour shift was directed by the team leader. A toolbox safety meeting was conducted at the start of every 12-hour shift. The Captain had final authority on safety matters. The crew of the *Avalon Sea* were responsible for vessel operations and the operation of the overhead crane that deployed and retrieved the box corer. Up to two crew members worked with the WSP team during the deployment and retrieval of the box corer (Figure 4-1, C). Each three-person WSP team was on deck and responsible for sediment sample collection and processing. Two WSP personnel were responsible for the arming, loading, and unloading of the box corer. The third WSP team member was responsible for sub-sampling recovered box-corer samples and data recording (Figure 4-1, D). Figure 4-1, B shows an example of a sediment sample recovered with the box corer.

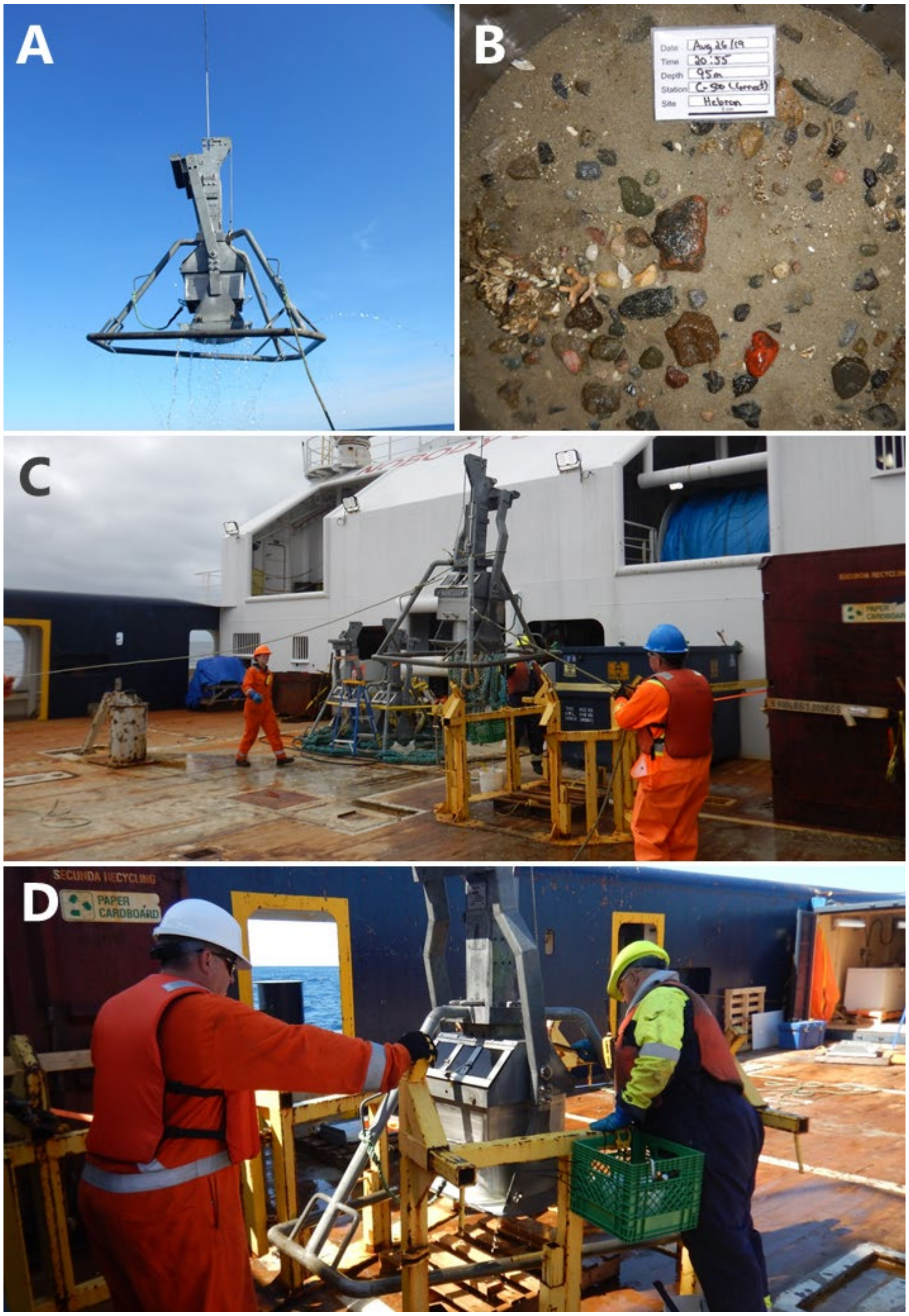


Figure 4-1 Sediment sampling operations, A) large-scale box corer, B) sediment sample example, C) sediment sample deck operations, D) sediment sampling.

Table 4.2 Coordinates (proposed and actual) for 2019 Hebron sediment sampling locations

Station ID	Station Type	Proposed: Easting	Proposed: Northing	Station Order	Actual: Easting	Actual: Northing
2-1250	Primary	699103	5161535	14	699105.32	5161539.18
2-2000	Primary	699768	5161890	15	699770.62	5161896.14
2-6000	Secondary	703285	5163791	16	703284.22	5163790.84
4-1250 QA/QC	Primary	692071	5156315	25	692067.80	5156309.84
4-2000	Primary	692220	5155580	26	692220.37	5155580.30
4-250	Primary	691868	5157299	40	691868.58	5157300.57
4-4000	Secondary	692620	5153620	27	692623.22	5153619.40
4-750 QA/QC	Primary	691968	5156809	23	691962.45	5156808.62
6-1000[1]	Primary	690989	5156961	32	690984.31	5156957.19
6-1500	Primary	690501	5156830	31	690497.02	5156827.19
6-3000	Secondary	689179	5156121	30	689181.26	5156119.68
6-500	Primary	691379	5157299	34	691376.31	5157300.96
6-6000 QA/QC	Secondary	686535	5154701	29	686538.37	5154700.78
8-1250	Primary	690942	5158431	38	690943.09	5158429.43
8-2000	Primary	690417	5158970	39	690418.19	5158967.16
8-250	Primary	691643	5157718	35	691641.23	5157722.52
8-6000[1]	Secondary	687660	5161860	41	687657.25	5161863.55
8-750 QA/QC	Primary	691293	5158081	37	691294.85	5158078.01
A-1000	Primary	698284	5161911	8	698287.25	5161911.95
A-1500	Primary	698430	5162390	9	698433.56	5162390.86
A-500[2]	Primary	698142	5161432	7	698141.25	5161430.26
B-1250[3]	Primary	699199	5160590	12	699195.57	5160586.21
B-250	Primary	698240	5160880	10	698242.30	5160881.48
B-3000	Secondary	700872	5160089	13	700868.60	5160084.46
B-750	Primary	698720	5160741	11	698722.20	5160742.38
C-1000	Primary	697718	5159992	18	697717.12	5159989.83
C-3000	Secondary	697136	5158081	19	697135.30	5158078.72
C-500	Primary	697854	5160472	17	697855.08	5160471.10
D-1250	Primary	696810	5161309	4	696812.24	5161309.40
D-250	Primary	697763	5161022	6	697764.89	5161025.03
D-750	Primary	697286	5161171	5	697286.82	5161174.74
FL-1000	Primary	692821	5157510	21	692816.76	5157511.18
FL-1250 QA/QC	Primary	696904	5160350	3	696905.85	5160352.36
FL-1500	Primary	693315	5157690	20	693311.51	5157691.67
FL-3000	Secondary	694196	5159371	1	694196.84	5159372.87
FL-500	Primary	692260	5157781	33	692259.00	5157782.69

[1] 6-1000 and 8-6000 were moved 100 meters away from Fibre op cable prior to the start of the field program

[2] No USBL position fix at A-500 due to equipment malfunction. Surface fix provided.

[3] B-1250 was moved ~20 m at 180 degree heading from proposed position after initial insufficient samples in the field.

All coordinates presented in UTMs, Zone 22, NAD83

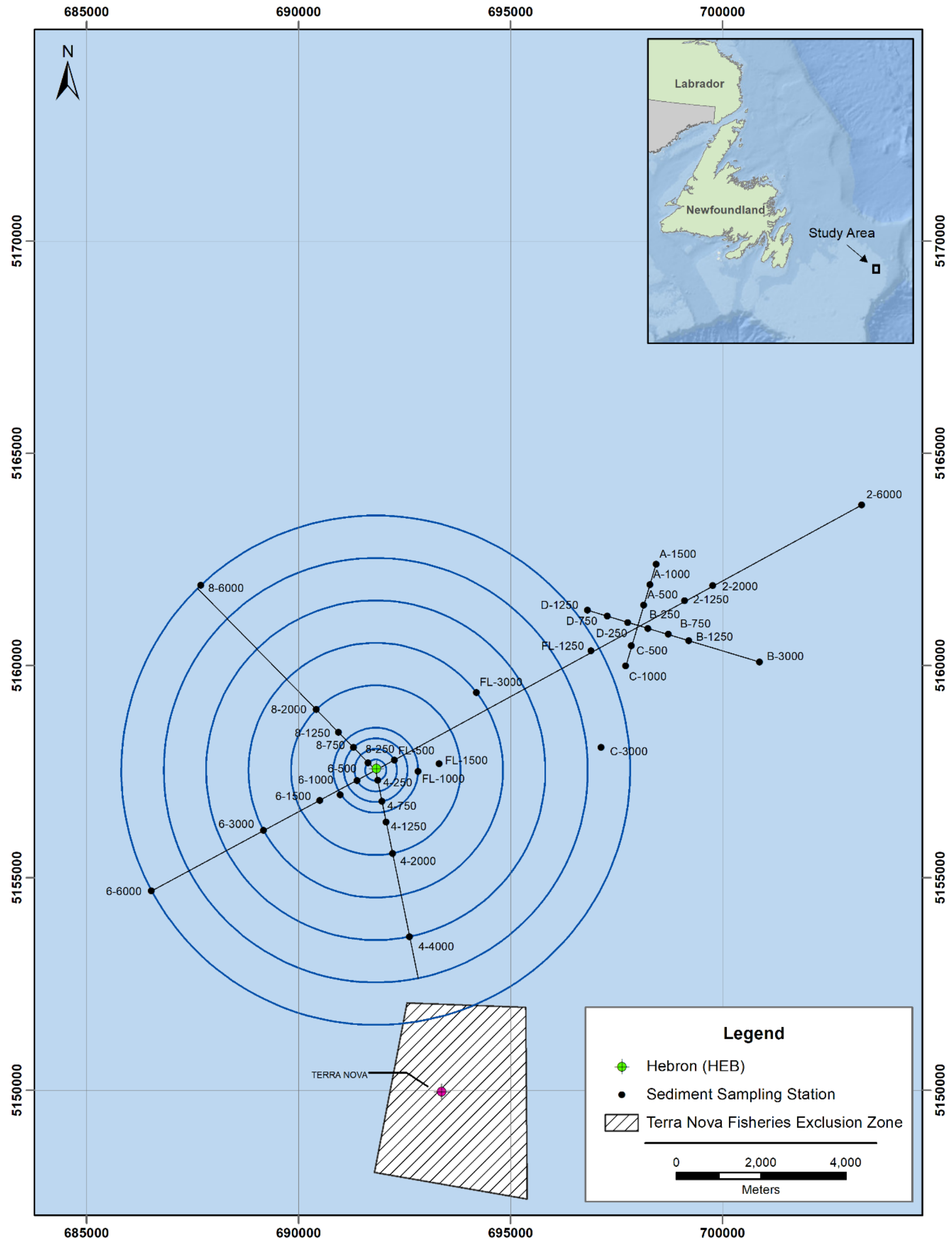


Figure 4-2 Hebron Production Field 2019 sediment sampling stations.

Field measurements (temperature, redox potential, sediment description with photograph) were taken for each box core sample. After field measurements were taken, each box core was sub-sampled for chemical (trace metals, PAHs, sulphide, particle size, toxicity, etc.) and benthic community (benthic invertebrates) analyses. Sub-samples were collected as follows:

- Chemistry and archive samples were collected from one half of the upper 5.0 cm from sub-sample core #1,
- Toxicity samples were collected from the other half of the core #1 sample from the upper 7.5 cm.
- Benthic community sampling was collected from the upper 15 cm from box corer sub-sample #2.
- All samples and measurements were collected from an undisturbed area of the box core.
- Dates, times, and station number were noted on all sample labels.

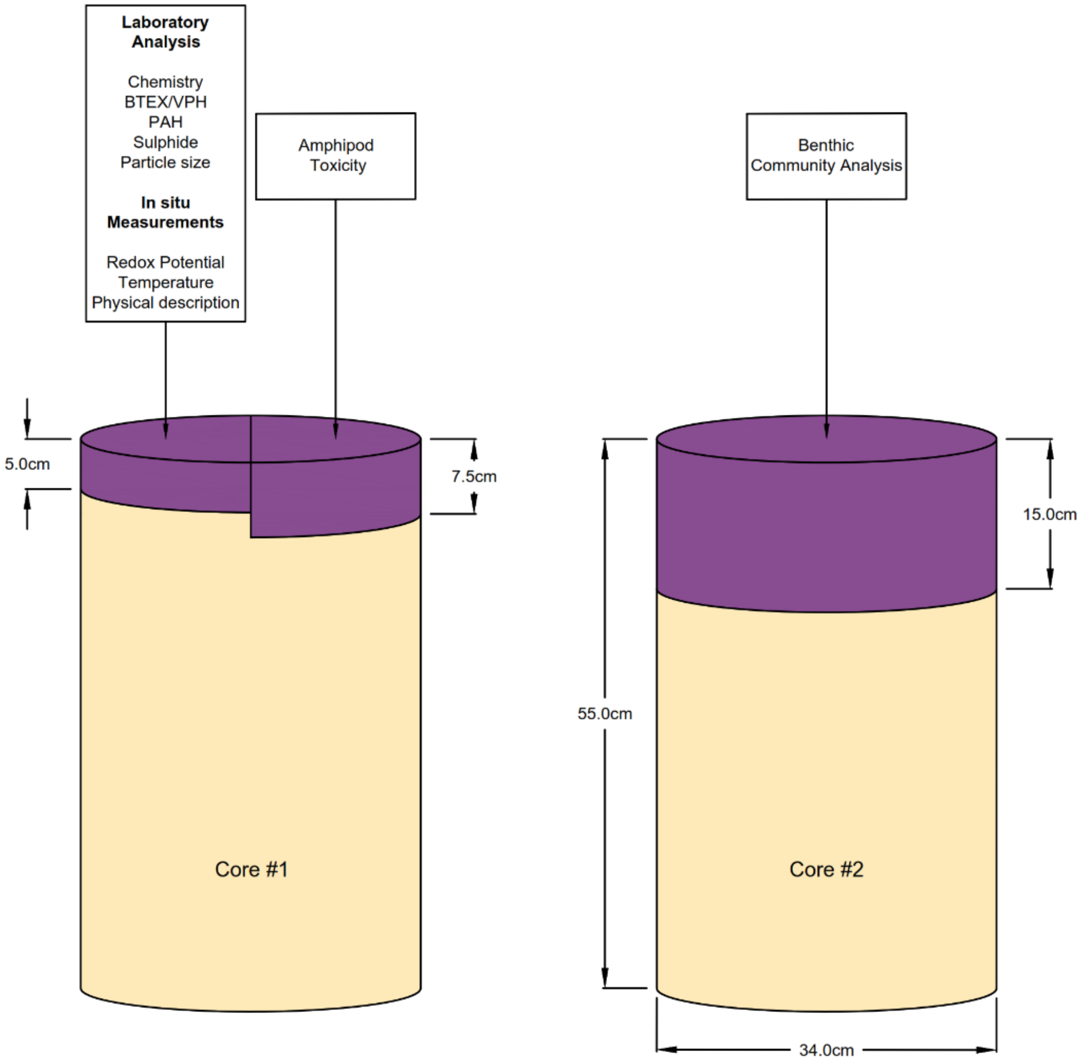


Figure 4-3 Sediment sub-sample collection diagram for each recovered box core sample

4.2 Laboratory and Statistical Analyses

The collected sediment is then analyzed to determine the presence of potential environmental effects on the sediment quality. The sediment quality component is comprised of three analyses forming a quality triad: sediment chemistry (including particle size), sediment toxicity, and benthic invertebrate community structure. Sediment samples are compared to baseline (EMCP 2016a) results and samples collected in subsequent EEM sampling years. The primary and supporting monitoring variables for the sediment quality component are listed below:

Variable Type	**Primary Variables**	**Supporting Variables**
Sediment Chemistry	Barium and Hydrocarbons ($>C_{10}$-C_{21})	Particle size Sulphides Redox Potential Organic carbon Ammonia Metals other than Barium
Sediment Toxicity	Amphipod Toxicity	
Benthic Community Structure	Total Abundance Biomass Richness Diversity	Multivariate Summary of Community Structure and/or Abundance of Individual Taxa

4.2.1 Sediment Chemistry

All sediment samples were analyzed for physical and chemical analytes by Bureau Veritas Laboratories (formerly Maxxam Analytics, Bedford, NS). Sediment samples were analyzed for the following analytes:

- Sediment particle size,
- Barium and Hydrocarbons,
- Total petroleum hydrocarbons (TPH),
- PAHs,
- total inorganic carbon (TIC) and total organic carbon (TOC),
- Metals other than barium,
- Sulphides, redox potential, and ammonia (as nitrogen, -N),
- Moisture,
- Sulphur.

Analytes were screened-in for further analysis if:

- 75 percent of samples for a given analyte were above the reportable detection limit (RDL),
- Are in produced water releases (e.g., $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons, barium) or are likely to be observed in future from drilling operations, or
- An analyte could be potentially affected by the Hebron GBS (e.g., sulphides).

Spatial and temporal trends of screened-in analytes were examined through exploratory and statistical analysis (EMCP 2017). Screened-in analytes are summarized in Table 4.3 including the RDL, number of samples analyzed, the number of stations with detected values (equal to, below, and above RDL), the average of the detected values (mean), standard deviation, median, minimum, and maximum detected values, and the Canadian Councils of Ministers of the Environment Interim Sediment Quality Guidelines (ISQG) and probable effect levels (PEL) for samples analyzed as part of the Hebron EEM program. For screened-in analytes, concentrations less than the RDL were expressed as ½ of the RDL.

Spatial trends were assessed with maps of screened-in analyte concentrations per station in relation to the Hebron GBS. Maps were generated using the R statistical software (R Core Team 2018). The Hebron GBS is indicated by a "+" in the plots and the X and Y axes represent the east-west and north-south distances in meters. Colour thresholds are used to display analyte concentrations at each sampling station. These plots are for illustrating patterns of changing analyte concentrations over successive survey programs only and no statistical inferences were made. Analyte concentration ranges within the legend in the spatial plots state the upper and lower range limits.

Non-parametric Spearman rank correlations were calculated to assess the significance of the relationships of the 2019 screened-in analytes with distance from the Hebron GBS and the Terra Nova floating production storage offloading (FPSO) facility. Scatterplots of each screened-in analyte were visually assessed and presented to examine these relationships. Parametric analysis was conducted to compare between sampling years. For screened-in analytes, concentrations less than the RDL were expressed as ½ of the RDL. Analytes were transformed where required to meet independent and normality assumptions for analysis (Draper and Smith 1998). Threshold regression models were preformed to determine the threshold distances for barium, and fuel and lube range hydrocarbons. An analysis of covariance (ANCOVA) was performed on the three sampling years (2019, 2018, and 2014 baseline). Only analytes measured in all three years were analyzed (e.g., sulphide is only measured in two out of three years and was removed from analysis). Spatial trends were analyzed with 'Year' as a factor and distance from the GBS (MinD) as a continuous covariate with a Year x MinD interaction term. ANCOVAs were preformed in PRIMER with PERMANOVA+(ver. 6.1.15, PRIMER-E Ltd, Plymouth, UK; Clarke and Warwick 2001).

4.2.2 Sediment Toxicity

Sediment toxicity bioassay is the second component of the sediment quality triad. Sediment toxicity analyses were conducted by Avalon Laboratories (Paradise, Newfoundland and Labrador). Sediment toxicity is determined by the survivability of amphipods in screened-in EEM sediment samples compared to laboratory control sediments and results in a binary result ("toxic" or "non-toxic). EEM sediment samples are screened in for toxicity testing based on two criteria:

- Stations at or within 500 m from the active drill center, or
- Samples at or above the no-effects PetroTox Threshold which is 150 mg/kg of C_{10}-C_{21}.

Stations at or within 500 m from the active drill center are automatically screened-in and may experience project-related effects due to their proximity (ECMP 2017). PureDrill IA 35-LV is the drilling mud base fluid used at Hebron and other drilling platforms on the Grand Banks of Newfoundland (ECMP 2017). The PetroTox model is used to predict the aquatic toxicity of petroleum substances from petroleum substance composition (Redman et al. 2012). 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 was 150 mg/kg threshold for PureDrill IA 35-LV. The hydrocarbons C_{10}-C_{21} are used as a marker for PureDrill 1A 35-LV (ECMP 2017). All samples at or above the no-effects threshold of 150 mg/kg hydrocarbons C_{10}-C_{21} were screened-in for toxicity testing.

Amphipod bioassays test the survival rate of individuals cultured in test sediments according to conditions outlined in the Biological Test Method: Acute test for sediment toxicity using marine or estuarine amphipods (Environment Canada 1992, EPS 1/RM/26 with October 1998 amendments) and Biological Test Method: Reference Method for determining acute lethality of sediment to marine or estuarine amphipods (Environment Canada 1998, EPS 1/RM/35). However, as per Environment and Climate Change Canada (ECCC) recommendations, pore water chemistry was replaced with sediment sulfide, ammonia, and redox analyses. Testing at the ECCC Atlantic Laboratory for Environmental Testing has demonstrated that whole sediment ammonia, sulfide, and redox measurements are more relevant than ammonia pore water measurements in toxicity testing. Furthermore, sulfide is not stable in aqueous solution and toxic levels cannot be accurately measured in pore water.

The bioassay procedure is thus, 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 analyzed using Dunnett's t-test. Sediment sulfide, ammonia, and redox potential concentrations for each sample were compared to a laboratory control sediment sample.

4.2.3 Benthic Community Structure

A total of 36 sediment samples for benthic community analysis were sent to Envirosphere Consultants (Windsor, NS). Samples were collected and processed in accordance with the Standard Methods 10200 (APHA 1995). This included preserving samples in 11L buckets with 10% buffered formalin in the field for shipment to the lab. Sample containers were checked for any leaks and labels checked against the chain-of-custody form accompanying the shipment.

In accordance with the methods, sediment sample processing included removing the formalin and washing each sample through a 0.5 mm sieve. Samples were portioned onto a gridded petri plate and examined with a dissecting microscope under 6.4X magnification, and all organisms (including fragments) were removed. When the plate was clear, it was re-examined under 16X magnification. After sorting the organisms of each sample were blotted with paper towels to remove surface water, placed into vials, weighed to the nearest mg, and preserved with 70% isopropanol. Samples were then sent to BioTech Taxonomy (Smithtown, NB) for taxonomic identification and enumeration. All samples were completely sorted, none required sub-sampling. Organisms from each sample were identified to the lowest possible taxonomic level using a stereo microscope with 6.7 to 45 x zoom magnification and a compound microscope with 40 to 400 x magnification.

Each station sample was analyzed for taxa identification, number of taxa, total abundance, total biomass, species richness, and community structure. Benthic community structure parameters reported for 2019 are: number of taxa (S), total abundance (N), total biomass (g), species richness (d), evenness (J'), and Shannon-Weiner diversity index (h'). Number of taxa indicate the number of species found at each site. Total abundance is the number of individuals (all species) found at each site. Biomass is the wet weight of all individuals found at each site. Species richness (d) considers the number of taxa (S) and number of individuals (N) present in a sample. The higher value (d) indicates the greater taxa richness. Evenness (J') indicates how evenly the number of individuals is distributed among the species present. Low scores (J') indicate more variation in abundances between taxa at each site. The Shannon-Wiener diversity index (H') is a measure of both abundance and evenness of species present at each site. A high value (H') indicates a highly diverse and equally distributed community where no one taxa is dominant.

Benthic community data was compared to previous EEM years and the baseline survey. Analysis focused on change in the main indices of community structure (described above) as a measure of changes in the environment at each station. Univariate and multivariate statistics were conducted on square root transformed benthic community data using PRIMER with PERMANOVA+(ver. 6.1.15, PRIMER-E Ltd, Plymouth, UK; Clarke and Warwick 2001, Anderson et al. 2008). While several taxon classes and families have been identified as environmental change indicators, they are often comprised of both tolerant and in-tolerant species. For this reason, both species and family level data were used for analysis. Visual interpretation of benthic assemblage structure was completed with non-metric dimensional scaling (nMDS) plots which were generated from a Bray-Curtis similarity matrix based on data at the family level of taxonomic identification. To examine the effect of distance from the GBS to station community structure, a main and pair-wise one-way PERMANOVA was conducted on a Bray-Curtis similarity matrix of species level assemblages. Distance from the GBS was treated as a categorical variable with stations falling into one of three distance bins ≤1,000 m, 1,000 m to 2,000 m, and stations >2,000 m. A similarity of percentages (SIMPER) analysis was conducted on species taxonomic level data to determine similarities of stations between distance bins and the top contributing species.

Multivariate analysis to detect statistically significant relationships between benthic assemblage structure (at the family taxonomic level) and screened-in analytes as predictor variables were conducted. A stepwise (with Akaike information criterion (AIC) selection criteria) distance-based linear model (DISTLM) was conducted. Relationships between predictor variables and benthic community structure were presented visually with a distance-based redundancy analysis (dbRDA) ordination plot with predictor variable overlay.

4.3 Results

From the screen-in criteria outlined in Section 4.2.1, a total of 19 analytes were screened-in for further analysis and are presented below. Table 4.3 presents the screened-in analytes and summarizes for each analyte: the RDL, number of samples analyzed, the number of stations with detected values (equal to, below, and above RDL), the mean, standard deviation, median, minimum, maximum detectable values and the Canadian Councils of Ministers of the Environment Interim Sediment Quality Guidelines (ISQG) and probable effect levels (PEL) for samples analyzed as part of the Hebron EEM program. The following section examines trends present in the screened-in analytes for the 2019 sediment samples and compares the findings to previous EEM years, sediment toxicity, and benthic community structure.

Table 4.3 Summary of screened in analytes from the 2019 Hebron EEM sediment samples

Analyte	RDL	Units	No. Samples	No. >RDL	No. =RDL	No. <RDL	Mean	St. Dev.	Median	Min.	Max.	ISQG	PEL
PARTICLE SIZE ANALYSIS													
Sand	0.1	%	36	23	0	13	4.719	7.660	0.545	0.1	34		
Gravel	0.1	%	36	36	0	0	94.278	7.700	98	65	99		
Fines	0.1	%	36	36	0	0	1.119	0.315	1.075	0.74	233		
TOTAL EXTRACTABLE METALS													
Barium	5	mg/kg	36	36	0	0	153.806	149.733	120	62	990		
Iron	50	mg/kg	36	36	0	0	1241.111	459.601	1100	640	2500		
Lead	0.5	mg/kg	36	36	0	0	1.947	0.443	1.8	1.3	3.2	30.2	11.2
Manganese	2	mg/kg	36	36	0	0	33.944	16.895	27	13	80		
Chromium	2	mg/kg	36	36	0	0	3.069	0.596	3.05	2.1	4.4		
Strontium	5	mg/kg	36	36	0	0	36.139	15.166	31	18	86		
Uranium	0.1	mg/kg	36	36	0	0	0.155	0.060	0.14	0.1	0.47		
Vanadium	2	mg/kg	36	36	0	0	4.381	1.181	4.2	2.7	7.2		
TIC/TOC													
Total Organic Carbon	500	g/kg	36	33	1	2	953.889	303.713	1050	500	1500		
HYDROCARBONS													
C10-C21 Hydrocarbons	0.25	mg/kg	36	20	0	16	2.577	11.071	0.33	0.25	66.9		
C21-C32	0.25	mg/kg	36	31	0	5	0.635	0.472	0.555	0.25	3		
OTHER													
Moisture	0.3	%	36	36	0	0	17.361	1.693	17.5	13	20		
Redox Potential	1	mV	36	28	0	8	54.528	75.345	79	-218	141		
Sulphide	0.5	µg/g	36	2	1	33	0.558	0.289	0.5	0.5	2.2		
Sulphur	0.001	%	36	36	0	0	0.025	0.013	0.023	0.014	0.093		
Ammonia	0.3	mg/kg	36	36	0	0	5.021	3.722	4.05	0.37	14		

4.3.1 Physical and Chemical Characteristics Results

To detect any spatial variations or patterns in screened-in analytes for the 2019 EEM samples, concentrations per station are represented in two-dimensional scatter plots. Plots were generated using the R statistical software (R Core Team 2018). The X and Y axes represent the east-west and north-south distances in meters from the Hebron GBS which is represented by a "+" in the plots. Sampling stations are represented by dots while color represents reported concentrations of each analyte. The legend for each plot reports the lower and upper limit of the concentration range represented by color. For the 2D plots, analyte values below RDL (<RDL) were expressed as half (0.5) RDL. These plots are for illustrating patterns of changing analyte concentrations only and no statistical inferences were made.

Results-Spatial

Particle Size

Particle size analysis for the 2019 EEM samples was completed on all stations. The primary particle size for all stations was sand with concentrations ranging between 65-99 percent while secondary particle size varied per sample. Of the secondary substrates, gravel ranged between 0.1 to 34 percent, percent fines ranged between 0.74 to 2.33 percent. Spatial distributions of particle size compositions are depicted in Figure 4-4 to Figure 4-6 in decreasing particle size. Gravel was above RDL (0.1 percent) in 23 of 36 samples and station 2-1250 to the northeast of the Hebron GBS (Figure 4-4). Sand was the primary substrate across all stations of which 17 of 36 had a composition of 99 percent sand. The lowest percent sand concentration was also located at 2-1250 (Figure 4-5). Percent fines concentration was between 0.74 to 2.33 percent with the highest concentration occurring at station 8-250 (Figure 4-6).

Particle size concentrations observed in 2019 were compared to baseline levels observed in 2014. Gravel concentrations were two standard deviations higher than the baseline mean in 15 of 36 samples. Of these only 4 stations are within 1,000 m of the Hebron GBS. For percent fines, only station 8-250 was two standard deviations above 2014 levels. Sand concentrations for all samples were below two standard deviations from the baseline mean.

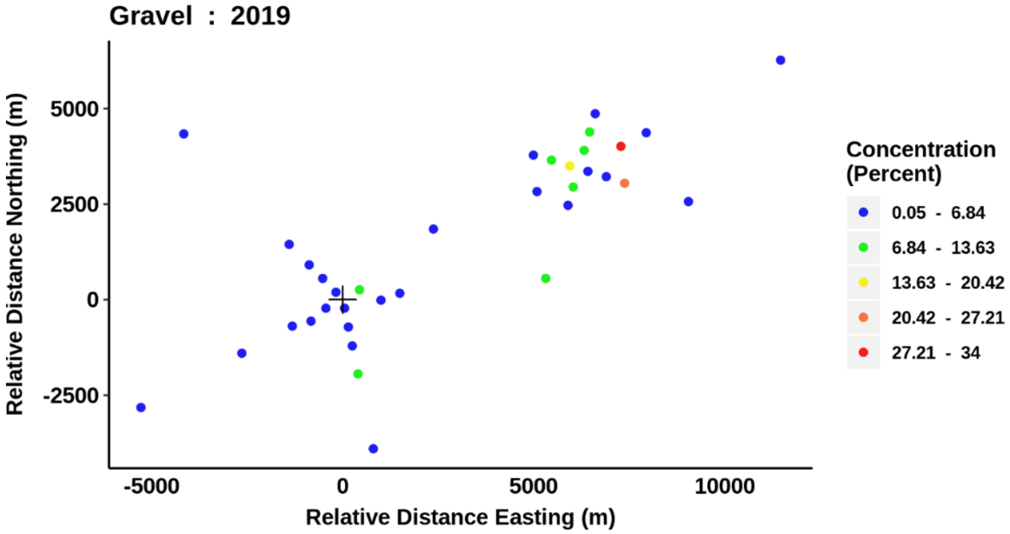


Figure 4-4 Spatial pattern of gravel (percent concentration) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (82% of samples) the average percent composition of 2014 baselines samples was 4.11% gravel.

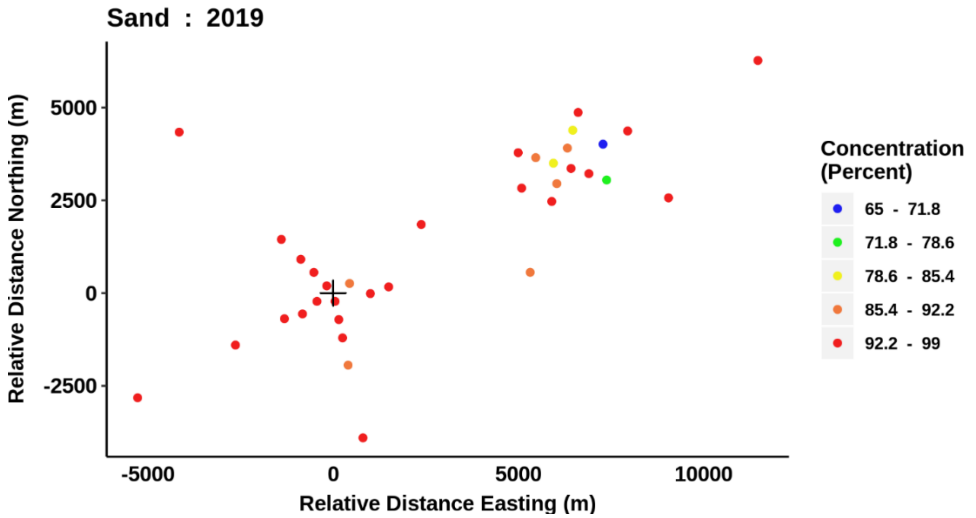


Figure 4-5 Spatial pattern of sand (percent concentration) from 2019 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with sand comprising on average 93.64% of each sample.

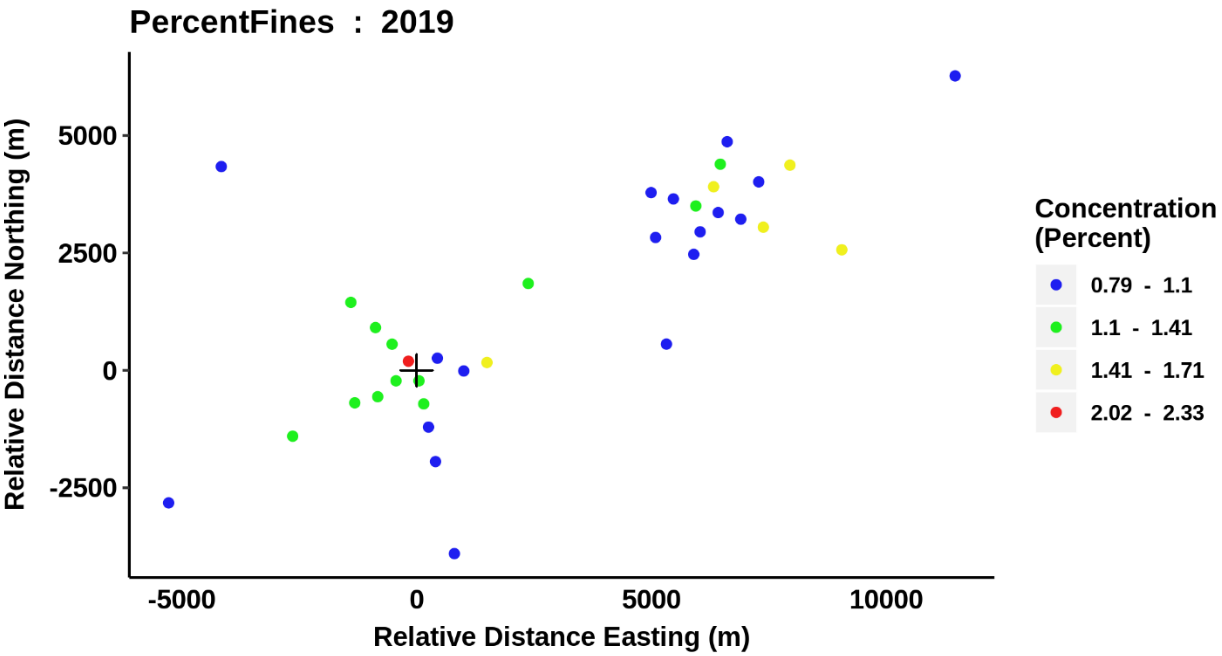


Figure 4-6 Spatial pattern of percent fines (percent concentration) from 2019 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with fines comprising on average 1.18% of each sample.

Total Extractable Metals

Spatial distributions for the eight extractable metals analyzed varied between analytes and are presented in Figure 4-7 to Figure 4-14. Barium concentrations ranged between 62 to 990 mg/kg. The highest concentration of barium occurred at station 8-250 (Figure 4-7). While the 2019 barium concentration at this station was higher than observed during baseline (99 mg/kg) it is a decrease from 2018 levels (1100 mg/kg). At total of 11 stations were two standard deviations above baseline barium concentrations of which five were within 1,000 m of the Hebron GBS. Of the other seven extractable metals analyzed, station 8-250 had relatively higher concentrations of iron (2300 mg/kg, Figure 4-8), lead (3.2 mg/kg, Figure 4-9), chromium (4.2 mg/kg, Figure 4-11), and vanadium (7.2 mg/kg, Figure 4-14). There were also relatively high concentrations of iron, lead, manganese (Figure 4-10), chromium, strontium (Figure 4-12), uranium (Figure 4-13), and vanadium observed at stations to the northeast of the Hebron GBS. The highest concentrations of uranium occurred at B-250, strontium occurred at B-1250, and vanadium, manganese, and iron occurred at 2-6000. These stations are more than 6,000 m from the Hebron GBS in the northeast cluster.

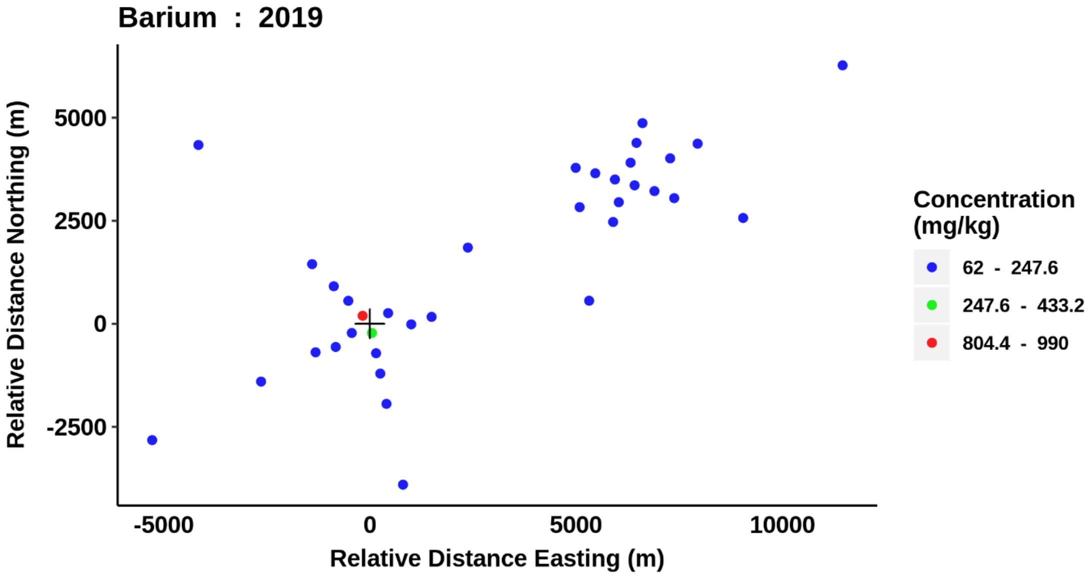


Figure 4-7 Spatial pattern of barium (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with an average concentration of 110 mg/kg.

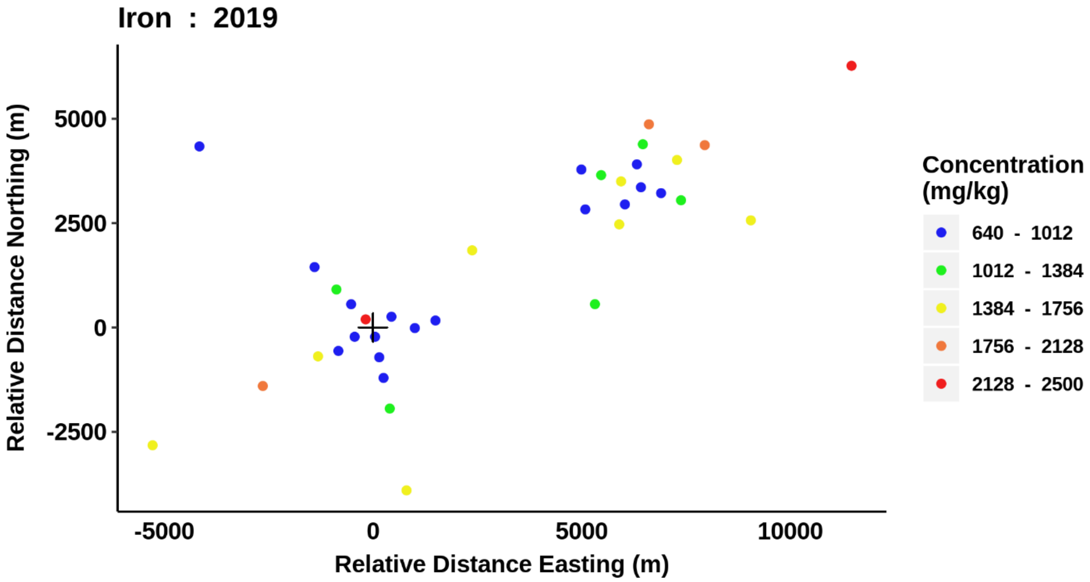


Figure 4-8 Spatial pattern of iron (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with an average concentration of 1123 mg/kg.

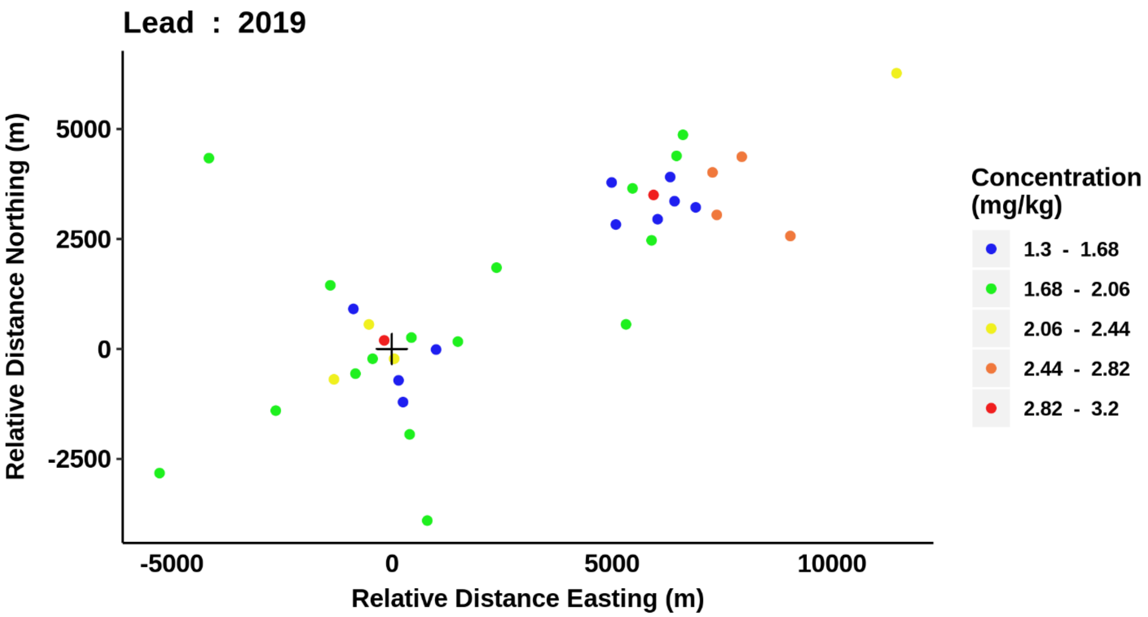


Figure 4-9 Spatial pattern of lead (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with an average concentration of 1.8 mg/kg.

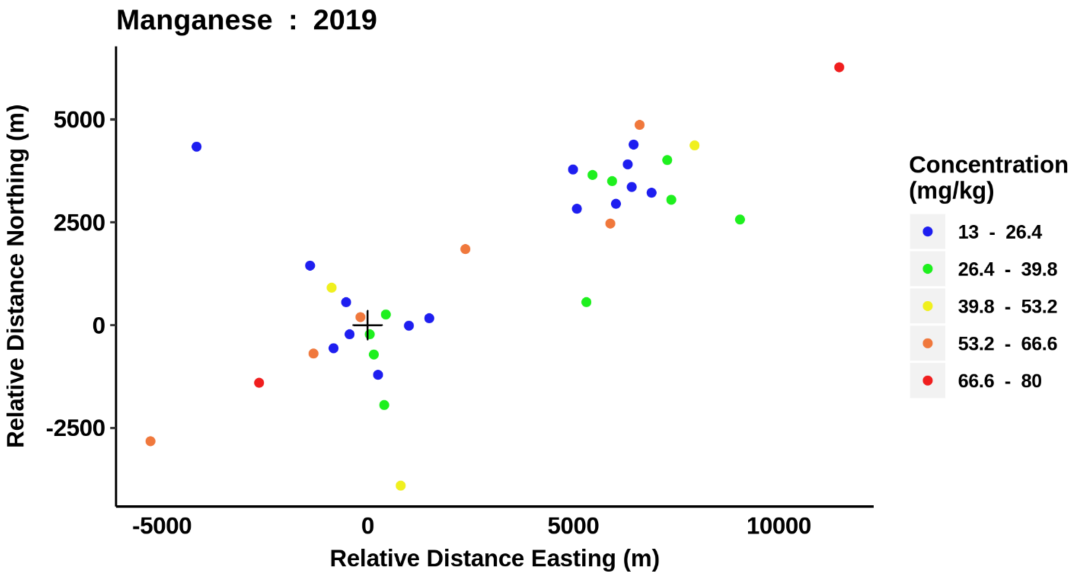


Figure 4-10 Spatial pattern of manganese (mg/kg) from 2019 EEM samples within the survey area around from the platform (cross). All 2014 baseline samples were above the detection limit with an average concentration of 30 mg/kg.

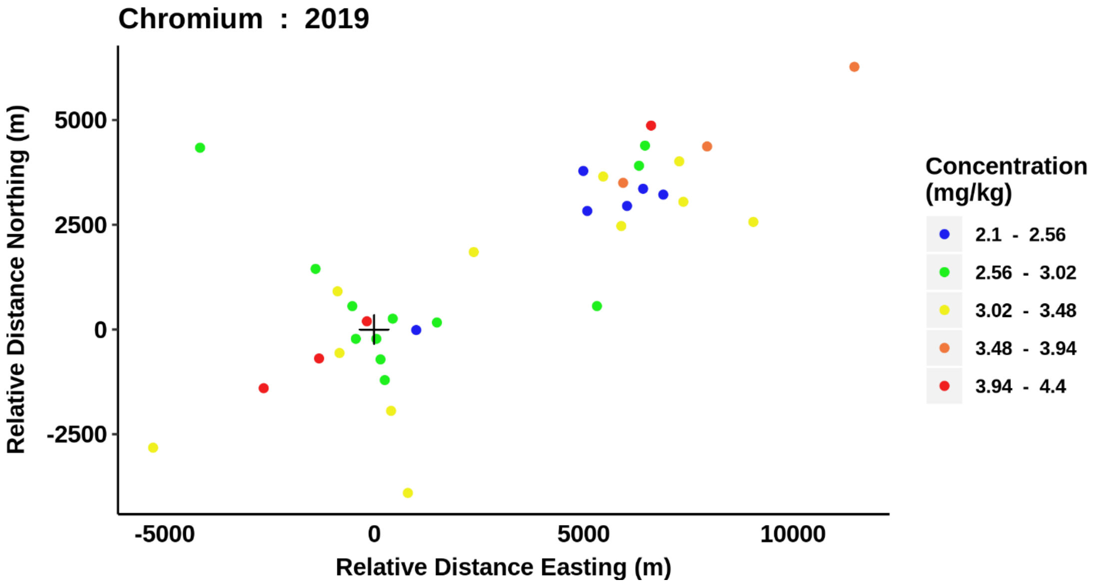


Figure 4-11 Spatial pattern of chromium (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 3.0 mg/kg.

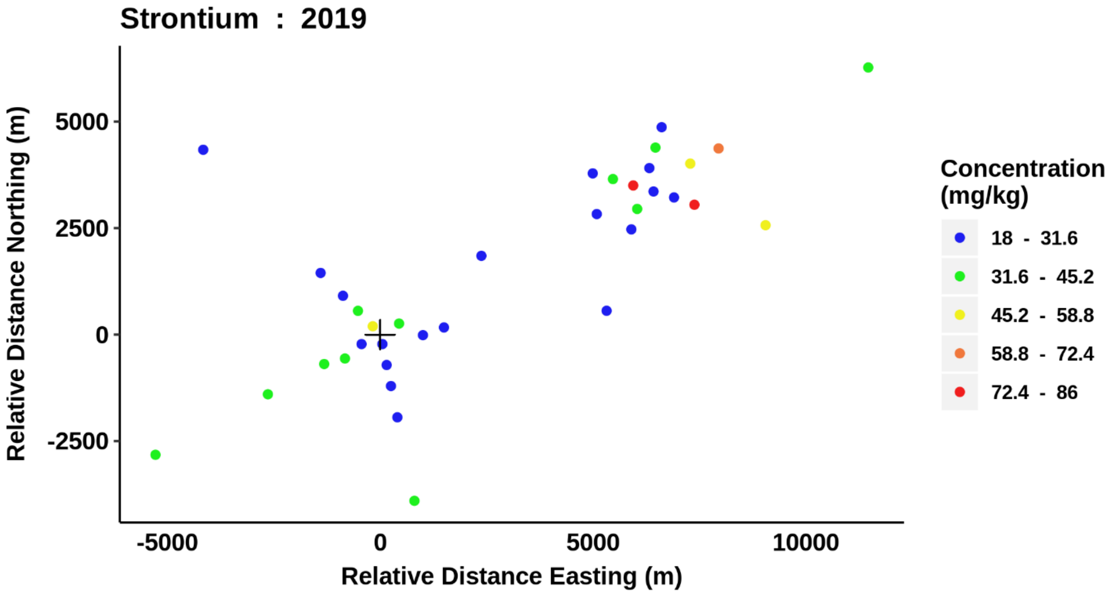


Figure 4-12 Spatial pattern of strontium (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 49.0 mg/kg.

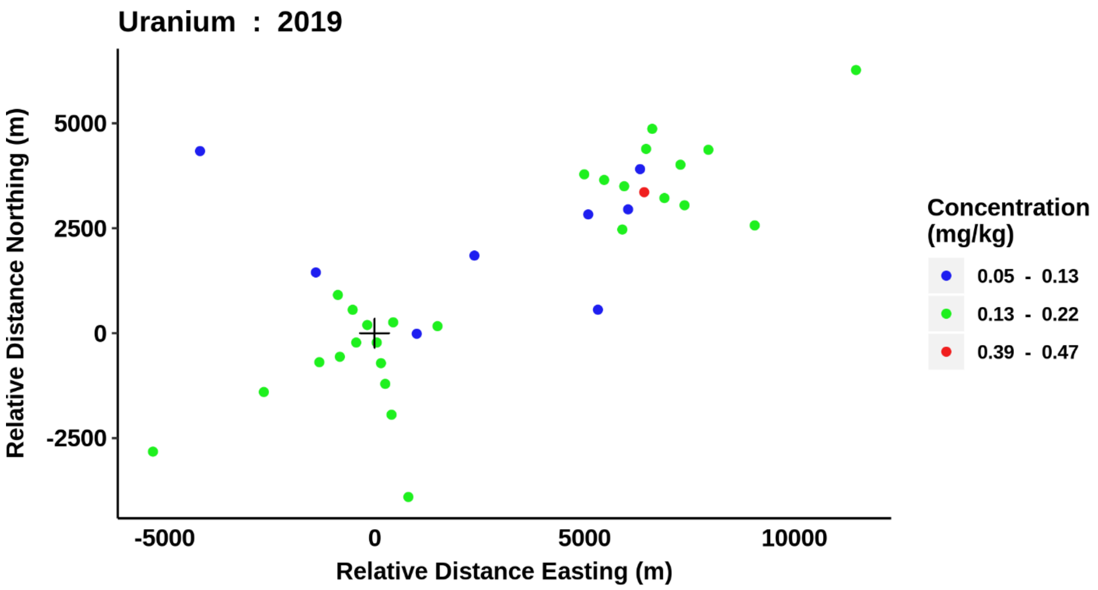


Figure 4-13 Spatial pattern of uranium (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 0.17 mg/kg.

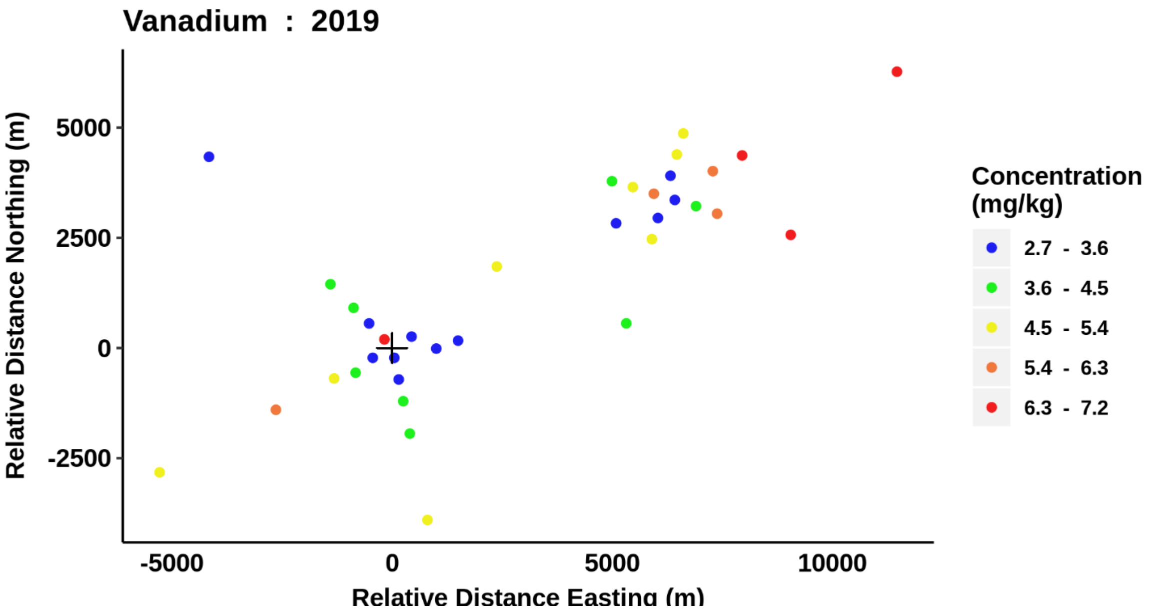


Figure 4-14 Spatial pattern of vanadium (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 4.3 mg/kg.

Hydrocarbons

Hydrocarbon concentrations ranged between 0.25 to 66.95 mg/kg for fuel range (C_{10}-C_{21}) and 0.25 to 3 mg/kg for lube range (C_{21}-C_{32}). The highest concentration of both hydrocarbon ranges occurred at 8-250. These ranges are an increase from those observed in 2018. In 2018, hydrocarbon concentrations ranged from 0.25 to 17.30 mg/kg (C_{10}-C_{21}) and 0.25 to 1.7 mg/kg (C_{21}-C_{32}) with the highest concentrations occurring at 8-250. Baseline levels for fuel and lube range hydrocarbons were between 0.125 to 1.3 mg/kg and 0.125 to 0.87 mg/kg, respectively.

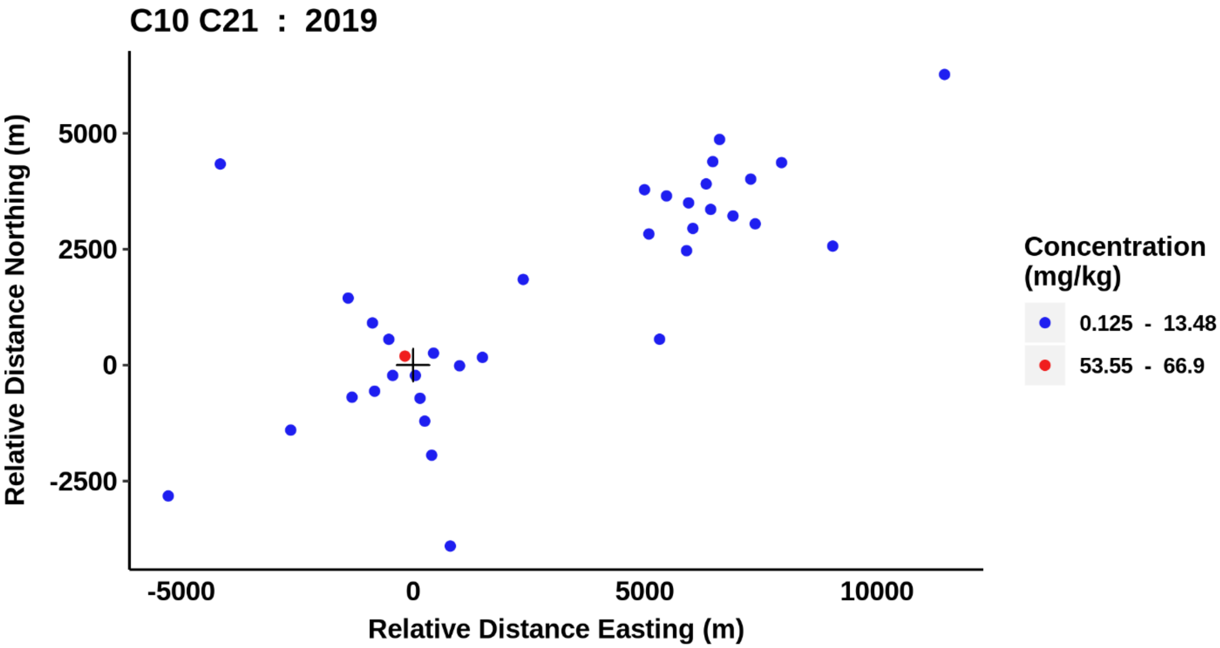


Figure 4-15 Spatial pattern of C_{10}-C_{21} (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (61% of samples) the average concentration of 2014 baselines samples was 0.48 mg/kg.

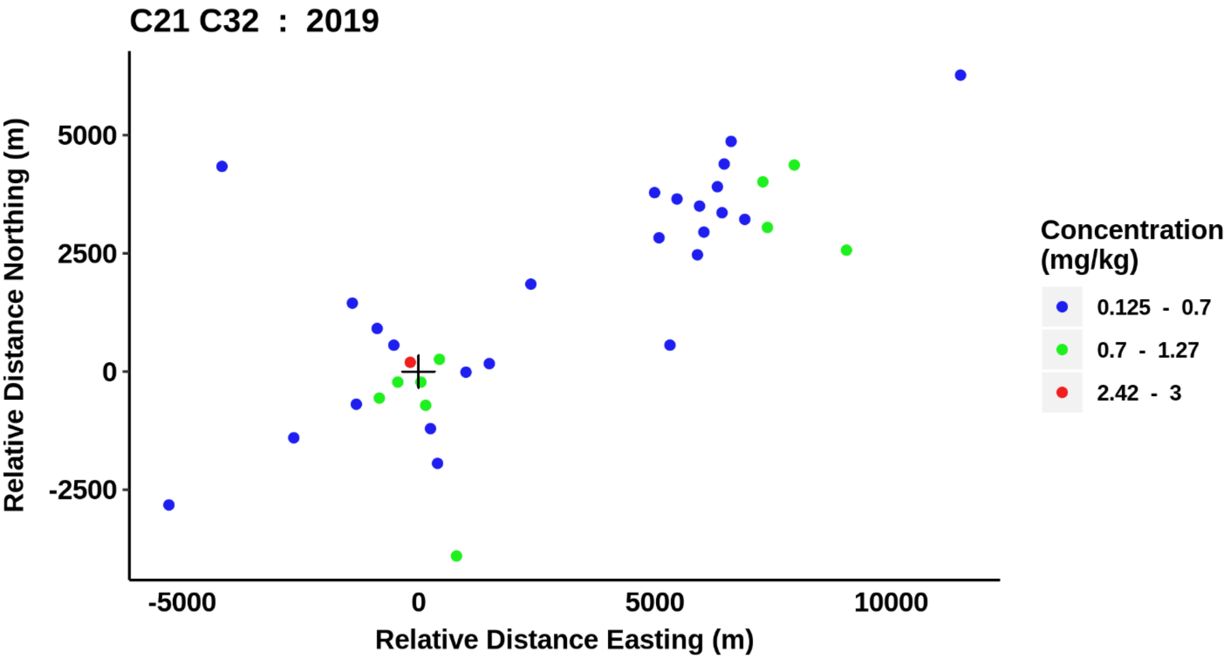


Figure 4-16 Spatial pattern of C_{21}-C_{32} (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (70% of samples) the average concentration of 2014 baselines samples was 0.44 mg/kg.

Other Analytes

Spatial distributions for the last five screened-in analytes and are presented in Figure 4-17 to Figure 4-21. Moisture concentrations ranged between 13 to 20 percent. The highest concentration of moisture occurred at station 8-250 (Figure 4-17). Moisture concentration ranges are similar from previous years (14 to 19 percent in 2018 and 11 to 18 percent in 2014). Redox potential ranged between -218 to 141 mV in 2019. This is a larger range compared to 2018 samples which had a redox potential range from 4 to 120 mV. Additionally, this is the first instance of negative redox potential values from the three survey years. Of the eight negative readings, seven occurred to the northeast of the GBS with the lowest reading occurring at A-1000 (Figure 4-18). The highest concentrations of sulphide and sulphur were reported at station 8-250. In 2018, the highest concentrations of sulphur were also reported at 8-250 while for sulphide the highest concentrations were observed at B-3000 to the northeast of the GBS. Sulphide was not assessed in 2014 but sulphur percent concentration was detected at 0.031 percent at only one station, D-250. Ammonia levels ranged from 0.37 to 14 mg/kg with the highest concentrations occurring to the northeast of the GBS specifically at A-1000 and B-1250 (14 mg/kg), 2-1250 (13 mg/kg), B-3000 (11 mg/kg). In 2018 the ammonia concentration ranged from 0.3 to 15 mg/kg with the highest concentration occurring at B-1250. Ammonia levels were not reported in 2014.

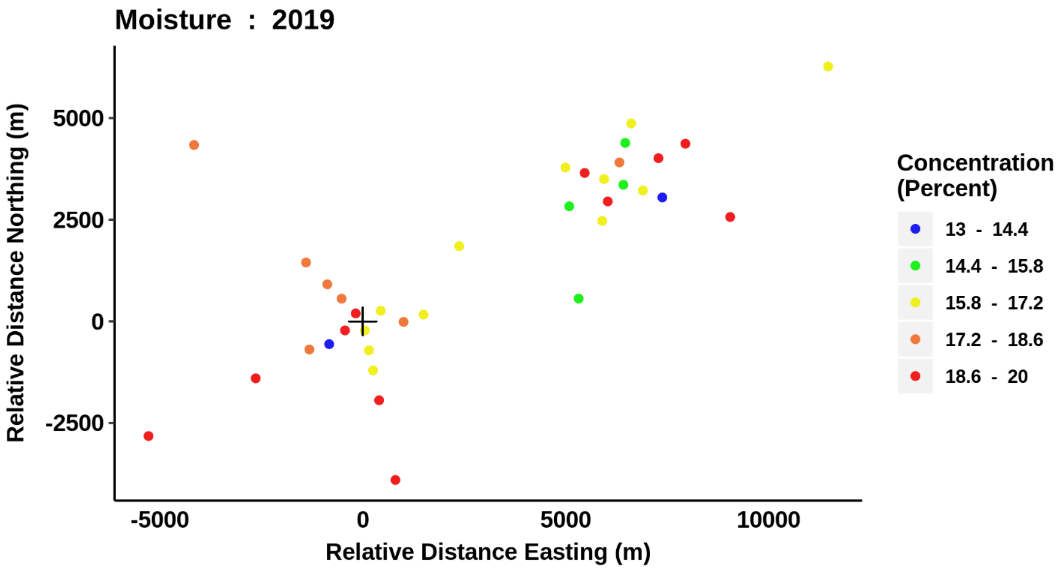


Figure 4-17 Spatial pattern of moisture (precent) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average moisture content of 2014 baselines samples was 15%.

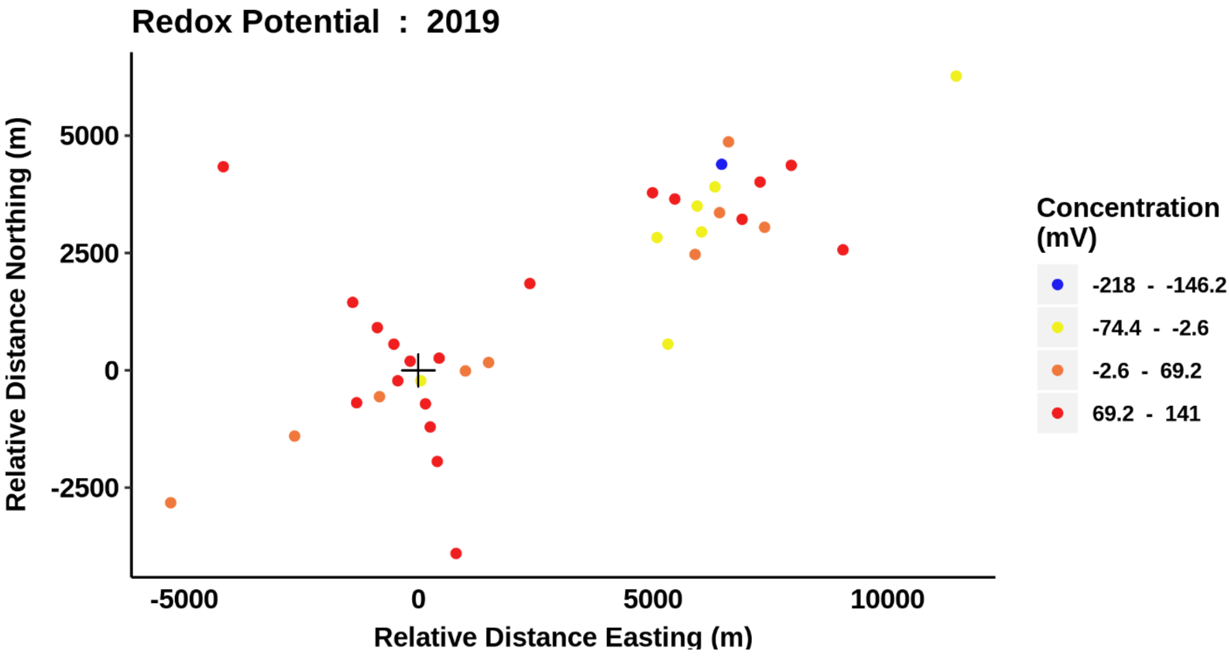


Figure 4-18 Spatial pattern of redox potential (mV) from 2019 EEM samples within the survey area around the platform (cross). Values not reported during 2014 baseline program.

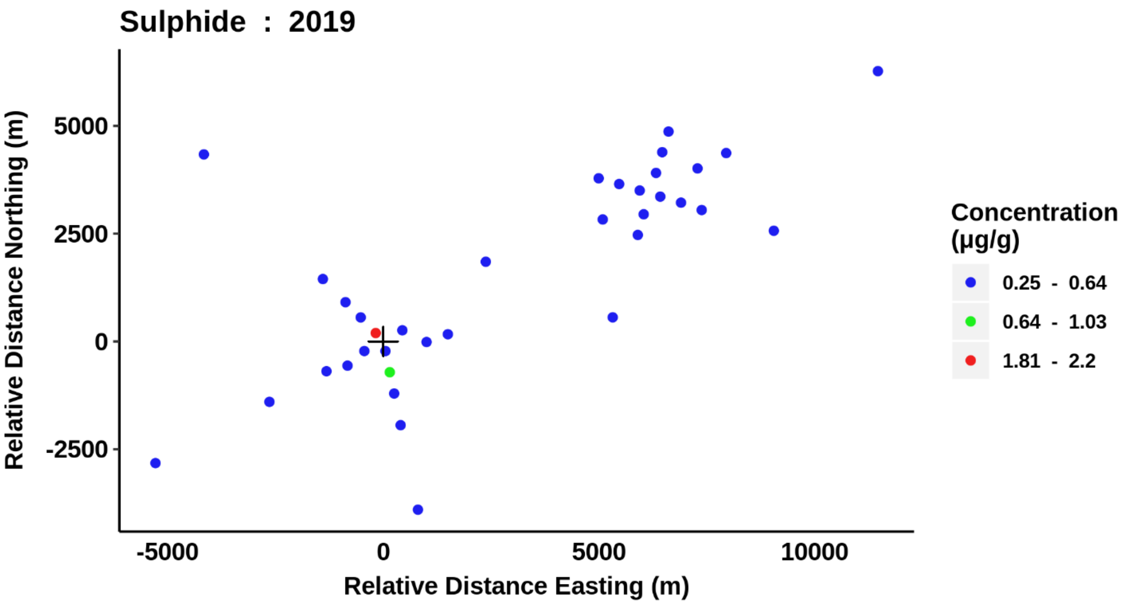


Figure 4-19 Spatial pattern of sulphide (µg/g) from 2019 EEM samples within the survey area around the platform (cross). Values not reported during 2014 baseline program.

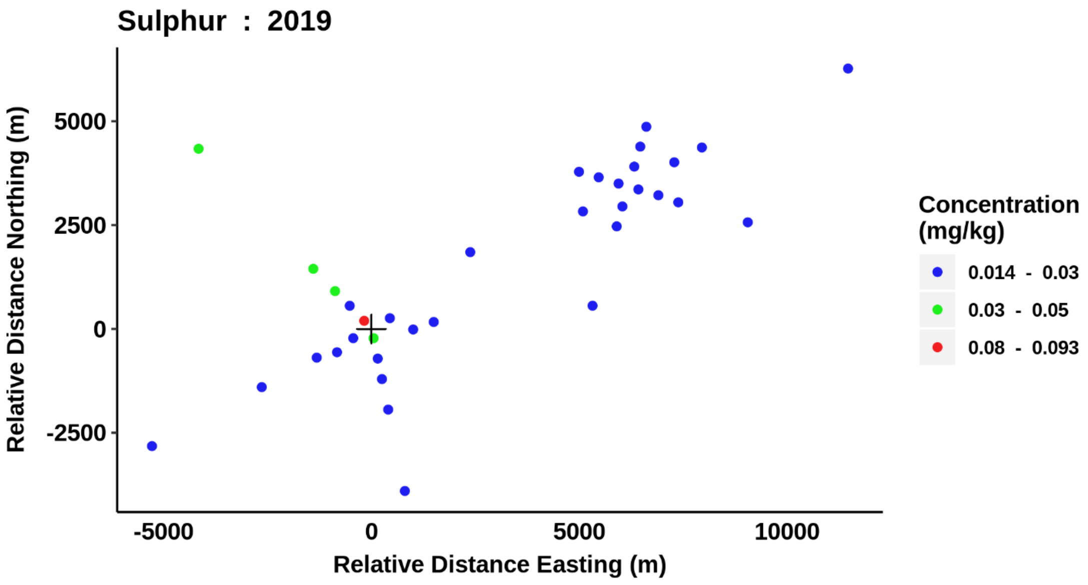


Figure 4-20 Spatial pattern of sulphur (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). When above the detection limit (15% of samples) the average concentration of 2014 baseline samples was 0.034 mg/kg.

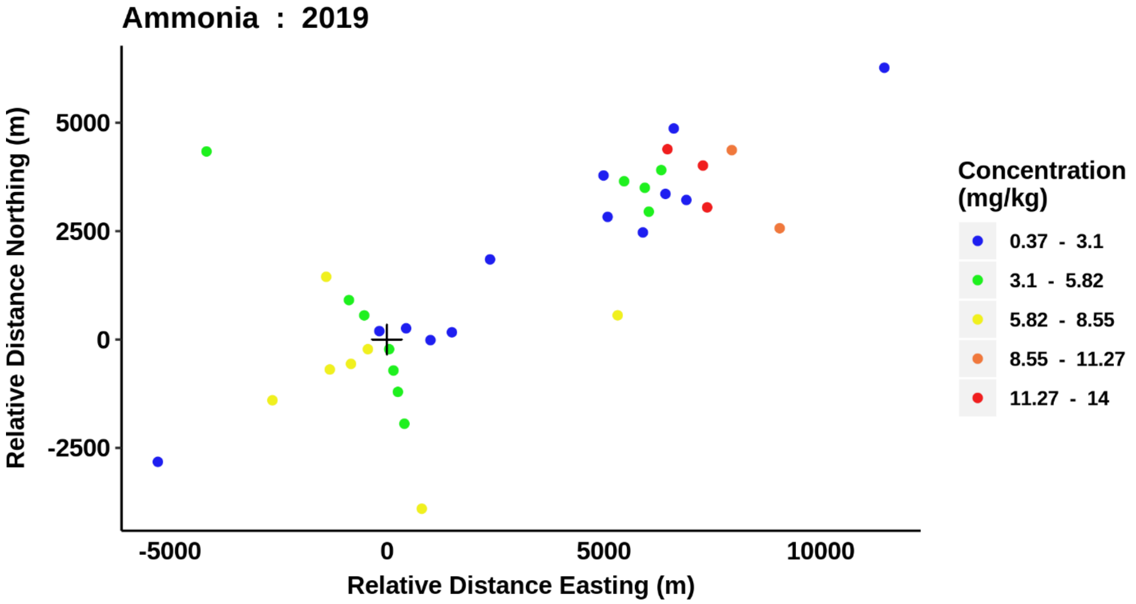


Figure 4-21 Spatial pattern of ammonia (mg/kg) from 2019 EEM samples within the survey area around the platform (cross). Values not reported during 2014 baseline program.

Results-Statistical

Spearman Rank Correlations

Spearman rank correlations were calculated for distance to the active drilling activity and to each analyte for screened-in analytes and are presented in Table 4.4 and Table 4.5. Scatterplots for screened-in analytes by distance from the Hebron GBS and Terra Nova FPSO are presented Figure 4-22 and Figure 4-23 respectively.

The percent concentrations of gravel and sand were statistically significant with distance to the Hebron GBS and Terra Nova (Table 4.4). Barium, total organic carbon, C_{10}-C_{21}, C_{21}-C_{32}, sulphide, and sulphur were negatively correlated with distance from the Hebron GBS (i.e., decreased concentration of analyte with increasing distance from the GBS) (Table 4.4, Figure 4-22). All other screened-in analytes concentrations were not statistically significant with distance. As noted at the GBS, there was a statistically significant inverse correlation between C_{10}-C_{21} hydrocarbons (Table 4.4). From the scatterplot the increase in hydrocarbon concentrations occurs within 1,000 m from the Hebron GBS (Figure 4-23).

There were several significant Spearman rank correlations coefficients found between analytes (Table 4.5). The hydrocarbons, barium, sulphide, and sulphur were most strongly correlated with percent fines. Similarly, barium was significantly correlated to the hydrocarbons, sulphide, and sulphur. Barium was most strongly correlated with C_{10}-C_{21} ($\rho S = 0.81$, $p \leq 0.001$). As expected, the particle sizes gravel and sand were either not correlated or negatively correlated with the hydrocarbons. Moisture was only correlated with barium ($\rho S = 0.35$, $p \leq 0.05$) while redox potential was not correlated with any other analyte (Table 4.5).

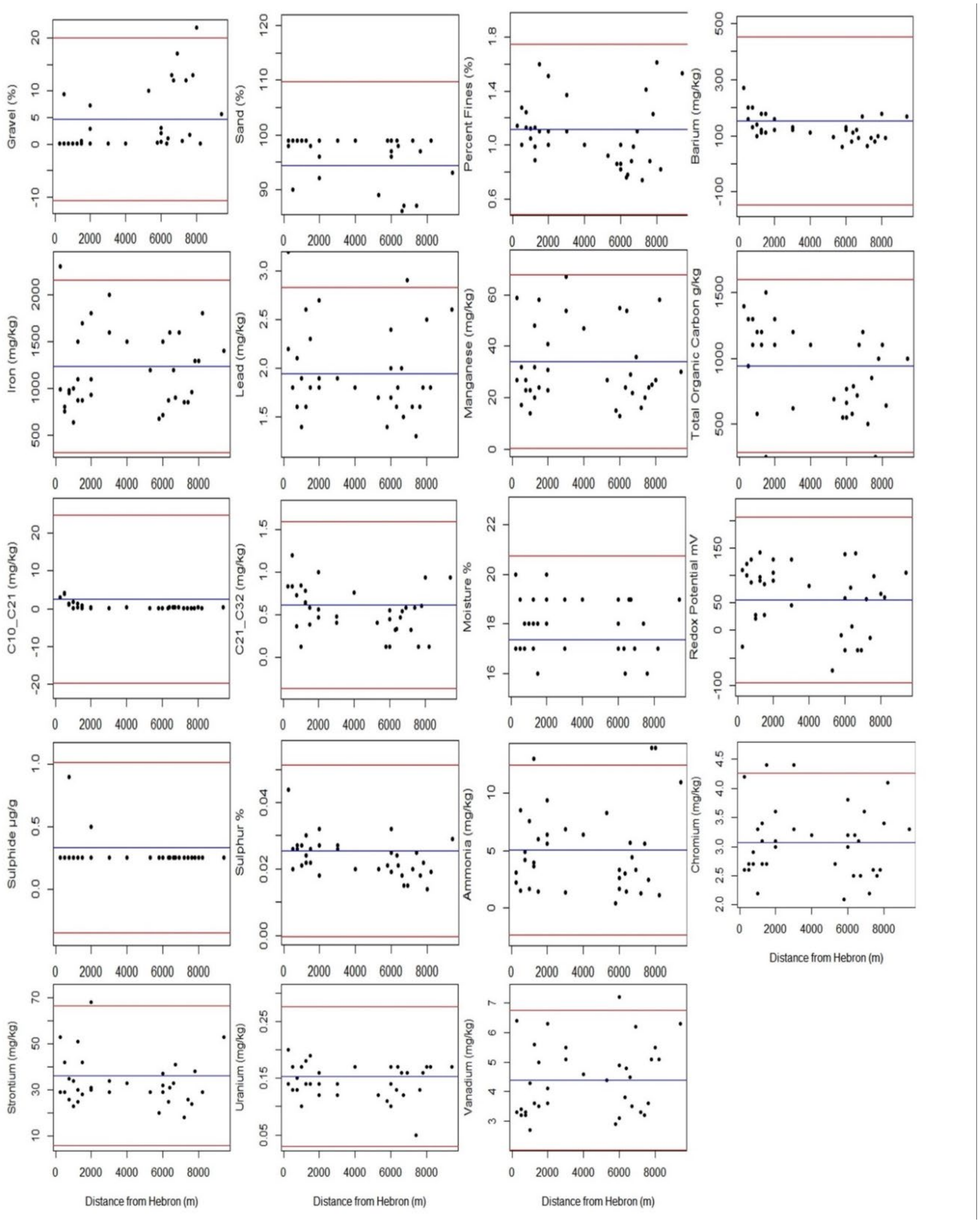
Table 4.4 Spearman rank correlations (ρ) of screened-in analytes with distance to Active Drilling Source in 2019

Analyte	Spearman Rank Correlation (ρ) with Distance from Activity	
	Hebron GBS	**Terra Nova**
Gravel	0.464**	0.484**
Sand	-0.399*	-0.418*
Fines	-0.28	-0.187
Barium	-0.504**	-0.185
Iron	0.164	0.154
Lead	-0.103	0.115
Manganese	0.009	-0.006
Total Organic Carbon	-0.507**	-0.455**
C10-C21	**-0.566*** **	-0.462**
C21-C32	-0.357*	-0.218
Sulphide	-0.331*	-0.192
Sulphur	-0.507**	-0.305
Ammonia	0.013	0.006
Moisture	-0.226	-0.15
Redox Potential	-0.293	-0.103
Chromium	0.005	0.062
Strontium	0.027	0.185
Uranium	0.026	0.058
Vanadium	0.285	0.295
*p≤0.05, **p≤0.01, ***p≤0.001 (**BOLD**), n=36		

Table 4.5 Spearman Rank Correlation Matrix (ρ) of screened-in analytes in 2019

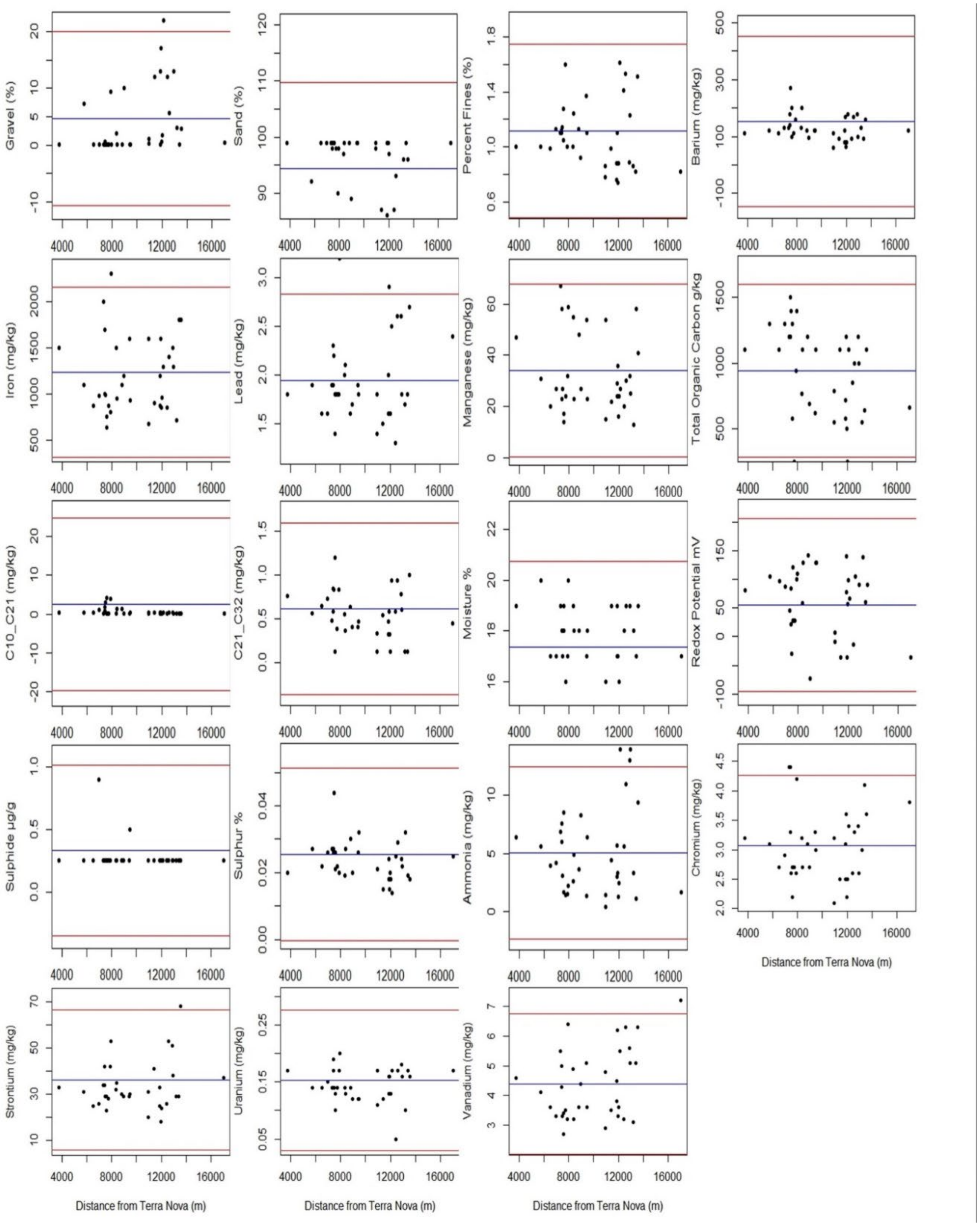
Analyte	Gravel	Sand	Percent Fines	Barium	Iron	Lead	Manganese	TOC	C10-C21	C21-C32	Sulphide	Sulphur	Ammonia	Moisture	Redox Potential	Chromium	Strontium	Uranium
Sand	-0.94																	
Silt	0.01	-0.05																
Clay	-0.01	-0.03																
Percent Fines	-0.01	-0.03																
Barium	0	-0.08	**0.69*****															
Iron	0.07	-0.11	0.24	0.4														
Lead	0.25	-0.31	0.47**	**0.75*****	**0.7*****													
Manganese	-0.1	0.07	0.14	0.32	**0.91*****	0.51**												
TOC	0.14	-0.19	0.26	**0.55*****	0.28	0.41*	0.26											
C10-C21	-0.13	0.06	0.47**	**0.81*****	0.06	0.38*	0.12	**0.59*****										
C21-C32	0.18	-0.23	**0.63*****	**0.7*****	0.36*	**0.57*****	0.31	**0.71*****	**0.67*****									
Sulphide	-0.22	0.15	**0.52*****	**0.61*****	0.21	0.27	0.16	0.26	**0.6*****	0.42*								
Sulphur	-0.41*	0.32	0.46**	**0.68*****	0.14	0.27	0.14	0.3	**0.62*****	0.37*	**0.67*****							
Ammonia	0.46**	-0.48**	0.26	0.25	0.16	0.32	-0.02	**0.55*****	0.12	**0.53*****	-0.05	-0.02						
Moisture	0	0.01	0.18	0.36*	0.22	0.22	0.27	0.33	0.2	0.24	0.21	0.3	0.16					
Redox Potential	-0.27	0.21	0.11	0.24	-0.07	0.11	0.04	0.05	0.28	0.06	0.19	0.23	-0.02	0.45**				
Chromium	0.01	-0.07	0.3	0.51*	**0.86*****	**0.69*****	**0.8*****	0.41*	0.2	0.37*	0.24	0.23	0.27	0.36	0.2			
Strontium	**0.55*****	**-0.56*****	0.49**	**0.56*****	**0.55*****	0.82	0.38*	0.48**	0.27	**0.57*****	0.11	-0.08	0.51**	0.15	-0.02	**0.58*****		
Uranium	-0.05	0	-0.08	0.16	0.35*	0.43**	0.27	0.09	0.21	0.24	0.12	-0.01	-0.05	-0.18	0.08	0.23	0.18	
Vanadium	0.26	-0.29	0.29	0.38*	**0.93*****	**0.79*****	**0.75*****	0.27	0	0.42*	0.12	0.03	0.31	0.13	-0.11	**0.8*****	**0.7*****	0.36

*p≤0.05, **p≤0.01, ***p≤0.001 (**BOLD**), n=36



Note: Red lines indicate the mean values ±2 SD for each analyte.

Figure 4-22 Scatterplots of analyte concentrations versus distance (m) from the Hebron GBS



Note: Red lines indicate the mean values ±2 SD for each analyte.

Figure 4-23 Scatter plots of analyte concentrations versus distance (m) from Terra Nova

Threshold Regression Models

Threshold regression models were conducted on barium, C_{10}-C_{21} hydrocarbons, and C_{21}-C_{32} hydrocarbons (Figure 4-24 to Figure 4-26). As observed in other analyses, concentrations for these analytes decrease with increasing distance from the platform. The threshold distance with the lowest unexplained variance occurred at 500 m from the platform. This is consistent with observed concentrations at 8-250 and 4-250, which had higher relative concentrations compared to other sampling sites and baseline concentrations at those sites.

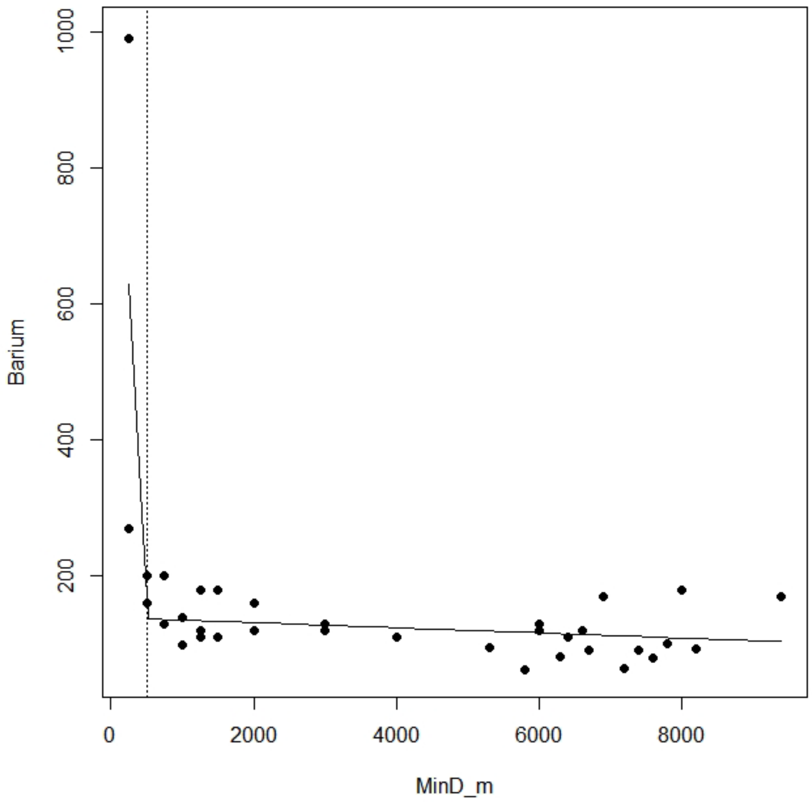


Figure 4-24 Distance gradient for concentration of barium (mg/kg) with distance form the Hebron GBS (MinD_m). The dotted line indicates a threshold of 500 m.

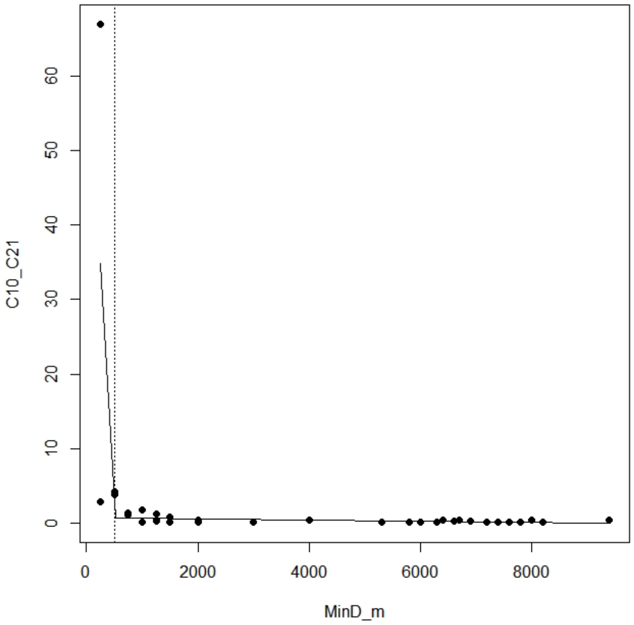


Figure 4-25 Distance gradient for concentration of C_{10}-C_{21} hydrocarbons (mg/kg) with distance form the Hebron GBS (MinD_m). The dotted line indicates a threshold of 500 m.

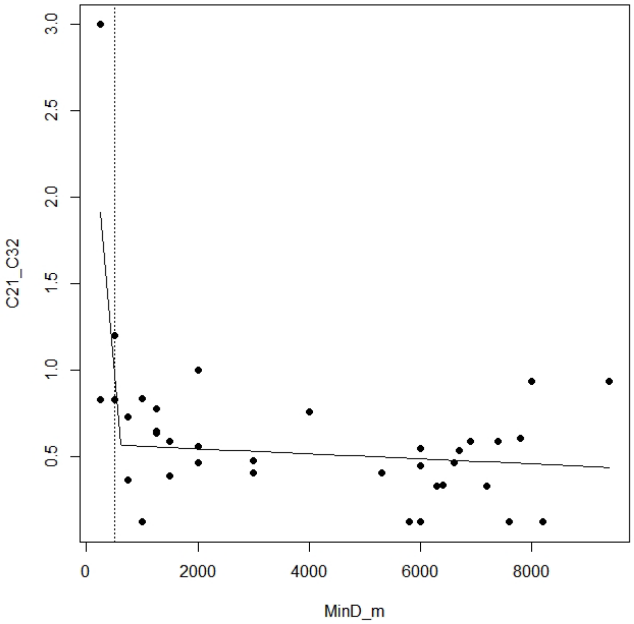


Figure 4-26 Distance gradient for concentration of C_{21}-C_{32} hydrocarbons (mg/kg) with distance form the Hebron GBS (MinD_m). The dotted line indicates a threshold of 500 m.

Multi-Year Comparisons

Multivariate statistical analysis for multi-year comparisons showed a difference between the factor Year (2014, 2018, and 2019) relative to covariate factor MinD (distance from the Hebron GBS) (Table 4.6). There was a statistically significant difference between years. Analyte concentrations for 2018 and 2019 have increased at several stations compared to baseline levels (2014). Distance from the Hebron GBS was also statistically significant. Stations closer to the GBS and particularly 8-250 had higher analyte concentrations in both 2018 and 2019 when compared to baseline levels.

Table 4.6 ANCOVA analysis results for screened-in analytes for all survey years.

Source	df	SS	MS	Pseudo-F	P(permutation)	permutations
MinD	1	91.679	91.679	8.7132	**0.0001***	9961
Year	2	288.05	144.02	13.741	**0.0001***	9911
MinD x Year	2	45.684	22.842	2.1793	0.0236*	9935
Res	101	1058.6	10.481			
Total	106	1484				

Note: statistically significant at $p<0.05$ (*),$p<0.001$ (**BOLD**)

4.3.2 Toxicity

Screening criteria for toxicity testing included any sample at or above the no-effect PetroTox threshold (≥150 mg/kg C_{10}-C_{21} hydrocarbons) and all stations at or within 500 m from Hebron Platform and. Similar to 2018 (EMCP 2019) and at baseline in 2014 (ECMP 2016a), no samples levels above the PetroTox threshold thus, only the four stations within 500 m from the platform were tested for amphipod toxicity (Table 4.7).

Amphipod survival was greater than 97 percent in all four samples tested and results indicated the sediment is non-toxic. Based on these results, no further statistics were conducted. Site FL-500 had the lowest amphipod survival at 97%. Samples collected and evaluated in 2018 (EMCP 2019) and 2014 were also non-toxic to amphipods (ECMP 2016a). The highest reported level of C_{10}-C_{21} hydrocarbon, for these four stations (and highest across all stations), was 66.9 mg/kg at 8-250 (on radial 8 from the platform at a 250 m distance). This is an increase from 17.3 mg/kg observed at this site during the 2018 EEM program (EMCP 2019).

As per recommendations from ECCC, pore water analysis was replaced with sediment ammonia, sulfides, and redox potential analyses. ECCC laboratories have implemented updated procedures to address discrepancies seen in pore water analyses for sediment toxicity and these updates have been implemented since the 2018 sampling program. In comparison to the control sample, EEM sediment sample levels of ammonia and redox potential were lower. Sulfide levels were higher at 8-250 (3.22 µg/g) and FL-500 (0.58 µg/g) than those observed in the laboratory control sediment (<0.1 µg/g). Sediment samples from stations 4-250 and 8-250 were noted as having a slight sulfur odor and the sediment sample from site FL-500 had a strong sulfur odor. A sulphur odor was not previously reported in Hebron EEM sediment samples from the laboratory and will continue to be monitored in future sampling programs. These results are summarized in Table 4.8.

Table 4.7 Amphipod toxicity testing summary for sediment samples screened in for the 2019 sampling year.

Station ID	Amphipod Survival (percent)	Sample Standard Deviation	Significant Difference from Control	30 % Reduction from Control	Interpretation
4-250	100	0	No	No	Non-toxic
6-500	100	0	No	No	Non-toxic
8-250	100	0	No	No	Non-toxic
FL-500	97	4.47	No	No	Non-toxic
Control Sediment*	100	0	NA	NA	NA

NA= Not Applicable
*The laboratory reference sediment was used as the control for the statistical analyses of the stations

Table 4.8 Amphipod testing summary (2019) and sediment physiochemical analysis for ammonia, sulfides, redox potential, and PetroTox level.

Station ID	% Mortality	Toxicity	Dry Sediment Ammonia (µg/g NH_3-N)	Dry Sediment Sulfides (µg/g S)	Wet Sediment Redox Potential (Eh)	C_{10}-C_{21} hydrocarbons (mg/kg)
4-250**	0	Non-toxic	0.35	<0.1	388	2.9
6-500	0	Non-toxic	0.23	<0.1	391	4.2
8-250**	0	Non-toxic	0.26	3.22	399	66.9
FL-500***	3.0	Non-toxic	1.04	0.58	325	3.9
Control Sediment*	0	Non-toxic	1.16	<0.1	431	NA

*Laboratory reference sediment was used as the control for comparison
**Slight sulfur odor was noted in the sediment upon closure
***Strong sulfur odor was noted in the sediment upon closure

4.3.3 Benthic Community Structure

The purpose of examining changes in the benthic invertebrate community structure is to identify alterations to the benthic habitat from potential project-related effects. Community monitoring includes looking at changes in abundance, biomass, species richness, and community structure. The community monitoring parameters for Y2 EEM (2019) sediment samples are presented in Table 4.9.

Overall, decreases were detected in all six of the community monitoring variables compared to baseline levels (except for biomass which was not recorded for baseline levels). Total abundance in 2019 was lower than baseline 2014 levels in 34 of 36 stations (19 of 36 stations in 2018) (Figure 4-27). Seven out of eight stations within 1,000 m of the GBS showed a downward trend with only 8-750 showing a slight increase from 2018 abundance levels. The number of taxa observed were lower in 15 of 36 stations from baseline levels with no change detected in 4-250. The mean between the three sampling years remains relatively similar S=32 (2014), S=33 (2018), S=35 (2019). Total biomass was not reported in 2014 however it has been reported in the subsequent EEM years. In 2019 the mean biomass was 53.63 g from 2018 levels mean=44.71 g. However, 17 of 36 stations reported lower biomass than 2018 levels, of which only two occurred within 1,000 m of the GBS. Species richness shows a decline over the three survey years with a mean of 11 in 2014, 5.58 in 2018, and 6.38 in 2019. Thirty-three of 36 stations report levels lower than baseline levels with the lowest species richness values observed mainly in stations within 1,000 m of the GBS. The downward trend however has not been observed in species evenness or the Shannon-Weiner species diversity index.

Evenness evaluates how evenly the individuals are distributed among the species present. High values (closer to 1) indicate slight variation in abundances between taxa in a sample and a low value indicates more variation. The Shannon-Weiner (H’) index evaluates the species diversity in each sample. Changes in species diversity could indicate a change in environmental conditions at each site and when compared to previous EEMs temporal changes in diversity can be evaluated. The higher the H′ value the higher the species diversity. Evenness ranged between 0.37 to 0.91 with the highest and lowest values distributed throughout the samples. Across all stations, 2019 evenness values are higher than baseline levels with only three stations reporting lower values. Increases in the Shannon-Weiner (H’) index from baseline levels (2014) were observed at 32 of 36 sampling stations and 23 from 2018 levels. Decreases in H′ from baseline levels were observed at four stations (FL-500, 2-1250, FL-1500, B-1250) located to northeast of the Hebron GBS. Of these, only one site was within 500 m (FL-500) of the GBS and the others were more than 1000 m. There appears to be a slight upward trend between 2018 and 2019 levels in several monitoring parameters which is expected, and should continue to be monitored in future EEM surveys.

Table 4.9 Community monitoring parameters for the 2019 EEM program. Stations are ordered in increasing distance from the Hebron (HEB) GBS. Light blue indicates 5 lowest values, orange indicates 5 highest values.

Site	Distance to HEB (m)	Distance to TN (m)	Number of taxa (S)	Total Abundance (N)	Total Biomass (g)	Species Richness (d)	Evenness (J')	Shannon-Weiner H'($\log_e$)
4-250	250	7490	25	81	87.50	5.46	0.74	2.37
8-250	250	7940	21	100	92.18	4.34	0.78	2.36
6-500	500	7600	27	124	50.48	5.39	0.75	2.48
FL-500	500	7900	26	114	130.75	5.28	0.85	2.78
4-750	750	6980	16	33	17.14	4.29	0.91	2.52
8-750	750	8380	22	193	75.82	3.99	0.80	2.47
6-1000	1000	7410	13	27	47.78	3.64	0.91	2.35
FL-1000	1000	7580	26	112	31.60	5.30	0.78	2.55
4-1250	1250	6490	31	231	55.49	5.51	0.76	2.62
8-1250	1250	8810	30	162	97.80	5.70	0.82	2.79
6-1500	1500	7440	29	186	124.82	5.36	0.77	2.61
FL-1500	1500	7720	27	174	116.10	5.04	0.78	2.59
4-2000	2000	5730	28	179	12.81	5.21	0.76	2.53
8-2000	2000	9480	23	155	19.20	4.36	0.86	2.69
6-3000	3000	7300	33	282	52.02	5.67	0.81	2.84
FL-3000	3000	9440	12	94	125.90	2.42	0.69	1.71
2-1250	7500	12910	59	435	5.87	9.55	0.73	2.97
2-2000	8250	13530	49	198	45.06	9.08	0.82	3.20
4-4000	4000	3730	45	279	30.67	7.81	0.83	3.17
C-3000	5300	8950	60	529	5.10	9.41	0.78	3.18
FL-1250	5800	10970	24	387	165.80	3.86	0.37	1.19
6-6000	6000	8320	22	115	24.59	4.43	0.83	2.57
8-6000	6000	13190	30	112	16.19	6.15	0.87	2.95
D-1250	6300	11850	26	181	65.51	4.81	0.74	2.41
C-1000	6400	10930	30	91	43.00	6.43	0.87	2.97
D-750	6600	11870	52	429	4.60	8.41	0.78	3.08
C-500	6700	11430	60	306	1.45	10.31	0.82	3.36
D-250	6900	11900	70	438	21.20	11.34	0.85	3.63
B-250	7200	11950	23	95	89.86	4.83	0.76	2.39
A-500	7400	12420	34	144	48.41	6.64	0.84	2.98
B-750	7600	12040	26	87	44.62	5.60	0.85	2.76
A-1000	7800	12920	59	256	22.06	10.46	0.89	3.61
B-1250	8000	12120	51	225	1.37	9.23	0.79	3.10
A-1500	8200	13420	17	87	60.54	3.58	0.61	1.73
B-3000	9400	12600	61	338	38.30	10.30	0.87	3.60

Site	Distance to HEB (m)	Distance to TN (m)	Number of taxa (S)	Total Abundance (N)	Total Biomass (g)	Species Richness (d)	Evenness (J’)	Shannon-Weiner H’($\log_e$)
2-6000	12250	17010	62	318	58.91	10.59	0.84	3.48
Mean			35	203	53.63	6.38	0.79	2.74

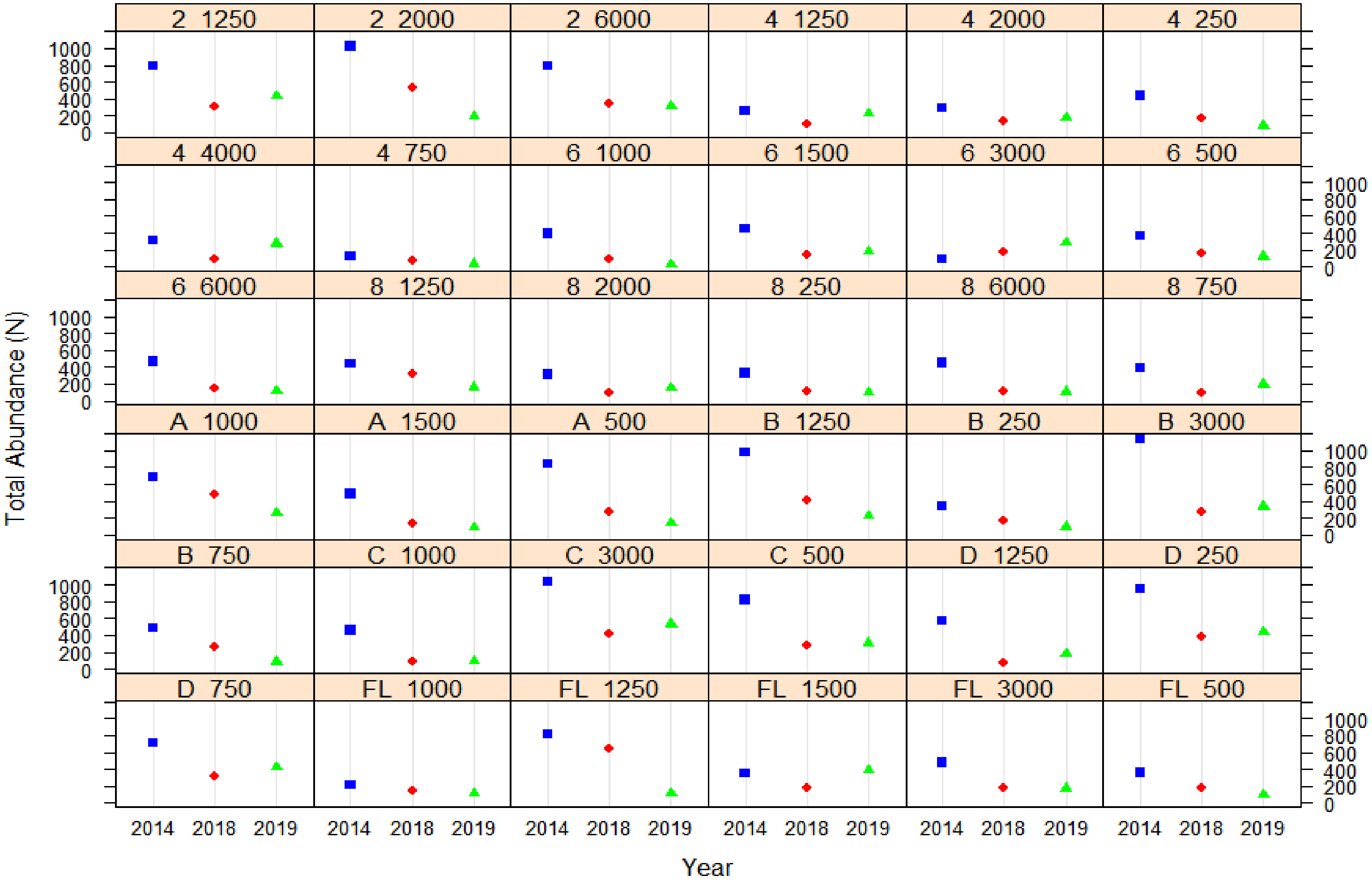


Figure 4-27 Total abundance (N) per station from 2014-2019.

However, significant differences were detected between benthic invertebrate assemblages (e.g., taxa abundance) with respect to distance to the GBS among samples collected in 2019 (Table 4.10). Stations >2,000 m (Far-field) distance from GBS were statistically different from stations ≤1,000 m (Near) and stations 1,000 m to 2,000 m (Mid-field) distance. Stations less than 2,000 m from the GBS were not statistically different from each other. Non-metric dimensional scaling (nMDS) plot shows separation between stations within 2,000 m of the GBS and greater than 2,000 m to the northeast of the GBS (Figure 4-28). At the 60% similarity level there are four groups. These groups appear to correspond to distance from the GBS.

SIMPER analysis was conducted to the species level and stations were grouped into three distance bins from the GBS (≤1,000 m, 1,000 m to 2,000 m, and >2,000 m) for comparison. Within 1,000 m from the GBS, four species contributed 49% of the similarity from SIMPER analysis. Three of the four species are annelids, and one is a bivalve species. Two of the three annelid species were from the polychaete families Cirratulidae (*Tharyx* sp.) and Syllidae (*Exogone hebes*) contributing 16.32% and 8.99% respectively while the third was from the Clitellata family Naididae and contributed 17.38%. The bivalve was the species *Cyrtodaria siliqua* from the family Hiatellidae and individually contributed 6.40%. This species contributed 3.24% to similarity in stations located between 1,000 m and 2,000 m from the GBS and 0% in stations > 3,000 m. However, this species was not noted as a contributor to similarity in either the 2014 baseline survey or the 2018 EEM year one survey. Stations more than 1,000 m from the GBS were mainly characterized by the presence of annelid species. Stations found within 1,000 m to 2,000 m were 65.86% similar of which six species contributed 51.20% of the group similarity. Of the species present, four are polychaetes and two are ciltellates. Stations >3,000 m from the GBS had a 39.10% similarity of which 11 species (seven polychaetes, two cilettate, one nemerte, and one arthropod) contributed 49.52% to the total. The polychaetes consisted of Spionidae (n=3), Syllidae (n=1), Paraoindae (n=1), and cirratulidae (n=1). The Clitellata were indeterminate Clitellata and Naididae. The assemblage of taxa at stations around the GBS could reflect the overall condition of the sediment.

The presence and abundance of invertebrate taxa are commonly used as environmental indicators. Overall, polychaetes accounted for 50% of all taxa observed followed by Clitellata at 21% and Amphipoda at 10%. The Capitellidae, the most commonly used indicator of marine pollution world-wide as they are found in organically enriched areas and tolerant of low-oxygen conditions (Gray and Elliot 2009). Results from the baseline survey found, this family was mainly observed in the northeast cluster (n=82). Total abundance decreased in 2018 (n=61) and 2019 (n=28). Distribution of Capitellidae species were similar to baseline in 2018 (individuals mainly found in the northeast cluster). In 2019, these species were distributed more broadly within the survey area, however the majority were found within the northeast cluster. Spionidae were observed in high abundances at many stations located to the northeast in the GBS at distances > 3,000 m. Clitellates were observed in relatively large abundances at FL-1250 (85%), A-1500 (75%), and FL-3000 (71%). Within the class Citellata, organisms were either identified as indeterminate or to the family Naididae. While many of the organisms could be classified as Naididae, they could not be taken to the species level which is important for further analysis due to the varying pollution tolerances for species in this family. The polychaete species *Tharyx* sp. and *Exogone hebes* were observed throughout the survey area being in 31 and 35 samples, respectively. *Tharyx* sp. accounted for 31% of all taxa present and the greatest abundances were observed at stations 6-3000, 4-4000, 8-1250 and 8-750 (highest abundance).

Other invertebrate taxon observed included crustaceans, molluscs, and echinoderms. Percent abundance contribution for annelids, arthropods, molluscs, and echinoderms were similar between 2018 and 2019 (Table 4.11). Compared to baseline levels, year one and year two EEM survey years had increases in annelids and arthropods, and decreases in echinoderms. Percent contribution of molluscs were similar between all survey years. The most common crustacean was the Tanaid, *Leptognathia cea* which was observed at 28 of 36 stations. This is similar to observations in 2018 where this was the most abundant crustacean species (n=439) and was observed at 31 of 36 stations. Contamination tolerance in this specific species is unknown however changes in the composition of crustacean species will continue to be monitored for changes. The most abundant molluscs were the gastropod *Lepeta caeca* and the bivalve *Cyrtodaria siliqua*. These were also the most abundant mollusc species observed identified in 2018. While the presence and abundance of invertebrate classes and families are used as indicators of disturbance to the environment, tolerances vary within each group and individual species should continue to be examined.

Table 4.10 Results of One-way PERMANOVA testing main and pair-wise effects on distance bin from GBS on Bray-Curtis similarities of benthic invertebrate assemblage

Source	df	MS	Pseudo-F	P(perm)	Unique Perms
Main testing					
Distance bin from GBS	2	5258.5	3.1567	**0.0016**	4977
Residuals	33	1665.8			
Total	35				
Pair-wise testing					
Distances bin from GBS	**Denom. Df**		**t**	**P(perm)**	**Unique Perms**
Near, Mid	14		1.2487	0.1046	3449
Mid, Far	26		1.7599	**0.012**	4978
Far, Near	26		1.9671	**0.0022**	4977
Perm= permutation, **Bold** values indicate statistically significance (***P*<0.05**) Near: <1,000 m; Mid: 1,000 m to 3,000 m; Far: >3,000 m from the Hebron GBS					

Table 4.11 Percent contribution by the four most common phyla.

Year	Survey	Annelida	Arthropoda	Mollusca	Echinodermata
2014	Baseline	54.85	13.70	4.10	6.26
2018	Year 1	68.45	22.24	4.43	1.95
2019	Year 2	70.51	21.04	3.92	1.71

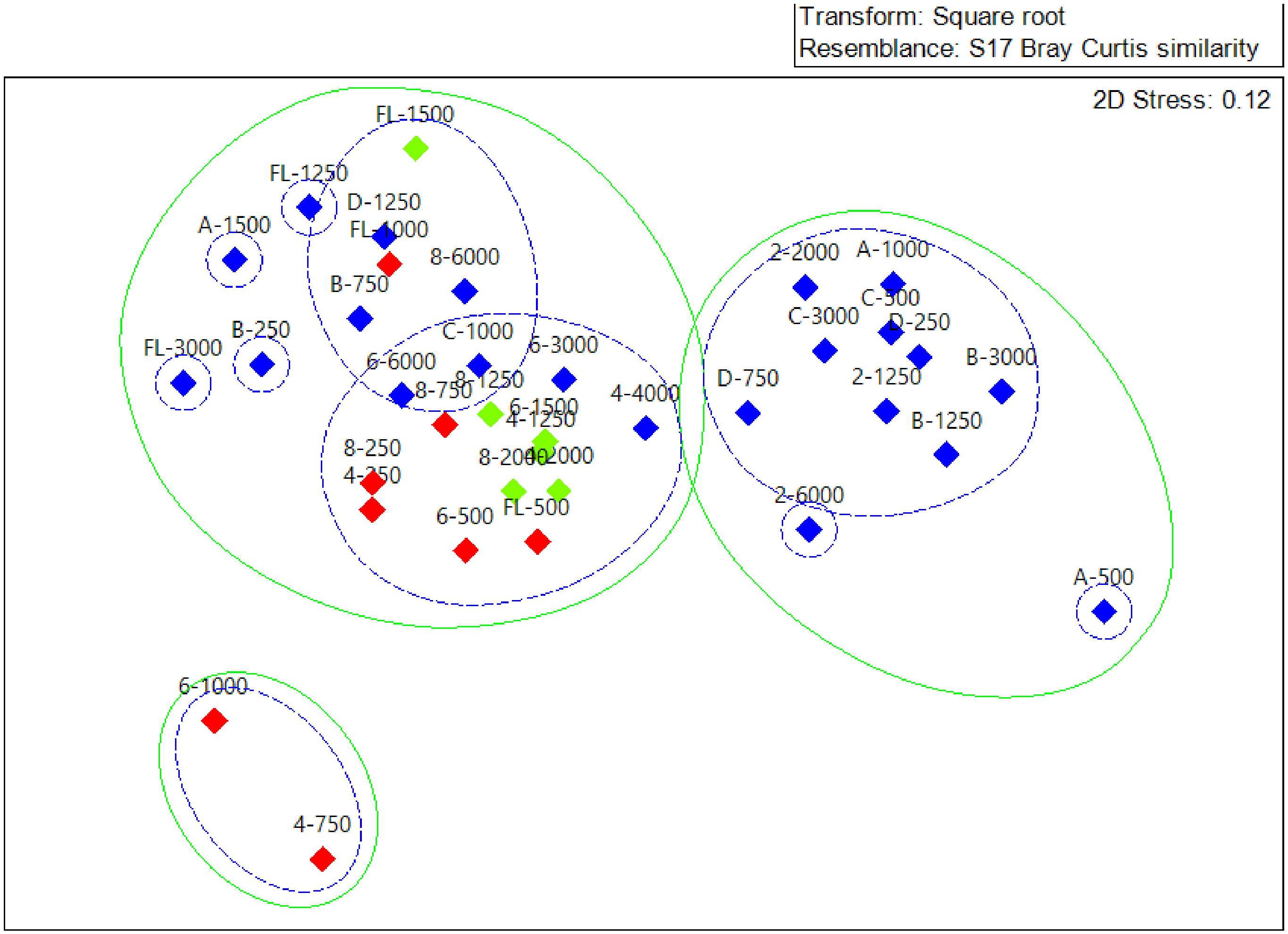


Figure 4-28 nMDS plot of benthic fauna family abundance per site colors by distance to GBS (red: ≤ 1,000 m, green: 1,000 to 2,000 m, blue: >2,000 m), circles indicate clusters of 40% (green line) similarity and 60% similarity (blue dotted line).

From a step-wise DISTLM analysis, four variables explained 40% of the observed variation between benthic infauna family assemblage structure and sediment analyte predictor variables (Table 4.12). Three variables that contributed the most to model explanation and account for over 38% of the total variation were percent sand concentration (26%), total organic carbon (8.33%), distance from the HEB GBS (4.61%). Particle size is a key factor in explaining benthic infauna community variation between stations and sand remains the primary sediment fraction. In 2018, the percent sand concentration accounted for 21% of model variation (EMCP 2019). Findings from baseline analyses found that particle size and water depth explained 43% of the model variation (ECMP 2016a). Changes in particle size composition at each sampling station and analytes associated with certain particle sizes could change the benthic infauna community in subsequent EEM years. This is expected and will continue to be monitored.

Visual examination of the benthic infauna assemblage (at the family level) is presented in a dbRDA plot with predictor variable overlay (Figure 4-29). As expected, the stations located the farthest from the Hebron GBS are influenced mainly by distance from the GBS. Sand is the dominant particle size, but the concentration of other particle sizes differs between stations. Percent gravel concentration is higher at stations to the northeast, farthest from the GBS. Percent fines concentration is higher at stations closer to the GBS. Samples < 2,000 m of the are more strongly associated with total organic carbon levels, while stations in the northeast cluster are associated with distance from the GBS.

Table 4.12 Results of DISTLM multivariate step-wise regression of predictor analytes on benthic infauna family assemblages

Analyte	AIC	SS (trace)	Pseudo-F	*P*	Variance Explained (%)	Cumulative R^2	Residual df
Sand	257.02	10409	8.8015	**0.001***	64.01	0.20563	34
Total Organic Carbon	255.37	4271.7	3.9224	**0.001***	20.52	0.29002	33
Distance to HEB	254.25	3476	3.4265	**0.003**	11.35	0.35869	32
Moisture	254.19	2401.1	2.4761	**0.01**	4.12	0.40613	31
Bold values indicate statistical significance of *P*<0.05. * indicates a statistical significance of *P*<0.001							

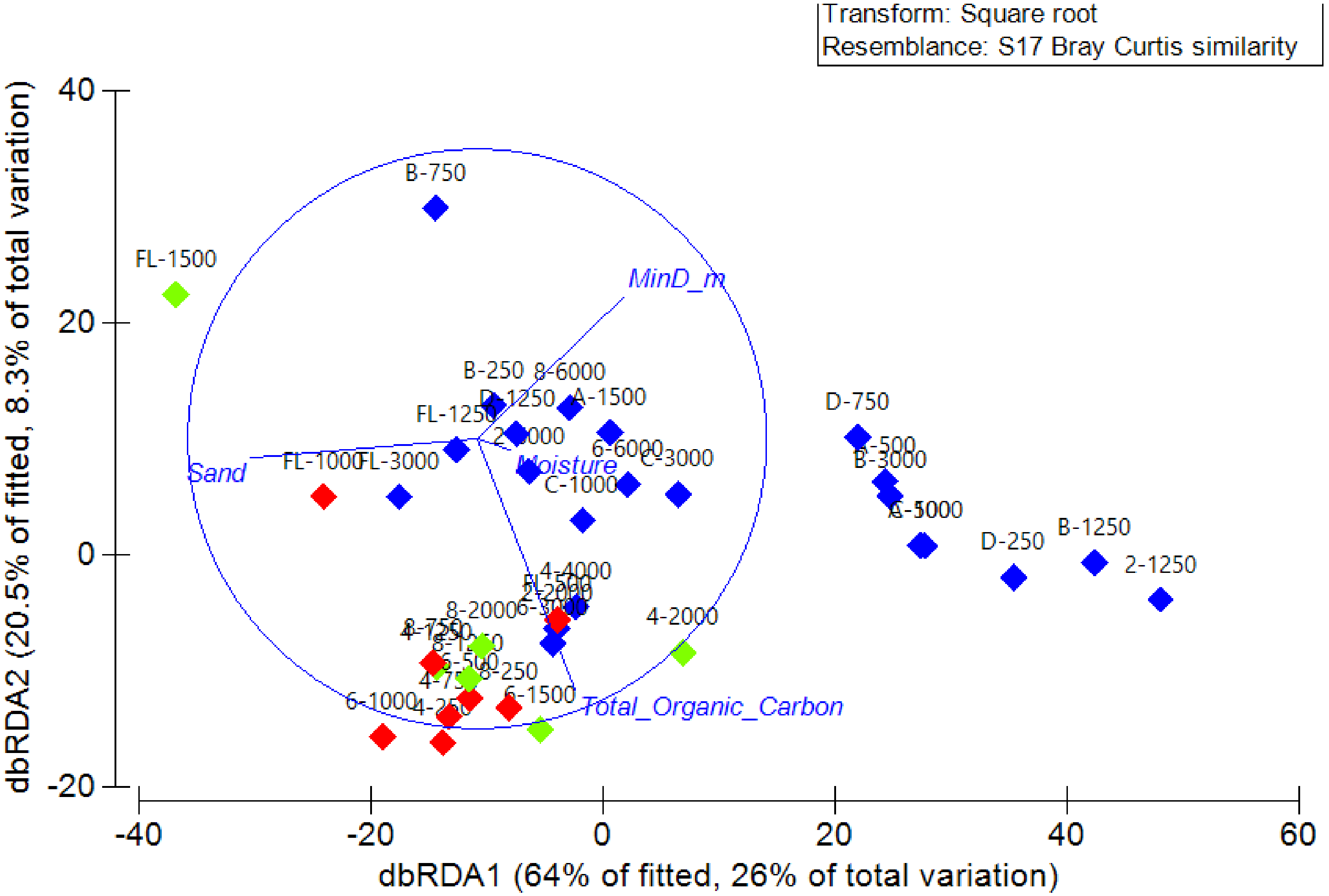


Figure 4-29 dbRDA plot of Y2 EEM site benthic invertebrate family abundance (sq-rt transformed) and sediment analytes best fit DistLM model. Symbol colors: red: ≤1,000 m, green: 1,000 to 2,000 m, blue: >2,000 m

4.4 Summary of Results

4.4.1 Physical and Chemical Characteristics

A total of 19 analytes were screened-in for further analysis in 2019. There was a statistically significant difference between sampling years. Analyte concentrations for 2019 have increased at several stations compared to baseline levels (2014). Distance from the Hebron GBS was also statistically significant. Stations closer to the GBS and particularly 8-250 had higher analyte concentrations in 2019 when compared to baseline levels. Barium, total organic carbon, C_{10}-$C_{21,}$ C_{21}-C_{32}, sulphide, and sulphur were negatively correlated with distance from the Hebron GBS (i.e. decreased concentration of analyte with increasing distance from the GBS). All other screened-in analytes concentrations were not statistically significant with distance.

Particle size concentrations of the sediment samples consisted of mainly sand with secondary particle sizes consisting of gravel and percent fines. Stations farther than 1,000 m from the GBS had higher concentrations of gravel which is consistent with previous EEM survey years. Percent fines has increased by two standard deviations from baseline levels at station 8-250 which is an expected project effect.

Station 8-250 sediment samples had the highest concentrations of barium, C10-C21 and C21-C32 hydrocarbons, moisture, sulphide, sulphur, and relatively higher concentrations of iron, lead, chromium, vanadium. The highest concentrations of uranium occurred at B-250, strontium occurred at B-1250, and vanadium, manganese, and iron occurred at 2-6000. These stations are more than 6,000 m to the northeast of the Hebron GBS. Additionally, the first instance of negative redox potential values from any of the three survey years occurred. Of the eight negative readings, seven occurred to the northeast of the GBS with the lowest reading occurring at A-1000. Negative redox readings indicate a reduced environment or anoxic conditions in the sediment.

4.4.2 Toxicity

No Hebron EEM sediment samples were at or above PetroTox thresholds thus, only samples < 500 m from the GBS were screened-in for toxicity testing. Of the four samples evaluated, all were deemed non-toxic and had amphipod survival rates at or above 97%. These results are comparable to toxicity rates observed in 2018 and 2014.

4.4.3 Benthic Community Structure

Overall, decreases were detected in all six of the community monitoring variables compared to baseline levels (except for biomass which was not recorded for baseline levels). The number of taxa observed were lower in 15 of 36 stations from baseline levels with no change detected in 4-250. The mean between the three sampling years remains relatively similar S=32 (2014), S=33 (2018), S=35 (2019). Total abundance is lower in 2019 from baseline levels, particularly in stations within 1,000 m of the GBS. While mean biomass increased between 2019 from 2018 levels, nearly half of all stations reported lower biomass levels. Species richness declined from 2014 to 2019 but may be increasing with 2019 levels being higher than 2018 levels. Across all stations, 2019 evenness values are higher than baseline levels with only three stations reporting lower values. Increases in the Shannon-Weiner (H’) index from baseline levels (2014) were observed at 32 of 36 sampling stations and 23 from 2018 levels. Decreases in H’ from baseline levels were observed at four stations (FL-500, 2-1250, FL-1500, B-1250) located to northeast of the Hebron GBS.

Overall, polychaetes accounted for 50% of all taxa observed followed by clitellata at 21% and amphipoda at 10%. Spionidae and Clitellates were observed in relatively high abundances at many stations at distances > 3,000 m located to the northeast in the GBS. The Capitellidae, the most commonly used indicator of marine pollution world-wide, were not abundant in 2019, 2018, or baseline within Hebron stations. Transitional zone indicator species *Tharyx* sp. and *Exogone hebes* were observed throughout the survey area. *Tharyx* sp. accounted for 31% of all taxa present. Reductions in crustacean, mollusc, and echinoderm populations can be significantly reduced by hydrocarbon contamination (Blackburn et al. 2014) however this was not observed in the 2019 sediment samples.

Three variables that contributed the most to model explanation and account for over 38% of the total variation were percent sand concentration (26%), total organic carbon (8.33%), distance from the HEB GBS (<5%). There were statistically significant differences in benthic community assemblages between stations at different distances. Stations >2,000 m (Far) distance from GBS were statistically different from stations ≤1,000 m (Near) and stations 1,000 m to 2,000 m (Mid) distance. Stations <2,000 m from the GBS were not statistically different from each other.

5.0 WATER QUALITY COMPONENT

5.1 Methods

5.1.1 Field Collection

Water quality sampling was conducted on August 28, 2019 after completion of the sediment sampling. This was the first year of produced water sampling during operations for the Hebron Project. Water sampling was conducted at fixed locations along three radials from the produced water discharge point: directly in line with the discharge point projecting out from the platform (north), one projecting perpendicular to the east of the discharge point (east), and the third projecting perpendicular to the west of the discharge point (west). The sampling stations were located 50 m, 100 m, and 500 m from the produced water discharge location along each radial (Figure 5-1).

Weather conditions during water sampling were generally good with winds ranging from 10-15 kts and wave height approximately 1.5 m. Marine weather forecasts indicated direction of primary surface swells were south to west and secondary swells were north northeast. Underwater currents as measured by an acoustic doppler current profiler (ADCP) were relatively low (<0.5 m/s) and towards the southwest.

Conductivity, Temperature, Depth (CTD) (Figure 5-2) profiles were conducted at N-50 and a reference station (Ref-1) to collect data on pH, temperature, conductivity, salinity, and dissolved oxygen through the water column (Figure 5-1). Water was collected using a string of 10 L Niskin bottles at three depths (surface: 1 m below the surface, middle: 25 m, and bottom 10 m above the seafloor) at each station (Figure 5-2). The middle sampling depth was based on plume location identified through CTD profiles at station N-50. Upon retrieval of the Niskin bottles, water was decanted into appropriate laboratory provided sample containers and stored at 4^0C. Field duplicates were collected at W-50 (bottom), W-500 (surface), and N-100 (bottom) stations. Water sampling raw data and QA/QC procedures are presented in Volume II of this report.

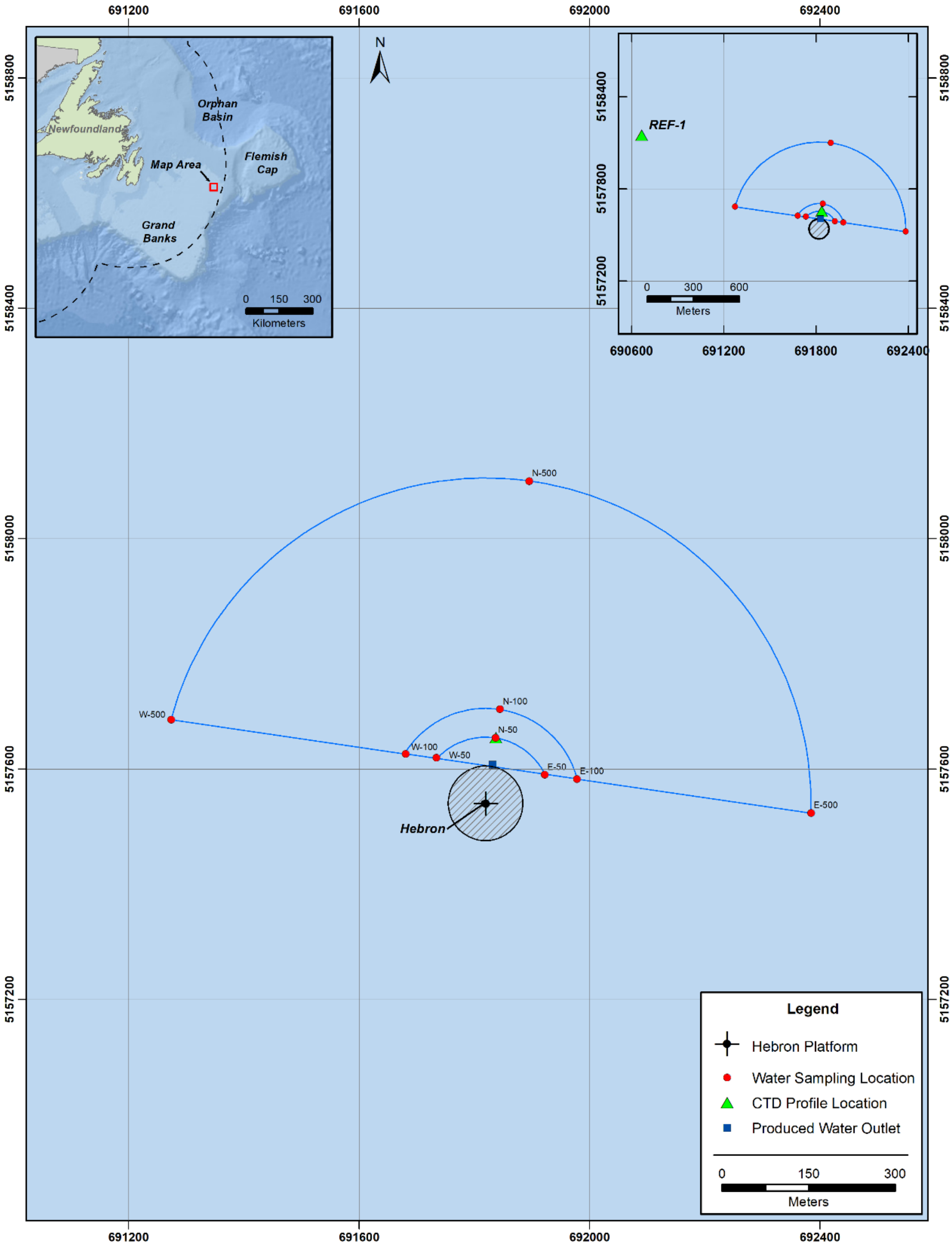


Figure 5-1 Water column sampling stations and CTD profile stations, August 28, 2019.

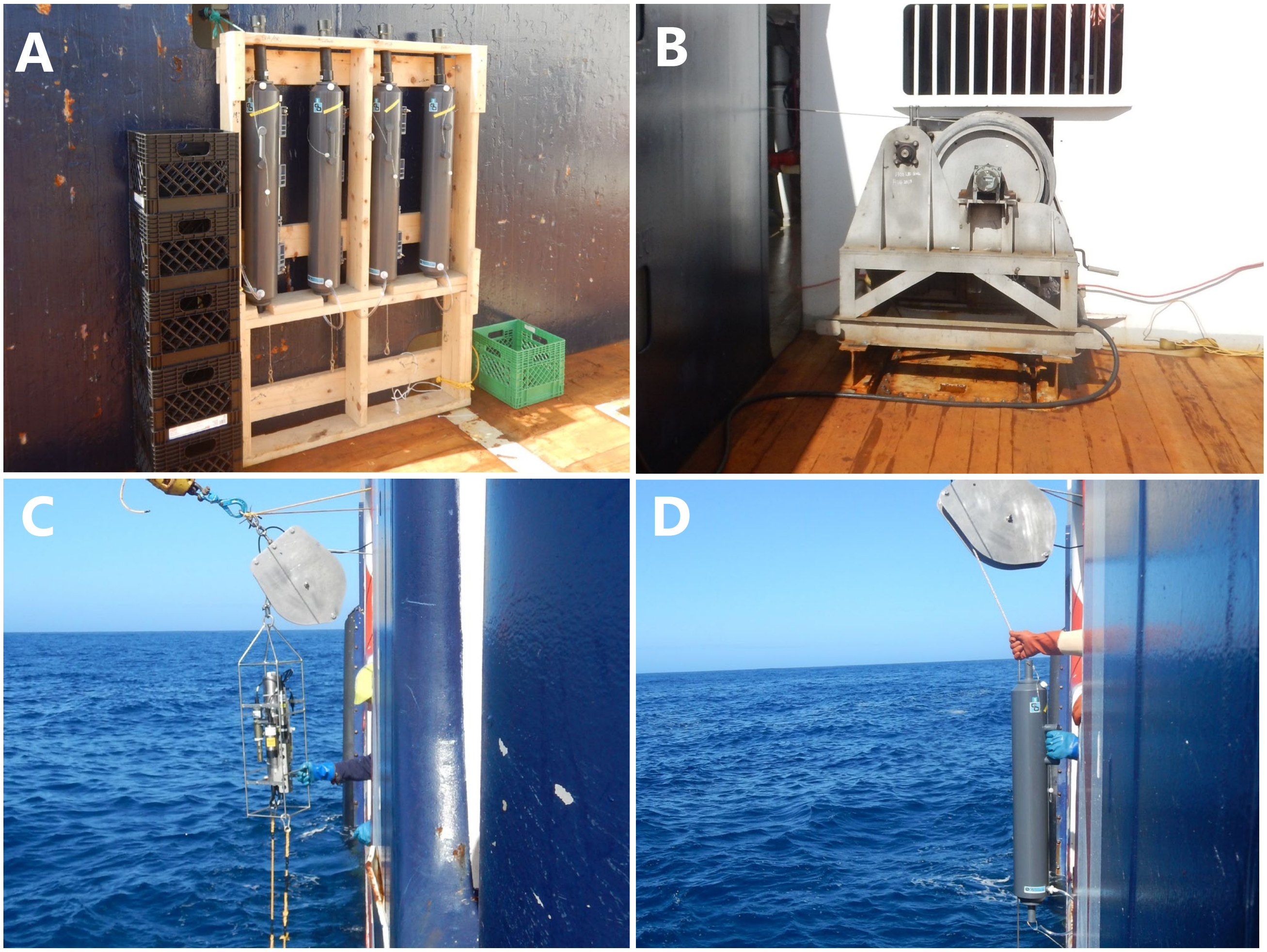


Figure 5-2 Field photos from the Hebron 2019 EEM Water Sampling Component, A) Niskin samplers on holding rack, B) hydrographic winch, C) Retrieval of CTD, D) Retrieval of Niskin sampler.

Discharged Produced Water Sampling

Produced water is sampled annually as part of normal operations for the Hebron Project (EMCP 2018). Produced water was sampled prior to discharge by a Hebron Platform technician on September 3, 2019. 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, radionuclides, alkylated phenols, PAHs, and alkyl-PAHs) and toxicity (sea urchin fertilization and Microtox) analyses. Chemical characteristics of the overboard produced water was used to assess potential enrichment or depletion in the marine environment based on field sampling.

5.1.2 Laboratory Analyses

All stations were sampled for chemical analysis including BTEX, hydrocarbons, total petroleum hydrocarbons (TPH) and trace metals. Metals, hydrocarbons, and PAHs were screened for reporting and analysis if 50 percent or more of tested samples exceeded their reported detection limit (RDL) at one or more stations. Detected analytes were compared against Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life (CCME 2014).

Table 5.1 Water chemistry parameters and associated detection limits across monitoring years.

Parameter	Unit	Detection Limit	
		2014	**2019**
Metals			
Aluminum	µg/L	10	10
Antimony	µg/L	0.50	0.50
Arsenic	µg/L	0.50	0.50
Barium	µg/L	1.0	1.0
Beryllium	µg/L	1.0	1.0
Bismuth	µg/L	1.0	1.0
Boron	µg/L	50	50
Cadmium	µg/L	0.050	0.050
Calcium*	mg/L	1000	1.0
Chromium	µg/L	0.50	0.50
Cobalt	µg/L	0.10	0.10
Copper	µg/L	0.50	0.50
Iron	µg/L	2.0	2.0
Lead	µg/L	0.10	0.10
Lithium	µg/L	20	20
Magnesium	mg/L	1.0	1.0
Manganese	µg/L	0.50	0.50
Mercury	µg/L	0.013	0.013
Molybdenum	µg/L	1.0	1.0
Nickel	µg/L	0.20	0.20
Phosphorus	µg/L	50	n/a
Potassium	mg/L	1.0	1.0
Selenium	µg/L	0.50	0.50
Silicon*	µg/L	100	1000
Silver	µg/L	0.050	0.050
Sodium*	mg/L	1.0	5.0
Strontium	µg/L	10	10
Sulphur	mg/L	20	20
Thallium	µg/L	0.10	0.10

Parameter	**Unit**	**Detection Limit**	
		2014	**2019**
Tin	µg/L	1.0	1.0
Titanium	µg/L	10	10
Uranium	µg/L	0.050	0.050
Vanadium	µg/L	10	10
Zinc	µg/L	1.0	1.0
Petroleum Hydrocarbons			
Benzene	mg/L	0.0010	0.0010
Toluene	mg/L	0.0010	0.0010
Ethylbenzene	mg/L	0.0010	0.0010
Total Xylenes	mg/L	0.0020	0.0020
C6 - C10 (less BTEX)	mg/L	0.010	0.10
>C10-C16 Hydrocarbons	mg/L	0.050	0.050
>C16-C21 Hydrocarbons	mg/L	0.050	0.050
>C21-<C32 Hydrocarbons	mg/L	0.10	0.10
Modified TPH (Tier1)	mg/L	0.10	0.10
Total Oil & Grease	mg/L	n/a	0.50
Polycyclic aromatic Hydrocarbons [a]			
1-Chloronaphthalene	µg/L	0.050	n/a
1-Methylnaphthalene	µg/L	0.050	n/a
2-Chloronaphthalene	µg/L	0.050	n/a
2-Methylnaphthalene	µg/L	0.050	n/a
Acenaphthene	µg/L	0.010	n/a
Acenaphthylene	µg/L	0.010	n/a
Anthracene	µg/L	0.010	n/a
Benzo(a)anthracene	µg/L	0.010	n/a
Benzo(a)pyrene	µg/L	0.010	n/a
Benzo(b)fluoranthene	µg/L	0.010	n/a
Benzo(e)pyrene	µg/L	0.010	n/a
Benzo(g,h,i)perylene	µg/L	0.010	n/a
Benzo(j)fluoranthene	µg/L	0.010	n/a
Benzo(k)fluoranthene	µg/L	0.010	n/a
Chrysene	µg/L	0.010	n/a
Dibenz(a,h)anthracene	µg/L	0.010	n/a
Fluoranthene	µg/L	0.010	n/a
Fluorene	µg/L	0.010	n/a

Parameter	Unit	Detection Limit	
		2014	2019
Indeno(1,2,3-cd)pyrene	µg/L	0.010	n/a
Naphthalene	µg/L	0.20	n/a
Perylene	µg/L	0.010	n/a
Phenanthrene	µg/L	0.010	n/a
Pyrene	µg/L	0.010	n/a
Other Parameters [a]			
Hardness	mg/L	0.50	0.50
Chlorophyll a	µg/L	0.50	n/a
Phaeophytin A	µg/L	0.50	n/a
Nitrogen (Ammonia Nitrogen)	mg/L	0.050	n/a
Phosphorus	mg/L	0.020	n/a
Total Inorganic Carbon	mg/L	0.50	n/a
Total Organic Carbon	mg/L	5.0	n/a
Total Suspended Solids	mg/L	1.0	n/a

Notes:
[a] Analysis for polyaromatic hydrocarbons and particular other parameters were discontinued in development of the EEM design plan (EMCP 2017).
* RDL varied across years.

5.1.3 Statistical Analyses

The physical and chemical characteristics of water samples includes quantitative assessment of frequently detected parameters (analytes above RDL detected in >50 percent of samples). Infrequently detected parameters (analytes above RDL that were detected in 20-49 percent of samples) were also noted.

Analysis of variance (ANOVA) were used to compare between the sampling Distance (50, 100, 500 m), Depth (surface, middle, bottom), and Direction (north [N], east [E], west [W]) and their interactions. 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). 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 as per the design plan (EMCP 2017). Half RDL was used for statistical analysis as a conservative value (EMCP 2017).

5.2 Results

5.2.1 Water Column Profiles

Water column profiles were collected at a reference station (Reference Station 1) outside the water sampling area and at station N-50 for determination of the middle depth range for sampling within the produced water plume (Figure 5-2). The depth ranges identified from the profiles included surface (<16 m), middle (16-70 m, and bottom (71-85 m), with the middle water sample set at 25 m.

At the reference station, the upper mixed layer was determined at <18 m water depth with relatively constant values for temperature (Figure 5-3), followed by a steep change (18 m to approximately 70 m, i.e., the thermocline), followed lastly by a steady temperature below the thermocline (>70 m). Conductivity showed a similar pattern to the temperature profile described above. The oxygen vertical profile was more complex but with a typical, similar general pattern for dissolved oxygen concentrations. The oxygen in the surface layer was near 100 percent saturation as it equilibrated with the air via surface exchange, but then becoming supersaturated in the mixed layer (i.e., >100 percent) (Libes 1992). This is caused by primary producers in the photic zone increasing the oxygen concentrations below the water surface but being reduced near the surface as it equilibrates with the surface air which is at 100 percent saturation (Libes 1992).

At station N-50, 50 m north of the produced water discharge, water column profiles were similar to the reference station in terms of thermocline, halocline, and oxycline depths (Figure 5-34). However, the thermocline at N-50 was not quite as steep as the reference which may be indicative and expected of the influence of platform discharges. This is illustrated in Figure 5-4 where the temperature profile for both the reference station (faint line) and N-50 (bold line) are graphed.

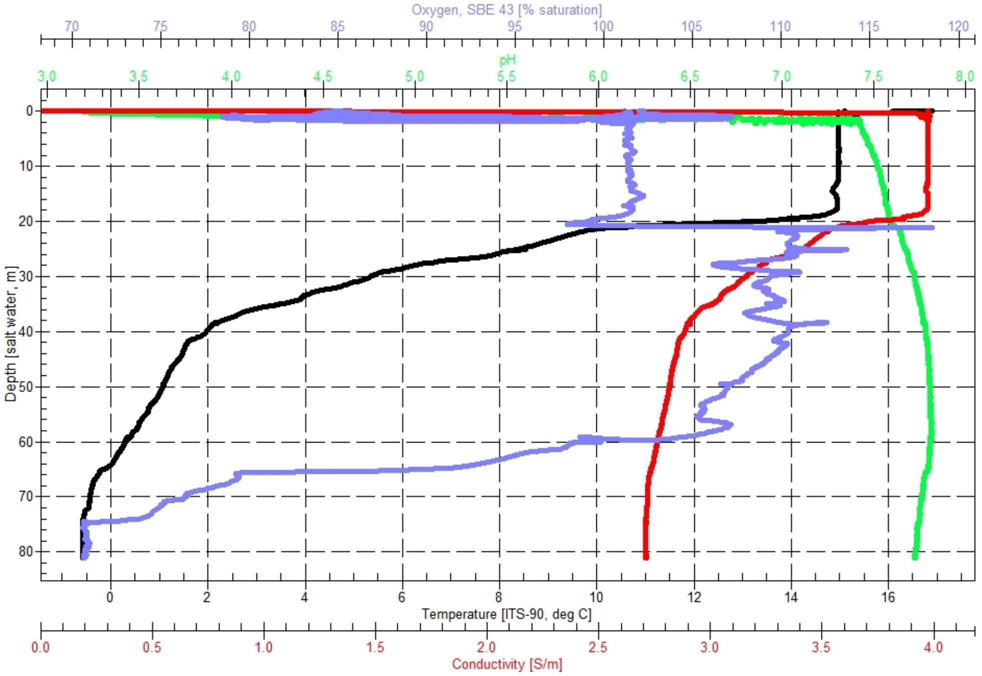


Figure 5-3 CTD Profile at a Reference Station 1.

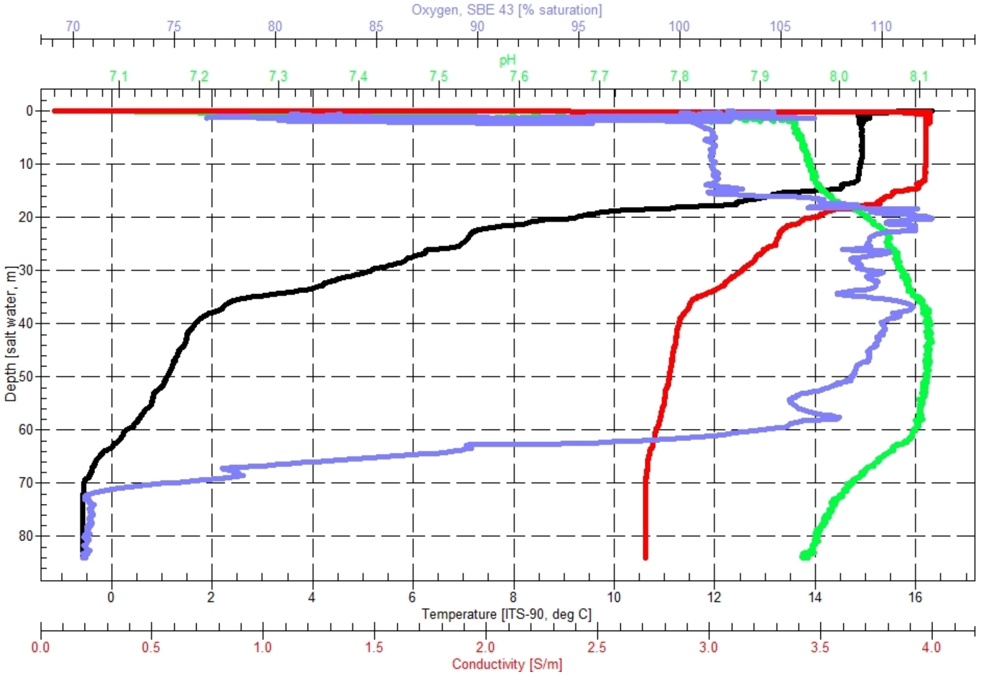


Figure 5-4 CTD Profile at Station N-50.

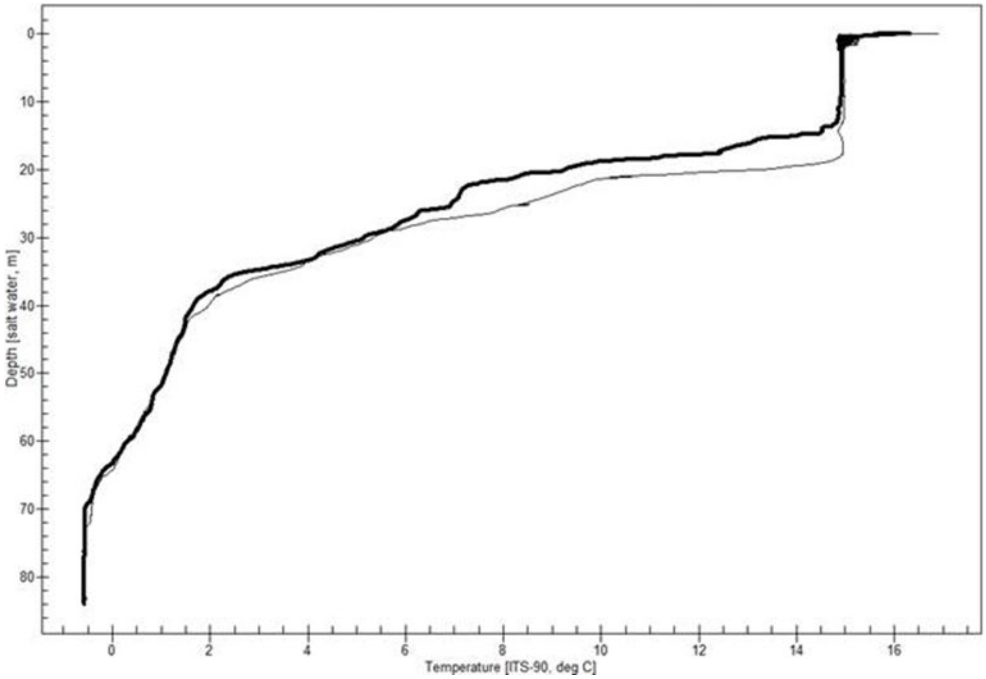


Figure 5-5 Temperature Profiles for the Reference station (faint line) and station N-50 (bold line)

5.2.2 Chemical and Physical Characteristics

Within Year Comparison

Parameter Screening

Nineteen water sample parameters (18 metals and total hardness [$CaCO_3$]) were frequently detected (detected in >50 percent of samples) within 50-500 m of the Hebron Platform produced water outlet (Table 5.2). Fifteen of these parameters were detected in all water samples including arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur, uranium, and zinc. Aluminum and iron were detected in 96 percent of samples and chromium was detected in 81 percent of samples. Copper was only detected in 52 percent of samples. Cobalt, lead, manganese, and mercury were infrequently detected in collected water samples; detected in <50 percent of samples (Table 5.3). Petroleum hydrocarbons (e.g., C_6 to $<C_{32}$, BTEX, TPH) were not detected in any water samples.

Chemical parameters detected in pre-discharged produced water that were also detected in water samples (Table 5.2) included barium, boron, calcium, iron, lithium, magnesium, potassium, sodium, strontium, sulphur and total hardness. These analytes may potentially increase water sample concentrations near the platform. Laboratory detection limits were elevated in discharged produced water due to the sample matrix with several RDLs above those for water samples including aluminum, arsenic, chromium, copper, molybdenum, and nickel. As a result, direct comparison to water samples with regards to possible increases due to produced water were not completed.

Statistical Analysis

Fifteen of the frequently detected analytes were significantly different by Distance-Direction interaction ($p<0.05$) based on two-way ANOVAs (Table 5.2, Figure 5-6). There were no other significant interaction terms among Distance, Depth, and Direction and were therefore removed from further analysis. Chromium levels in water were significantly different among distances from the produced water outlet with lower concentrations at 500 m stations relative to 50 m stations. (Tukey HSD $p<0.05$). Iron was significantly different among Distance and Direction, but not the interaction between the two factors. Pairwise comparisons indicated that iron concentrations with distance were not significantly different, however, concentrations were lower along the western samples relative to northern samples. In general, there were varied elevated concentrations of aluminum, arsenic, calcium, copper, molybdenum, nickel, strontium, sulphur and zinc towards the east and/or north closer to the produced water outlet (≤100 m) relative to the farther sampling stations (500 m) (Tukey HSD $p<0.05$).

For produced water constituents, pairwise differences were not detected among stations for lithium, magnesium, potassium, and total hardness (Tukey HSD $p>0.05$). However, there were relatively higher concentrations up to 100 m of the produced water outlet along the north and east radials for produced water constituents calcium (E-100, N-50, N-100), strontium (E-50, E-100, N-50, N-100), sulphur (E-100, N-100) relative to 500 m and/or west radial stations (Tukey HSD $p<0.05$). While analyte levels in water samples appear to be increasing along the west radial, this was not statistically significant (Tukey HSD $p>0.05$). Sodium, another produced water constituent, may have a depletion effect with an opposite trend with lower concentrations at nearby stations to the east and north and higher concentrations at the 500 m station (Tukey HSD $p<0.05$). Sodium also varied to the west with elevated concentrations at nearby stations and lower at the 500 m station (Tukey HSD $p<0.05$).

Sampling depth influenced aluminum, barium, and sodium concentrations with significant differences across depths (Figure 5-7). Post-hoc comparisons indicated that barium levels were higher in bottom water samples relative to middle and surface samples (Tukey HSD $p<0.001$). There were no pairwise differences among water samples from various depths for aluminum and sodium.

The produced water plume is predicted to initially follow the discharge path as it is entrained in seawater before following local ambient currents (Amec 2010). During water sampling, the underwater current direction was towards the southwest based on ADCP measurements. The water sampling program indicates general detection of produced water analytes within 50-100 m from the discharge outlet to the north and east stations. There were varied elevated detections of parameters at the 500 m station along the west radial; however, with the exception of sodium, they were not significantly higher.

Produced water modelling indicated under average low currents in August, dilution factors of 300 for oil to reach 0.1 ppm could be reached out to 352 m (Amec 2010), however, hydrocarbons were not detected in any water samples. Elevated barium in water samples collected near the bottom may be reflective of discharged cuttings near the seafloor (see Section 4).

CCME Guidelines

Of the detected analytes during the water sampling program, only Arsenic had an associated CCME guideline. Detected Arsenic levels were well below CCME marine water guidelines (CCME 2014).

Table 5.2 Summary of frequently detected chemical data from the 2019 EEM water sampling and corresponding value in overboard produced water.

Parameter	CCME	Hebron Water Sampling Stations									Overboard Produced Water	
		RDL	Units	N	%>RDL	Mean	St. Dev.	Median	Min.	Max.	RDL[a]	Value
Metals												
Aluminum	n/a	10	µg/L	27	96	27.0	14.9	31.0	<10	51	50	<50
Arsenic	12.5	0.50	µg/L	27	100	2.34	0.24	2.41	1.87	2.71	10	<10
Barium	n/a	1.0	µg/L	27	100	6.7	3.8	4.2	3.4	13.4	10	16000
Boron	n/a	50	µg/L	27	100	3840	152	3840	3640	4310	500	24000
Calcium	n/a	1.0	mg/L	27	100	379	34	377	331	447	1.0	1300
Chromium	n/a	0.50	µg/L	27	81	0.70	0.34	0.67	<0.50	1.65	10	<10
Copper	n/a	0.50	µg/L	27	52	1.97	2.81	0.52	<0.50	8.79	5.0	<5.0
Iron	n/a	2.0	µg/L	27	96	7.8	8.8	4.7	<2.0	45.5	500	3900
Lithium	n/a	20	µg/L	27	100	158	7	156	147	176	20	4000
Magnesium	n/a	1.0	mg/L	27	100	1157	67	1150	1060	1270	1.0	430
Molybdenum	n/a	1.0	µg/L	27	100	10.0	0.8	9.9	8.9	11.4	20	<20
Nickel	n/a	0.20	µg/L	27	100	0.79	0.58	0.54	0.21	2.44	20	<20
Potassium	n/a	1.0	mg/L	27	100	348	17	349	321	378	1.0	280
Sodium	n/a	5.0	mg/L	27	100	9271	471	9100	8680	10200	10	20000
Strontium	n/a	10	µg/L	27	100	7480	776	7810	6340	8650	200	300000
Sulphur	n/a	20	mg/L	27	100	843	59	857	753	937	50	50
Uranium	n/a	0.050	µg/L	27	100	2.820	0.179	2.830	2.56	3.18	1.0	<1.0
Zinc	n/a	1.0	µg/L	27	100	250	425	11	1.4	1210	50	<50
Calculated Parameters												

Total Hardness ($CaCO_3$)	n/a	0.50	mg/L	27	100	5704	352	5690	5170	6280	1.0	4900
Notes: [a] Elevated reporting limits for trace metals due to sample matrix.												

Table 5.3 Summary of infrequently detectable chemical data from the 2019 EEM water sampling and corresponding value in overboard produced water.

Parameter	Hebron Water Sampling Stations									Overboard Produced Water	
	RDL	**Units**	**N**	**%>RDL**	**Mean**	**St. Dev.**	**Median**	**Minimum**	**Maximum**	**RDL[a]**	**Value**
Cobalt	0.10	µg/L	27	33	0.15	0.18	0.05	<0.10	0.59	4.0	<4.0
Lead	0.10	µg/L	27	26	0.09	0.09	0.05	<0.10	0.33	5.0	<5.0
Manganese	0.50	µg/L	27	41	2.34	3.62	0.25	<0.50	10.80	20	97
Mercury	0.013	µg/L	27	33	0.009	0.004	0.007	<0.013	0.023	0.013	<0.013
Notes: [a] Elevated reporting limits for trace metals due to sample matrix.											

Table 5.4 Results of ANOVA (p-values) for frequently detected constituents.

Parameter	**p-value**			
	Distance	**Direction**	**Depth**	**Distance x Direction**
Aluminum	**<0.001**	**<0.001**	**0.022**	**<0.001**
Arsenic	**0.005**	0.642	0.725	**<0.001**
Barium	0.595	0.807	**<0.001**	0.691
Boron	0.593	0.431	0.298	0.145
Calcium	**<0.001**	**<0.001**	0.883	**<0.001**
Chromium	**0.005**	0.098	0.767	0.108
Copper	**<0.001**	**<0.001**	0.434	**<0.001**
Hardness	0.067	0.068	0.605	**0.001**
Iron	**0.031**	**0.019**	0.505	0.156
Lithium	0.220	0.522	0.185	**0.028**
Magnesium	0.160	0.150	0.555	**0.003**
Molybdenum	**0.027**	**0.031**	0.631	**<0.001**
Nickel	**<0.001**	**<0.001**	0.466	**<0.001**
Potassium	0.125	0.182	0.506	**0.002**
Sodium	**<0.001**	**0.017**	**0.008**	**<0.001**
Strontium	**0.003**	**0.004**	0.636	**<0.001**
Sulphur	**0.027**	**0.038**	0.649	**<0.001**
Uranium	0.065	0.091	0.546	**<0.001**
Zinc	**<0.001**	**<0.001**	0.618	**<0.001**

Notes:
[a] Bold indicates significant at $p<0.05$ threshold.

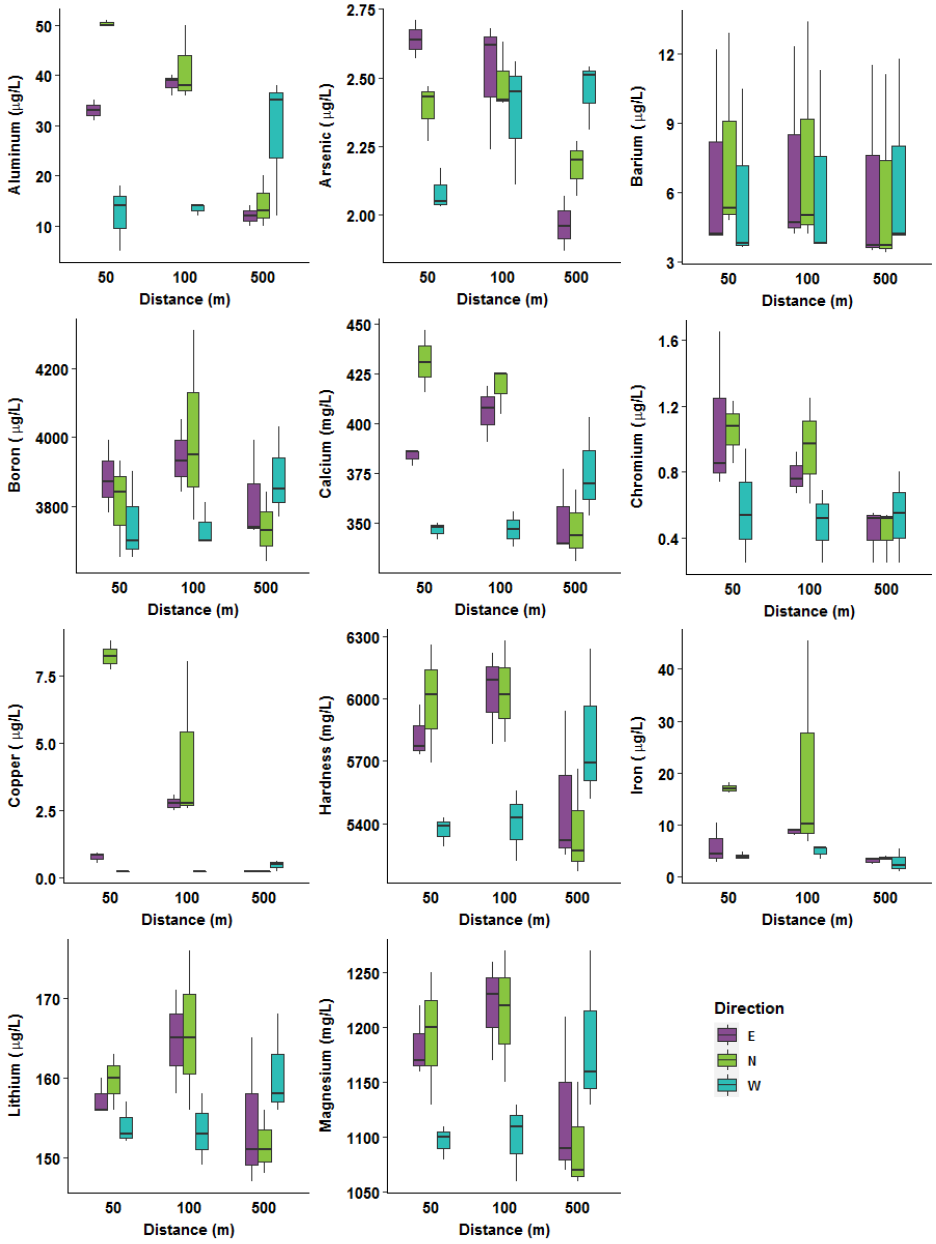


Figure 5-6 **Boxplots of frequently detected chemical parameters by radial direction (north, east, west) and distance from produced water outlet (50, 100, 500 m).**

Note: Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

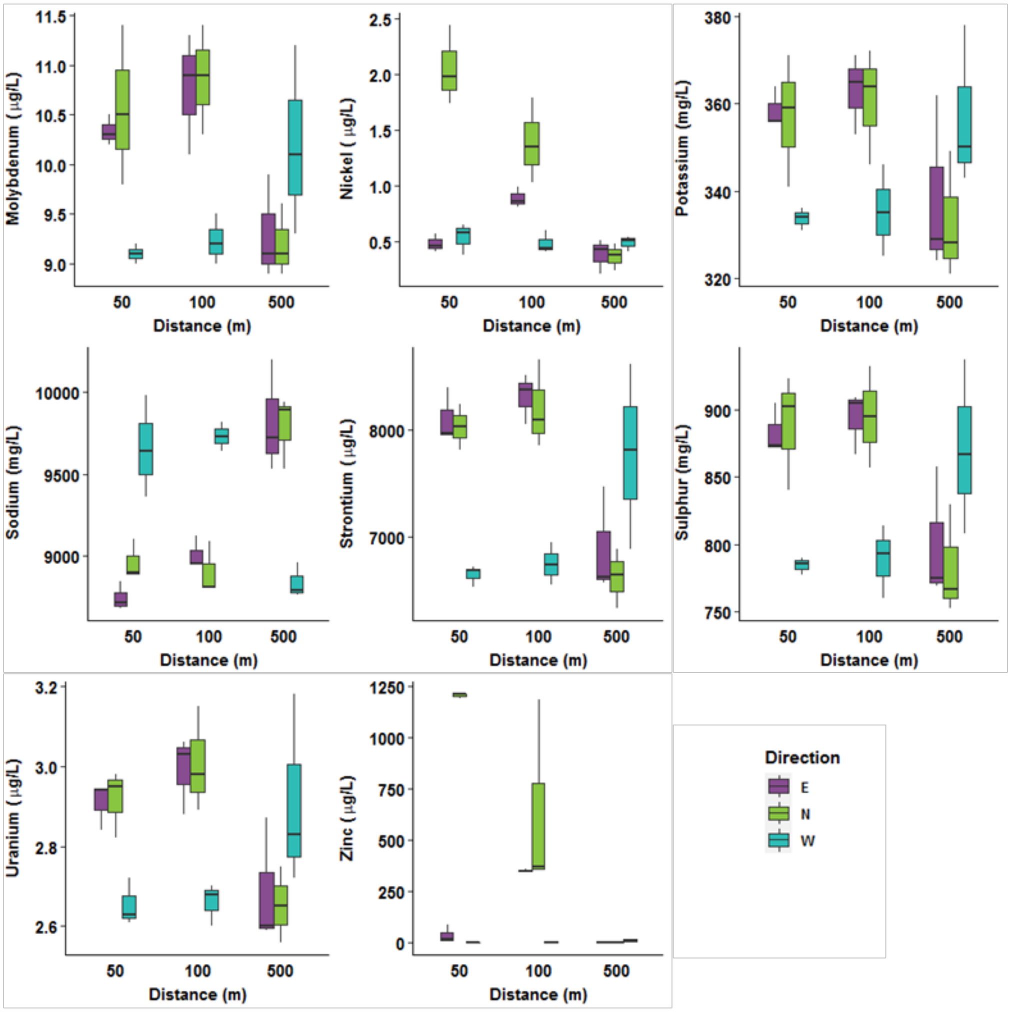


Figure 5-6 **Boxplots of frequently detected chemical parameters by radial direction (north, east, west) and distance from produced water outlet (50, 100, 500 m) (Continued).**

Note: Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

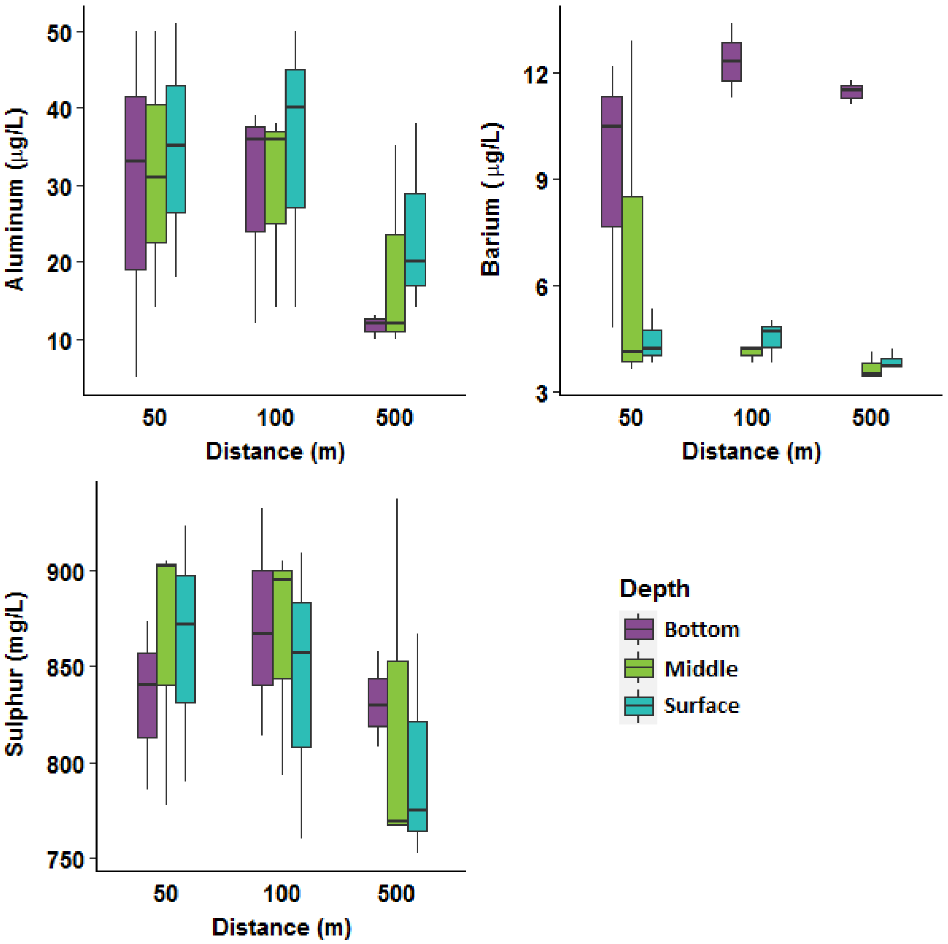


Figure 5-7 **Boxplots of statistically significant (two-way ANOVA) frequently detected chemical parameters by sampling depth (bottom, middle, surface) and distance from produced water outlet (50, 100, 500 m).**

Note: Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

Across Year Comparisons

Water sampling results were compared between the 2019 monitoring and 2014 environmental characterization results (Stantec 2014). As there were no operations in 2014, the water samples from planned sampling and reference stations were pooled as a baseline dataset. Almost all analyte levels detected in 2019 were significantly different ($p<0.001$) compared to 2014 water samples except for barium, magnesium, and hardness. However, analytes detected in 2019 were not consistently higher or lower relative to 2014 samples. Iron and strontium produced water constituents were higher in 2019 water samples relative to 2014 water samples while boron, lithium, calcium, potassium, sulphur, and sodium produced water constituents were lower in 2019 water samples relative to 2014 water samples.

Table 5.5 Results of ANOVA (p-values) for frequently detected parameters across baseline (2014) and monitoring (2019) year.

Parameter	p-value	Sampling Year with Higher Average Concentration
Aluminum	**<0.001**	2019
Arsenic	**<0.001**	2019
Barium	0.382	-
Boron	**<0.001**	2014
Calcium	**<0.001**	2014
Chromium	**<0.001**	2019
Copper	**<0.001**	2019
Hardness	0.984	-
Iron	**<0.001**	2019
Lithium	**<0.001**	2014
Magnesium	0.216	-
Molybdenum	**<0.001**	2014
Nickel	**<0.001**	2019
Potassium	**<0.001**	2014
Sodium	**<0.001**	2014
Strontium	**0.028**	2019
Sulphur	**<0.001**	2014
Uranium	**<0.001**	2014
Zinc	**<0.001**	2014

Notes:
[a] Bold indicates significant at $p<0.05$ threshold.

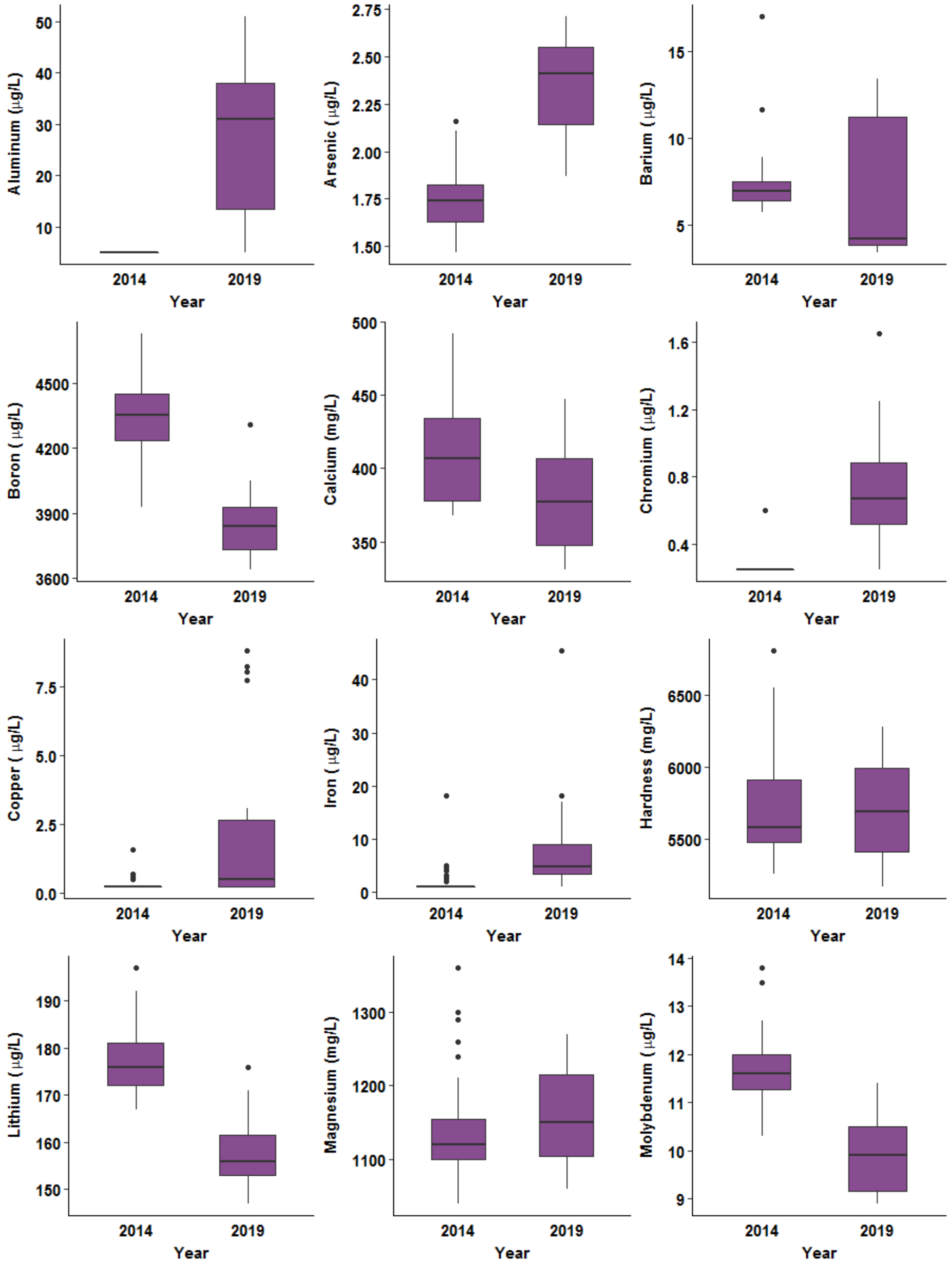


Figure 5-8 Boxplots of frequently detected chemical parameters for baseline (2014) and monitoring (2019).

Note: Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

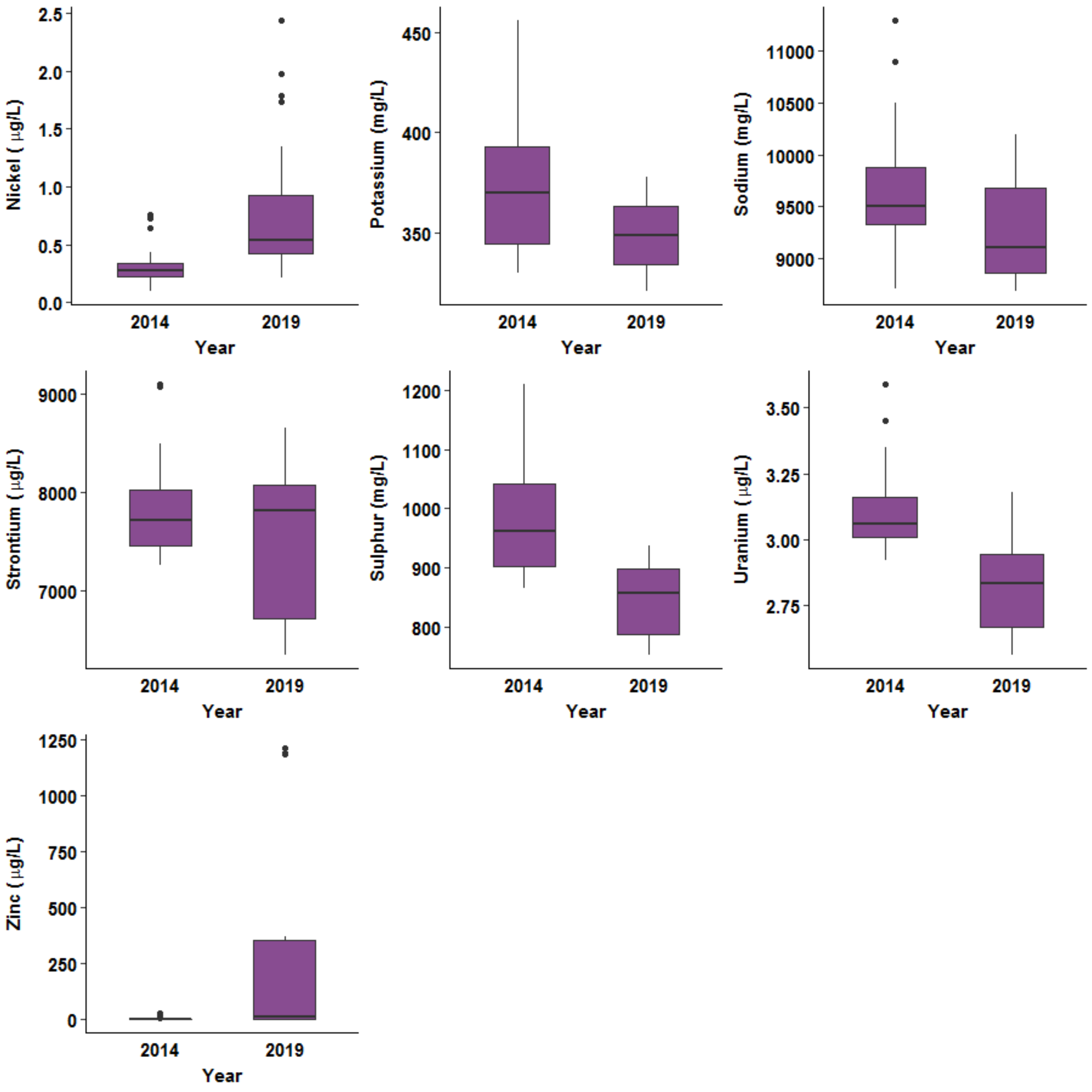


Figure 5-8 **Boxplots of frequently detected chemical parameters for baseline (2014) and monitoring (2019) (Continued).**

Note: Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

5.3 Summary of Results

For the 2019 water quality monitoring, samples were collected along radials north, east, and west of the produced water outlet from the Hebron Platform. Sampling depths were based on CTD profiles at N-50. Petroleum hydrocarbons (e.g., C_6 to $<C_{32}$, BTEX, TPH) were not detected in any water samples. Nineteen parameters, including 18 metals and total hardness, were frequently above detection limits in collected water samples. Majority of these analytes were detected in >80 percent of samples, with copper only detected in 52 percent of samples. Several of these analytes were also detected in the overboard produced water sampled from the Hebron Platform including barium, boron, calcium, iron, lithium, magnesium, potassium, sodium, strontium, sulphur and total hardness, indicating potential to influence receiving water concentrations. Statistical analyses indicated that the detected analytes significantly varied by the interaction between distance from the produced water outlet (50, 100, 500 m) and radial direction (N, E, W). There were no other significant interactions among Distance, sampling depth (surface, middle, bottom), and Direction; however, some significant differences were detected in individual parameters (Distance, Depth, Direction).

Chemical parameters were typically statistically higher to the north and/or east at the 50 and/or 100 m stations and lower at the 500 m stations. While analyte levels in water samples appear to be increasing along the west radial, this was not statistically significant. Produced water constituents calcium, strontium, and sulphur had elevated concentrations within 100 m of the produced water outlet relative to 500 m and west radial stations; however, there were no Distance-Direction pairwise differences for lithium, magnesium, potassium, and total hardness. Sodium, another produced water constituent, had an opposite trend to other analytes where there were lower values along the north and east radials at 50 and 100 m stations and higher concentrations at the 500 m stations. The produced water plume is expected to follow the discharge path initially before following local ambient currents. During water sampling, currents were relatively low (<0.5 m/s) and towards the southwest. The results indicate detection of the produced water plume within 50-100 m of the discharge outlet with decreasing concentrations with distance. Barium was statistically higher in bottom samples from 50-500 m from the platform and may be associated with discharged drill cuttings (see Section 4).

Detected chemical parameters in 2019 water samples were compared against 2014 environmental characterization results. Almost all analyte levels detected in 2019 were significantly different compared to 2014 water samples except for barium, magnesium, and total hardness. However, analytes detected in 2019 were not consistently higher or lower relative to 2014 samples. Differences among sampling years may not be indicative of produced water discharge as water chemistry may change daily regardless of produced water influence. Furthermore, produced water discharges in the first year of continuous discharge is relatively low to predicted levels for future operations.

6.0 COMMERCIAL FISH PROGRAM

6.1 Methods

6.1.1 Field Collection

The 2019 commercial fish and fish health sampling program was conducted aboard the fisheries research vessel (FRV) *Nuliajuk* using a 1200 Campelen trawl towed within a 2 km radius of the Hebron Platform and associated Reference Area. The Reference Area was located 80 km away from the Hebron Platform (Figure 6-1) and is a shared Reference Area with the Hibernia and Hibernia Southern Extension (HSE) fish sampling programs. All sampling was conducted according to the requirements of the Experimental License issued by Fisheries and Oceans Canada (NL-5394-19) (see Volume II). All fish processing and sampling was performed by WSP personnel. The crew of the FRV *Nuliajuk* 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 of the trawl 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 30 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 available, 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/stations and ship sources.

Comparisons were made between the 2019 and 2018 sampling programs, and the 2015 fish characterization (baseline) sampling. However, since the fish characterization program informed the eventual EEM design, there are differences between the existing and previous sampling methodology including minimum fish length and tissue chemistry compositing methodology. Further details on the 2015 Reference Area commercial fish results are presented in the 2018 EEM report (EMCP 2019).

Table 6.1 Sampling design differences between the 2015 Fish Characterization Study and Hibernia Southern Extension EEM Methodology and the Hebron EEM Methodology.

Parameters	2015 Fish Characterization Study (baseline) / HSE EEM	2018 and 2019 Hebron EEM
Minimum Fish Length	>250 mm	>300 mm
Fillet Body Burden Sampling	10 single fish fillets	5 fillet composites (each 10 fish minimum)
Liver Body Burden Sampling	10 liver composites (each 7 fish minimum as per (HMDC 2017)	5 liver composites (each 10 fish minimum)
Archive Sample	Heart, spleen, gonads	None
Gross pathology	Not completed	Completed

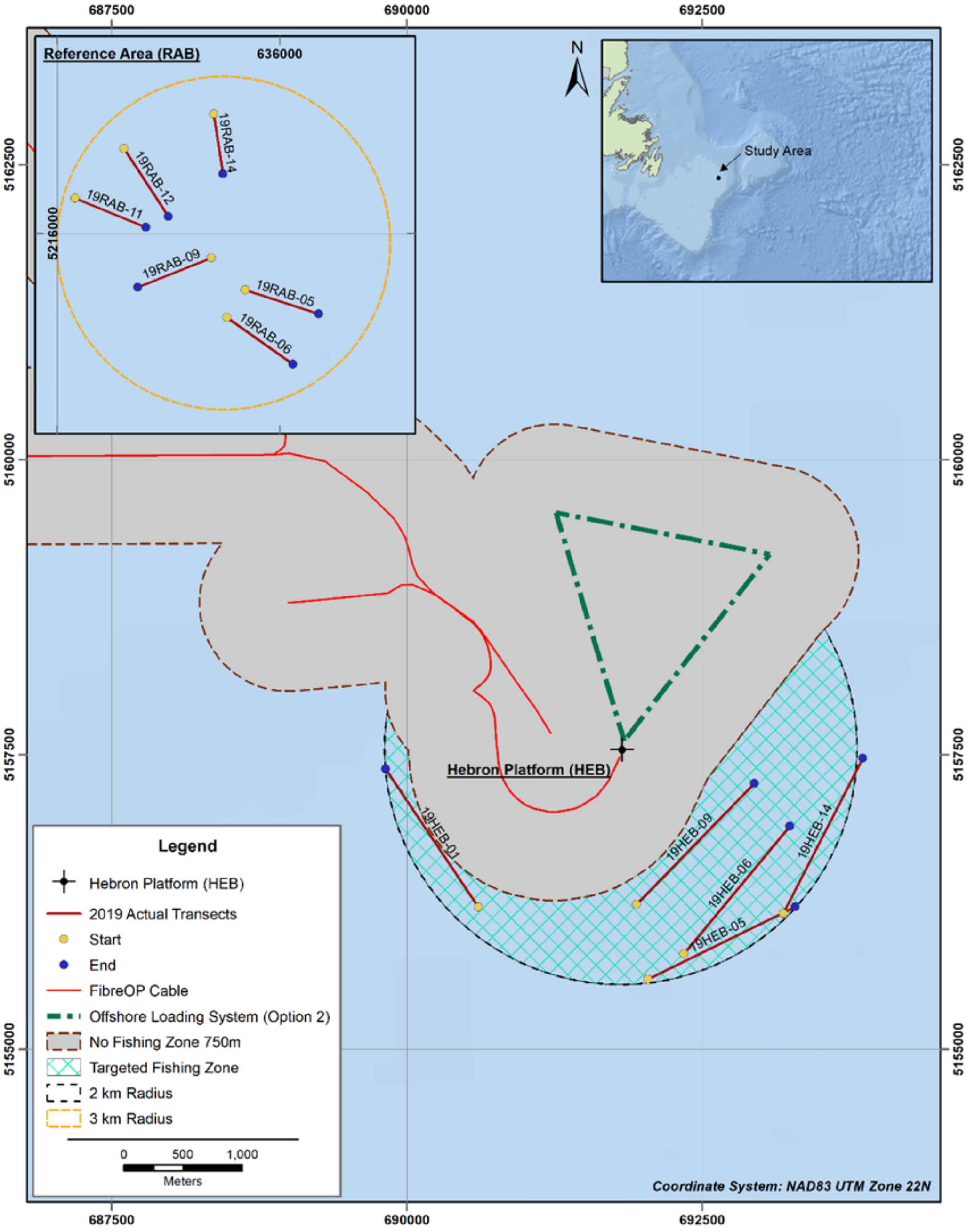


Figure 6-1 Hebron 2019 EEM commercial fish sampling program trawl locations.

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 killed by severing the spinal cord behind the head
3. The first gill arch was removed and stored in a Bio-tite container with 10 percent 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 hydrocarbon odours were also recorded.
6. Liver tissue was sampled for mixed function oxygenase analysis (Whirl-pak; -80°C preservation), histology (Bio-tite container with 10 percent neutral buffered formalin), and body burden (Whirl-pak; -20°C freezer).
7. The bottom fillet was removed for body burden analysis and stored in a Ziploc bag (-20°C freezer).
8. The otoliths were removed and stored in a coin envelope for fish aging.
9. Samples were grouped together by area and trawl number.

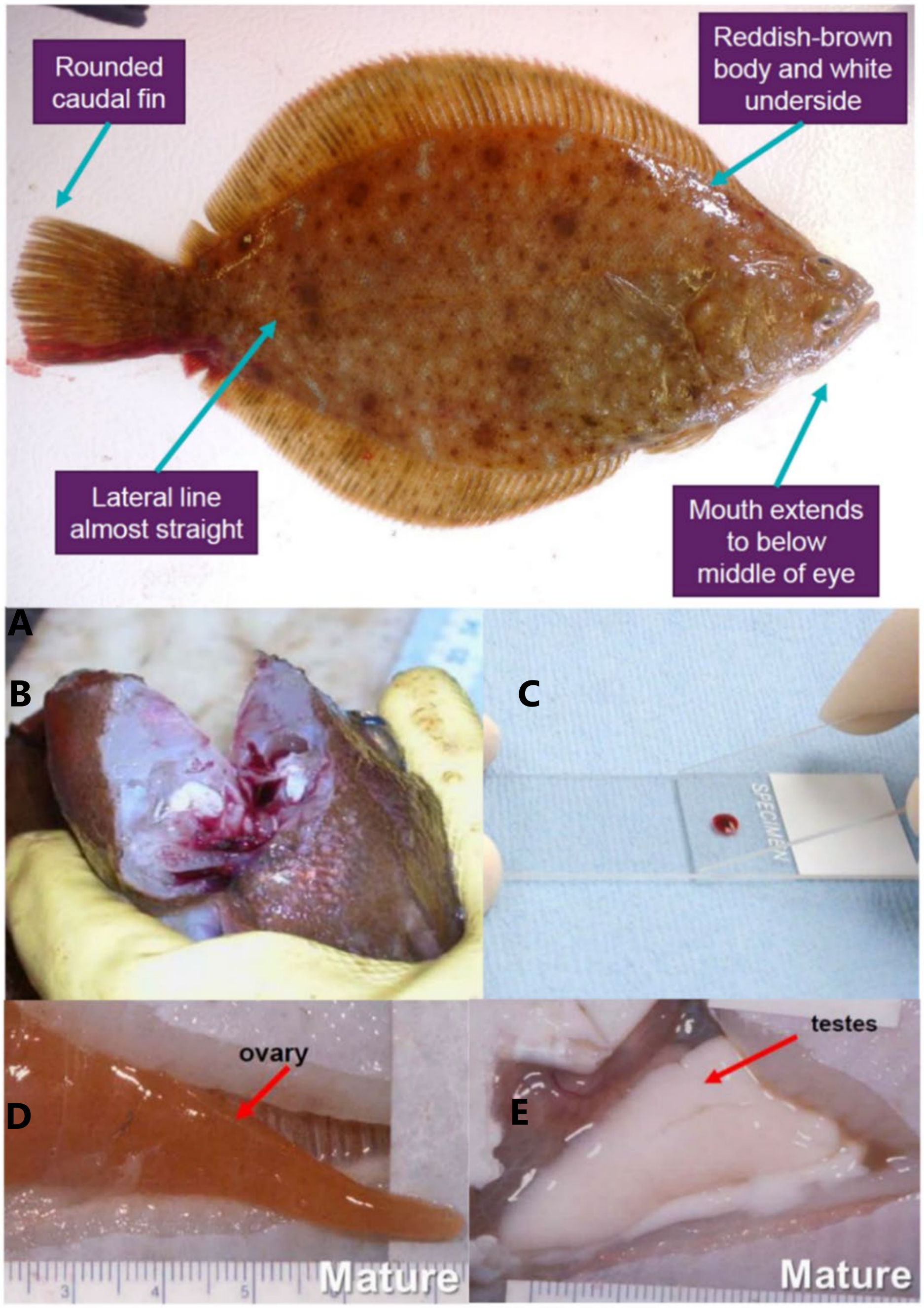


Figure 6-2 **Examples of field sampling measures taken aboard the FRV *Nuliajuk*: A) American plaice with identifying characteristics, B) otoliths being extracted, C) creating a blood smear, D) mature female ovary, and E) mature male testes.**

6.1.3 Laboratory and Statistical Analysis

Chemical Profiling

All fillet and composite liver samples were analysed for metals, fuel and lube range hydrocarbons ($>C_{10}$-C_{32}), and PAHs (EMCP 2017). Tissue and liver samples were composites of at least 10 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 analysis if 50 percent or more of tested samples exceeded their reported detection limit (RDL) at one or more stations. One-way ANOVAs were used to compare between the Hebron platform and Reference Area in 2019, and two-way ANOVAs were used to compare across years and stations. 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):

- For descriptive summaries, 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 (EMCP 2017).
- For statistical analysis, Half RDL was used as a conservative value (EMCP 2017).

Table 6.2 Analytes tested in American plaice fillets and liver composites in 2019.

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

Taste Testing

Chemical analysis of American plaice tissues that are sampled for the EEM program may not necessarily detect an overall difference in sensory perception of the sampled tissues. Therefore, sensory evaluations are typically performed using two qualitative assays; the triangle test and the Hedonic Scaling test (EMCP 2017). However, due to laboratory closures from the COVID-19 pandemic, taste testing was postponed until it could be carried out safely. However, the cold storage for the fish fillets malfunctioned prior to tests being carried out and samples were no longer usable for sensory analysis. As such, no taste panel results will be included for the 2019 EEM program.

Fish Health Program

The Hebron fish health survey was conducted to qualitatively assess American plaice collected adjacent to the Hebron Platform and the Reference Area (Figure 6-1). Tissues were subsampled and used as health indicators as indicated in Section 5.3 of the Design Plan (EMCP 2017). 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.

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 including potential project effects. Monitoring these characteristics over time near the Hebron Platform and at the Reference Area allows for monitoring potential effects. Sexual maturity stage was assessed for males and females according to standard DFO 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 the size of the fish 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 Hebron Platform and Reference Area using one-way ANOVAs and across years and stations with two-way ANOVAs.

Gross Pathology

Body condition of fish, such as parasite load or poor condition of various organs, can be the result of long-term stressors. Gross pathology of specimens was documented using a fish autopsy-based condition assessment adapted from Goede and Barton (1990) for field codes and Adams et al. (1993) for assignment of a health assessment index value (Volume II). Three health assessment indexes were 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 and not project effects). 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. Only qualitative assessments of gross pathology were conducted in 2015, therefore, only comparisons between 2018 and 2019 are possible. Fisher's t-test was used to compare each pathology between the Hebron platform and Reference Area, and one-way ANOVAs were used to compare the health assessment indices.

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) (EMCP 2017). Results from the Reference Area in 2015 were not available. Comparisons between stations in 2019 were done using one-way ANOVAs, and across years and stations (with only the Hebron platform in 2015) used two-way ANOVAs.

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), is measured via spectrophotometry (Hodson et al. 1991, Brooks et al. 2015; EMCP 2017). 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 stations in 2019, and two-way ANOVAs to compare across years and stations.

Histopathology

Chronic exposure of fish to crude oils is known to produce histopathological changes (reviewed by Khan 1990; see 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, microscopic 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 (EMCP 2017). 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 2019, while one-way ANOVAs were used to compare gill histopathologies. Cross-year comparisons were done 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 five trawls conducted at the Hebron Platform and six conducted at the Reference Area in 2019 (Figure 6-1). Trawl catches from the Hebron Platform 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 stations was sand lance (*Ammodytes dubius*; n=9,592 and 2,881 at the Hebron Platform and Reference Area, respectively), followed by American plaice (*Hippoglossoides platessoides*; n=465 and 382, respectively), followed by capelin (*Mallotus villosus*, n=229) at the reference area and mailed sculpin (*Triglops* sp., n=76) at the Hebron Platform (Table 6.3). Non-fish species were observed at lower densities, with northern shrimp (*Pandalus borealis*; n=76 and 217, respectively) being the most common. 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 70 American plaice collected from each survey location in 2019 (Figure 6-5). Male and female American plaice retained from both stations were comparable in size, though male fish tended to be larger at the Reference Area (Figure 6-5). For female fish, the greater proportion of larger fish were collected at the Hebron Platform, though the largest fish collected was a female at the Reference Area (Figure 6-5).

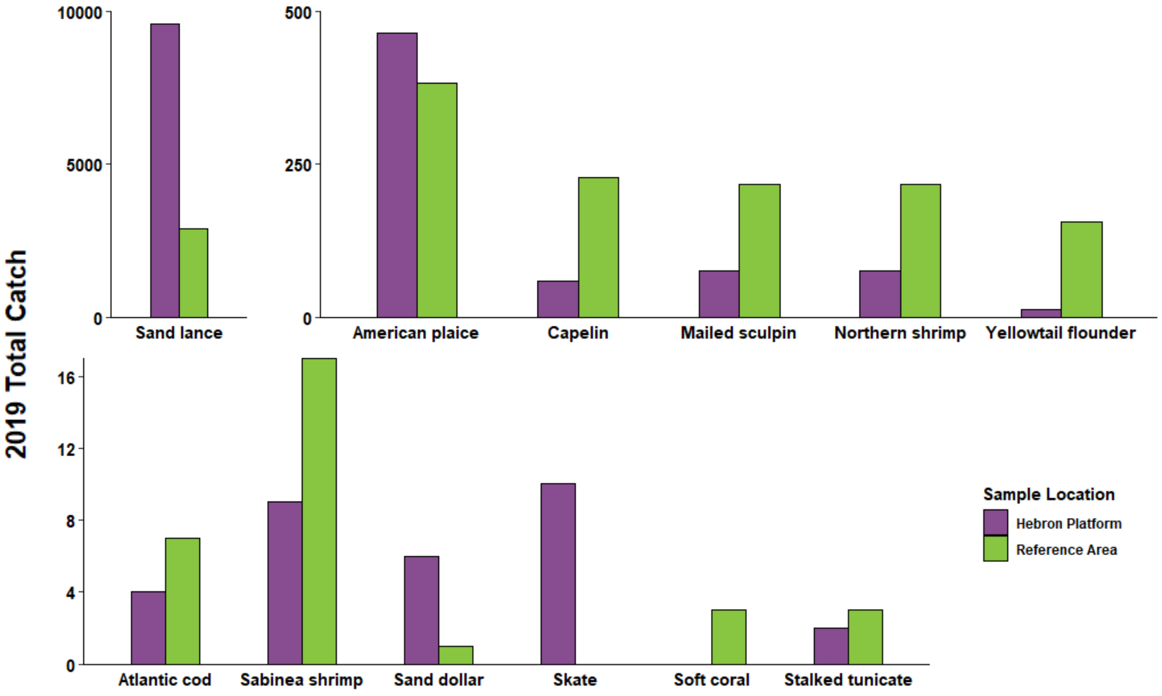


Figure 6-3 Catch at Hebron Platform and Reference Area during the 2019 EEM. Species with two or fewer individuals are not included here, see Table 6-3 for all fauna species caught.

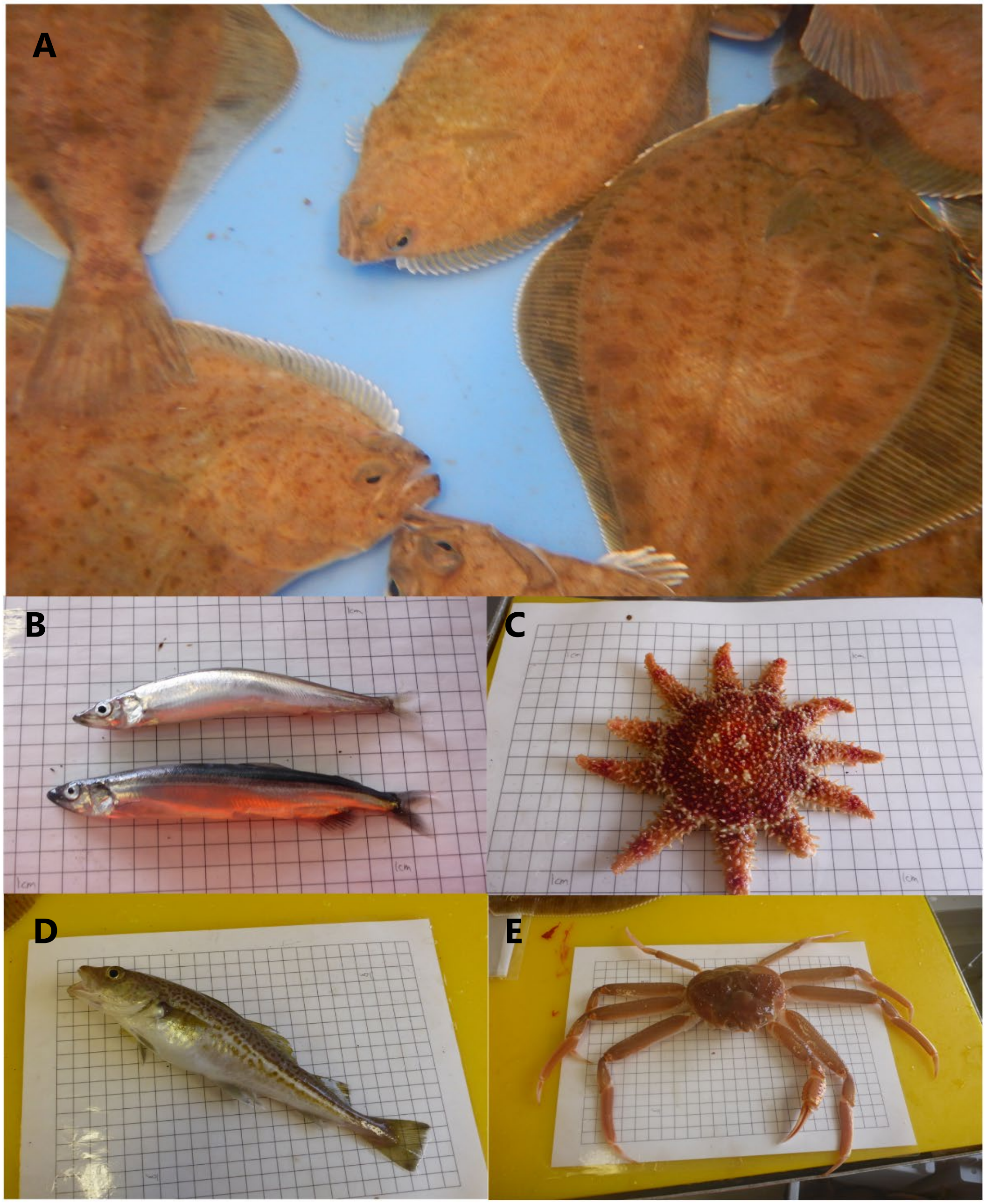


Figure 6-4 **Representative catch species from the Hebron 2019 EEM program: A) American plaice, B) capelin, C) spiny sunstar, D) Atlantic cod, and E) snow crab. See Table 7.1 for scientific names.**

Table 6.3 Total catch per species and catch per unit effort (number per trawl) around the Hebron Platform and Reference Area, 2019.

Faunal Group	Species Name	Scientific Name	Hebron Platform		Reference Area	
			Total Catch	CPUE (n=5)	Total Catch	CPUE (n=6)
Fish	Alligatorfish (NS)	*Aspidophoroides* sp.	0	0	1	0.17
Fish	American plaice	*Hippoglossoides platessoides*	465	93	382	63.7
Fish	Atlantic cod	*Gadus morhua*	4	0.8	7	1.17
Fish	Atlantic herring	*Clupea harengus*	0	0	2	0.33
Fish	Capelin	*Mallotus villosus*	58	11.6	229	38.2
Fish	Eelpout (NS)	Zoarcidae (F)	1	0.2	0	0
Fish	Greenland halibut	*Reinhardtius hippoglossoides*	1	0.2	0	0
Fish	Mailed sculpin	*Triglops* sp.	76	15.2	18	3
Fish	Sand lance	*Ammodytes dubius*	9,592	1,918	2,881	480.2
Fish	Sculpin (NS)	Cottidae (F)	0	0	1	0.17
Fish	Skate (NS)	Rajidae (F)	10	2	0	0
Fish	Snailfish	Liparidae (F)	1	0.2	0	0
Fish	Yellowtail flounder	*Pleuronectes ferruginea*	13	2.6	155	25.8
Annelid	Sea mouse	Aphroditidae (F)	0	0	1	0.17
Ascidian	Stalked tunicate	*Boltenia ovifera*	2	0.4	3	0.5
Cnidarian	Hydroid	Hydrozoa (C)	1	0.2	0	0
Cnidarian	Sea anemone	Actiniaria (O)	1	0.2	0	0
Cnidarian	Soft coral	Nephtheidae (F)	0	0	3	0.5
Crustacean	Barnacle	Cirripedia (IC)	0	0	1	0.17
Crustacean	Crab (NS)	Brachyura (IO)	1	0.2	0	0
Crustacean	Northern shrimp	*Pandalus borealis*	76	15.2	217	36.2
Crustacean	Sculptured shrimp	*Sabinea* sp.	9	1.8	17	2.83
Crustacean	Snow crab	*Chionoecetes opilio*	1	0.2	0	0
Echinoderm	Green sea urchin	*Strongylocentrotus droebachiensis*	0	0	2	0.33
Echinoderm	Sand dollar	*Echinarachnius parma*	6	1.2	1	0.17
Echinoderm	Spiny sunstar	*Crossaster papposus*	0	0	1	0.17
-	Unknown	-	1	0.2	0	0
Taxonomic Groups: 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)
Hebron Platform	HEB-01	10	10	10	961
	HEB-05	16	16	16	1,362
	HEB-06	18	18	18	1,612
	HEB-09	15	15	15	1,558
	HEB-14	11	11	11	881
	Total	**70**	**70**	**70**	**6,374**
Reference Area	RAB-05	16	16	16	1,326
	RAB-06	14	14	14	1,158
	RAB-09	9	9	9	663
	RAB-11	12	12	12	985
	RAB-12	15	15	15	1,344
	RAB-14	4	4	4	244
	Total	**70**	**70**	**70**	**5,720**

Table 6.5 Start and end coordinates for each trawl for the Hebron Platform Commercial Fish Sampling Program (UTM Coordinates, NAD83, Zone 22), 2019.

Trawl ID	Depth (m)	Station Type	Start		End	
			Easting	Northing	Easting	Northing
HEB-01	93.4	Hebron Platform	689833	5157331	690627	5156178
HEB-05	94.5	Hebron Platform	691857	5155569	693140	5156130
HEB-06	93.9	Hebron Platform	693232	5156884	692311	5155830
HEB-09	93.6	Hebron Platform	691869	5156183	692862	5157170
HEB-14	93.0	Hebron Platform	693140	5156154	693775	5157402
RAB-05	78.0	Hebron Reference Area	636746	5214547	635407	5214955
RAB-06	78.0	Hebron Reference Area	635090	5214481	636236	5213677
RAB-09	81.4	Hebron Reference Area	633295	5214992	634602	5215494
RAB-11	84.3	Hebron Reference Area	632372	5216522	633726	5216165
RAB-12	84.6	Hebron Reference Area	633981	5216328	633217	5217502
RAB-14	83.0	Hebron Reference Area	634944	5217303	634743	5218688

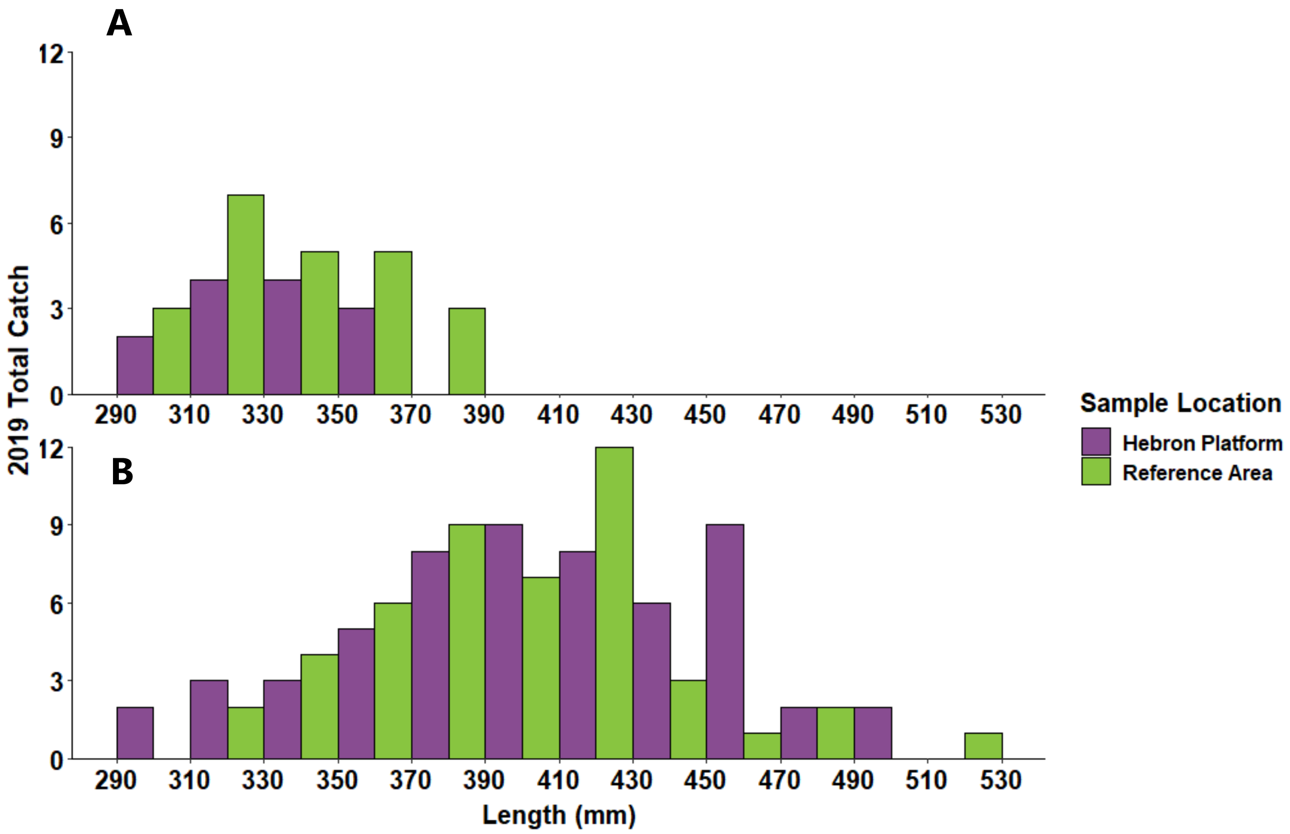


Figure 6-5 Length-frequency of male (A) and female (B) American plaice collected from the Hebron Platform and Reference Area in 2019.

Across-year Comparison

Two-way ANOVA comparison of CPUE results from 2015 to 2019 across both the Hebron Platform and Reference Area for all species showed no significant difference for either station, year, or their interaction (Table 6.6, Figure 6-6). CPUE at the Hebron Platform in 2019 was higher than all other years or stations due to a large catch of sand lance, but the large standard deviation caused no significant difference (Table 6.6). Significant differences existed for station, year, and their interaction for American plaice, indicating a potential project effect (Table 6.6). CPUE for American plaice across years is shown in Figure 6-6, with Hebron Platform having higher CPUE in 2018 and 2019, but not in 2015.

Table 6.6 Two-way ANOVAs of average CPUE of all species and American plaice collected from Hebron Platform and Reference Area from 2015 to 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
All Species					
Station	1	14312	14312	0.3626	0.548
Year	2	26492	13246	0.3356	0.716
Station*Year	2	21957	10979	0.2782	0.758
Residuals	102	4025686	39468		
American Plaice					
Station	1	3487	3487	10.424	**0.003**
Year	2	6647	3324	9.934	**<0.001**
Station*Year	2	2477	1238	3.702	**0.037**
Residuals	30	10036	335		
Notes: Bolded p-value denotes a significant result (α=0.05)					

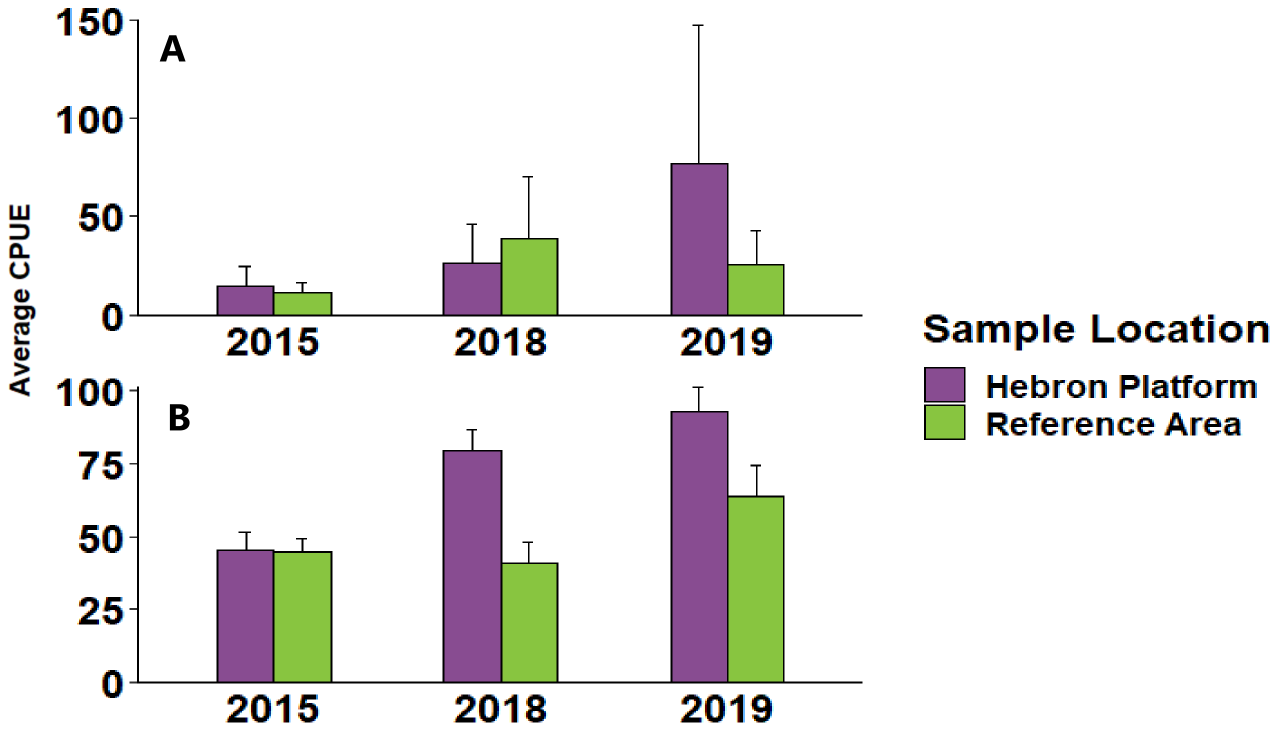


Figure 6-6 CPUE of A) all species, and B) American plaice collected from the Hebron Platform and Reference Area from 2015 to 2019.

6.2.2 Chemical Profiles of American Plaice Tissue

Five sets of composite tissue and liver samples were collected from American plaice from each of the two areas (Hebron Platform 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 Hebron Platform 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 five samples (Table 6.7). No other metals were above their RDLs. 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 Hebron Platform and Reference Area for arsenic (p=0.88), mercury (p=0.87), or zinc (p=0.51) (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 five samples (Table 6.8). Two samples from the Reference Area (0.18 mg/kg and 0.14 mg/kg) and two from the Hebron Platform (0.15 mg/kg and 0.18 mg/kg) contained silver above RDL, and one sample from the Reference Area contained vanadium above RDL (0.67 mg/kg). Hydrocarbons from the $>C_{16}$-C_{21} and $>C_{21}$-C_{32} ranges were detected in both the Platform and the Reference Area for all five livers tested (Table 6.8). Hydrocarbons from the $>C_{10}$-C_{16} were detected in all five samples from the Platform area and only in three samples from the Reference Area (Table 6.8). No PAHs were detected above RDL in any sample (Table 6.8). One-way ANOVAs found no significant difference between the Hebron Platform and Reference Area for arsenic, cadmium, iron, manganese, mercury, selenium, or zinc (Table 6.8). Copper was found to differ between the two stations (p=0.014) and was higher at the Reference Area (Table 6.8). Hydrocarbons in all three ranges did not significantly differ between stations (Table 6.8).

Table 6.7 Summary statistics of 2019 Hebron Platform 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**
Hebron Platform Fillet composites (n=5)								**Reference Area Fillet composites (n=5)**						
Metals								**Metals**						
Arsenic	0.50	5	3.74	0.27	3.6	3.5	4.2	5	3.82	0.99	3.5	2.9	5.6	0.880
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	5	0.086	0.012	0.093	0.066	0.100	5	0.084	0.021	0.073	0.060	0.110	0.874
Selenium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Zinc	1.5	5	3.92	0.34	3.9	3.5	4.4	5	4.08	0.31	4.0	3.7	4.6	0.506
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 2019 Hebron Platform 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		**Hebron Platform Liver (n=5)**						**Reference Area Liver (n=5)**						
Arsenic	0.50	5	5.56	0.70	5.9	4.3	6.2	5	7.62	2.24	6.6	5.3	11.0	0.117
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	5	0.88	0.08	0.90	0.76	0.99	5	1.13	0.22	0.96	0.93	1.40	0.066
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	5	4.96	2.53	4.6	4.3	6.3	5	6.76	0.86	6.4	6.1	8.4	**0.014**
Iron	15	5	49	2.5	50	46	52	5	65	17.4	57	53	99	0.114
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	5	0.96	0.08	0.95	0.87	1.10	5	0.93	0.05	0.93	0.86	1.00	0.571
Mercury	0.01	5	0.043	0.013	0.049	0.023	0.056	5	0.038	0.013	0.039	0.017	0.059	0.633
Selenium	0.50	5	2.26	0.22	2.3	1.9	2.6	5	2.42	0.19	2.3	2.2	2.7	0.312
Zinc	1.5	5	32.4	1.85	32	30	35	5	36.2	3.19	34	33	41	0.073
Hydrocarbons								**Hydrocarbons**						
$>C_{10}-C_{16}$	15	5	26.2	10.4	20	18	46	3	25.6	11.0	26	<RDL	45	0.691
$>C_{16}-C_{21}$	15	5	75.2	18.2	68	58	110	5	67.2	18.8	64	43	100	0.558
$>C_{21}-C_{32}$	15	5	224	74.2	190	170	370	5	198	69.7	200	130	320	0.623
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

Across-Year Comparison of the Hebron Platform and Reference Area Tissue Data

Tissues collected in 2015 (baseline) consisted of 10 fillets from individual fish, while 2018 and 2019 data consisted of five composite fillets from multiple individuals. However, comparisons of metal and hydrocarbon loading in these two sample types (i.e., composite verses individual fish) is still possible. Consistent with the sediment chemistry analysis methodology, remaining analytes having values below RDL in more than half of all samples tested were not subject to analysis though values are mentioned in the text below.

Metals in Hebron Platform and Reference Area Fillets

Consistent with 2015 and 2018 results, arsenic, mercury, and zinc were detected in all American Plaice fillets from both the Hebron Platform and Reference Area in 2019 (Table 6.7). No other metals, hydrocarbons, or PAHs were detected in fillet samples. Results from previous years have had sporadic samples above their RDL for aluminum, selenium, and strontium, though none were observed in 2019. The concentration of arsenic, mercury, and zinc in fish tissue from all EEM years is presented in Figure 6-7.

Separate two-way ANOVA results for arsenic, mercury, and zinc are given in Table 6.9. No significant results for station, year, or station-year interaction were found for arsenic and mercury ($\alpha=0.05$). For zinc, station and the interaction between station and year were not significant ($p=0.57$ and $p=0.65$, respectively). However, zinc was significantly different among monitoring years ($p=0.02$). Figure 6-7C shows zinc concentrations were lowest in 2018 and highest in 2015, with 2019 generally between the two.

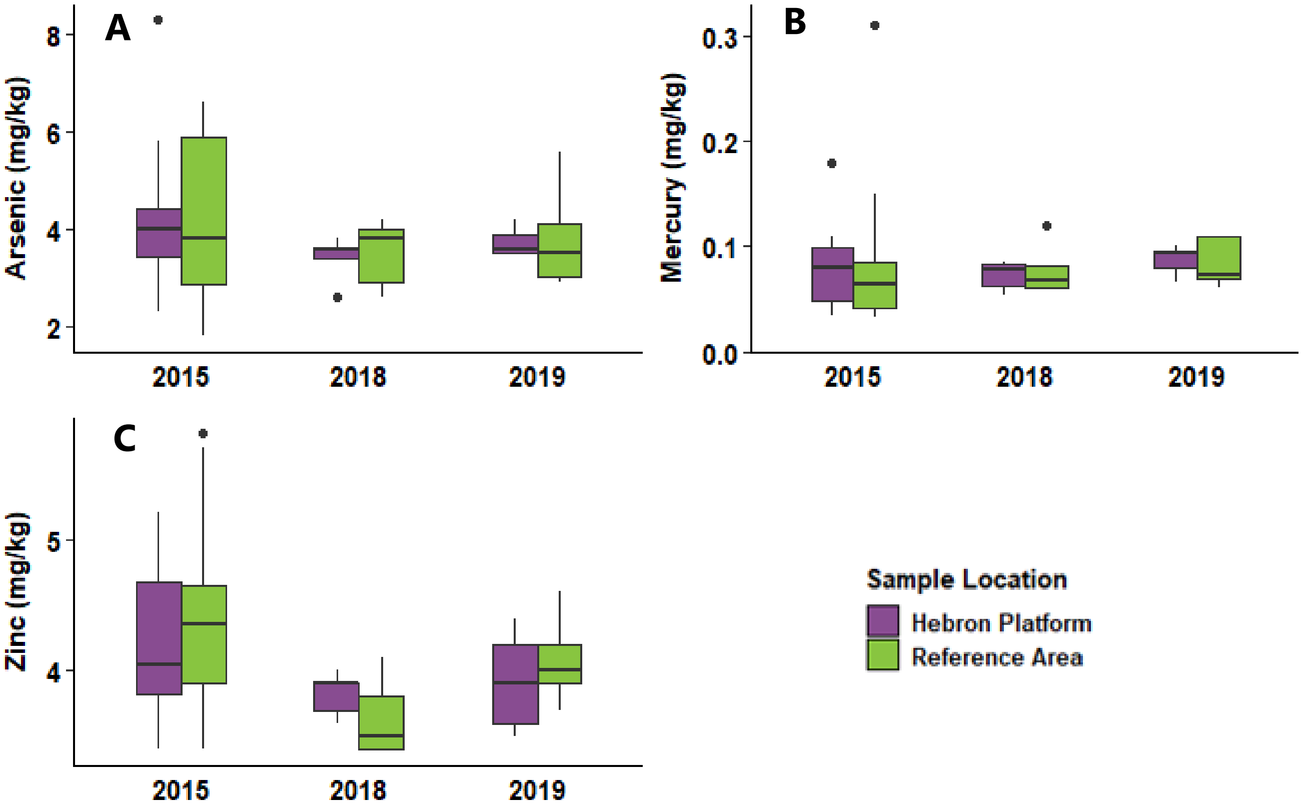


Figure 6-7 **Boxplots of arsenic (A), mercury (B), and zinc (C) in American Plaice fillet tissue from the Hebron Platform and Reference Area from 2015-2019.**

Table 6.9 Two-way ANOVAs for arsenic, mercury, and zinc concentration in fillet tissue from American Plaice collected from Hebron Platform and Reference Area in 2015, 2018, and 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Station	1	0.016	0.016	0.009	0.926
Year	2	4.769	2.385	1.290	0.288
Station *Year	2	0.025	0.013	0.007	0.993
Residuals	34	62.845	1.848		
Mercury					
Station	1	2.6e-4	2.6e-4	0.102	0.752
Year	2	9.6e-4	4.8e-4	0.187	0.830
Station *Year	2	1.9e-4	9.4e-5	0.037	0.964
Residuals	34	8.7e-2	2.6e-3		
Zinc					
Station	1	0.100	0.100	0.327	0.571
Year	2	2.669	1.334	4.368	**0.020**
Station *Year	2	0.266	0.133	0.435	0.651
Residuals	34	10.385	0.305		
Notes: Bolded p-value denotes a significant result (α=0.05)					

Metals in Hebron Platform and Reference Area Livers

Consistent with the 2015 and 2018 results, arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in all liver composites for the Hebron platform and Reference Area in 2019 (Table 6.8). Cobalt, silver, and vanadium have been inconsistently observed in samples from previous years. No samples were above RDL for cobalt in 2019, but two samples from both the Hebron Platform and Reference Area were above their RDL for silver, and one sample from the 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 percent of samples are not above RDL.

Comparisons across years (2015-2019) and across stations (Hebron Platform and Reference Area) for the eight metals listed above with greater than 50 percent of samples above RDL were compared using a two-way ANOVA. No difference between years, stations, or station-year interaction was observed for mercury or zinc (α=0.05; Table 6.10). Arsenic, copper, and selenium were significantly different between years (p=0.008, 0.048, and <0.001, respectively; Table 6.10) with copper and selenium decreasing from 2018 to 2019, and arsenic increasing from 2018 to 2019 (though still lower than 2015) (Figure 6-8). Cadmium and iron were significantly different between stations (p=0.005 and 0.021, respectively; Table 6.10) and both were higher at the Reference Area across years (Figure 6-8). Manganese significantly differed for both station (p=0.002) and year (p=<0.001; Table 6.10) with higher levels in 2018 and 2019 than in 2015, and higher at the Hebron Platform compared to the Reference Area (Figure 6-7).

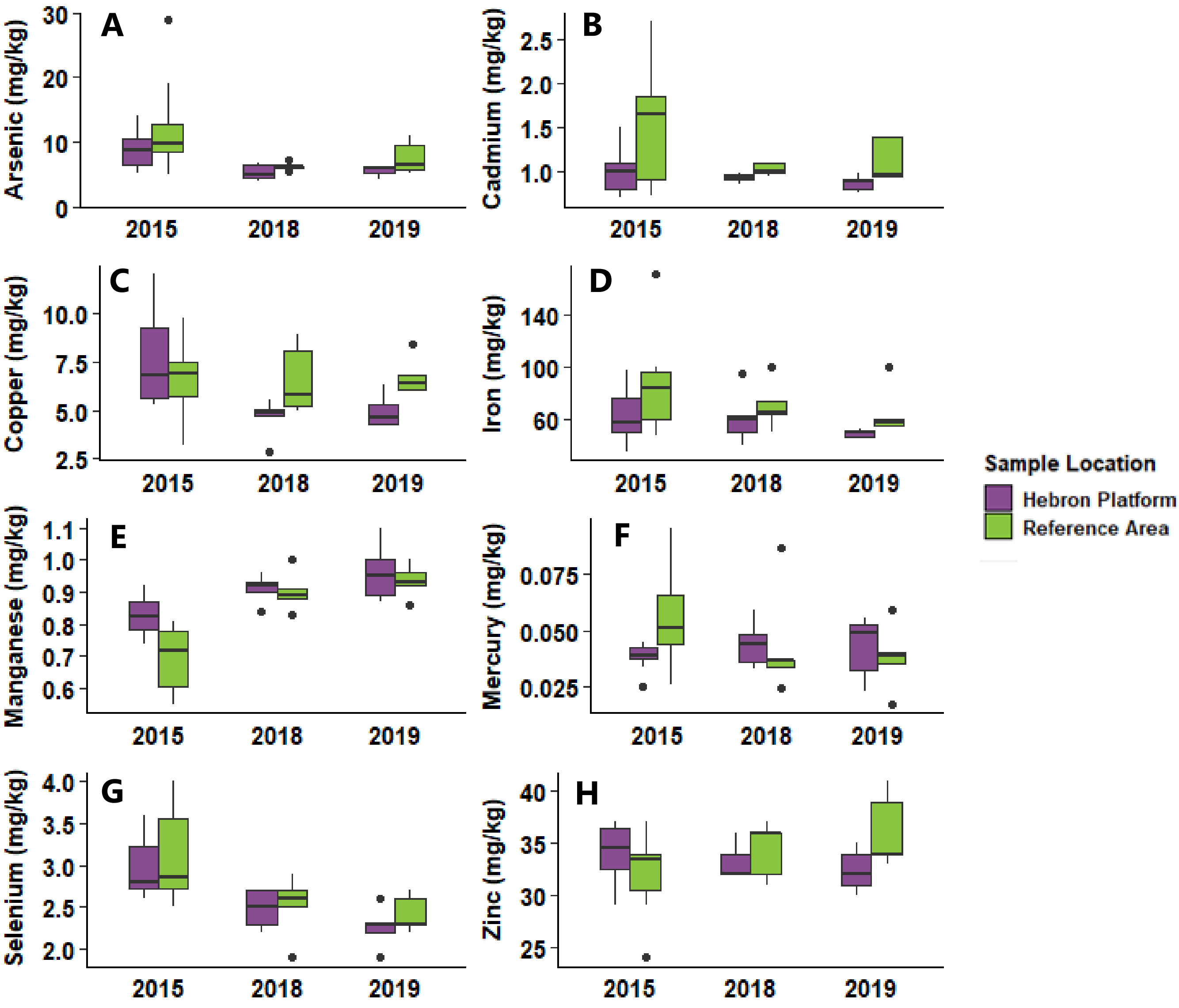


Figure 6-8 Boxplots of arsenic (A), cadmium (B), copper (C), iron (D), manganese (E), mercury (F), selenium (G), and zinc (C) in American Plaice liver composites from the Hebron Platform and Reference Area.

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 Hebron Platform and Reference Area in 2015, 2018, 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Station	1	57.4	57.4	3.451	0.072
Year	2	184.9	92.5	5.563	**0.008**
Station *Year	2	8.7	4.3	0.261	0.772
Residuals	34	565.2	16.6		
Cadmium					
Station	1	1.156	1.156	8.799	**0.005**
Year	2	0.684	0.342	2.604	0.089
Station *Year	2	0.297	0.149	1.134	0.334
Residuals	34	4.467	0.131		
Copper					
Station	1	2.50	2.50	0.779	0.384
Year	2	21.31	10.66	3.322	**0.048**
Station *Year	2	19.078	9.54	2.974	0.065
Residuals	34	109.06	3.21		
Iron					
Station	1	3367	3367	5.838	**0.021**
Year	2	1815	908	1.574	0.222
Station *Year	2	436	218	0.378	0.688
Residuals	34	19609	577		
Manganese					
Station	1	0.057	0.057	11.00	**0.002**
Year	2	0.286	0.143	27.61	**<0.001**
Station *Year	2	0.034	0.017	3.24	0.052
Residuals	34	0.176	0.005		
Mercury					
Station	1	6.16e-4	6.16e-4	2.133	0.153
Year	2	3.62e-4	1.81e-4	0.626	0.541
Station *Year	2	1.07e-3	5.37e-4	1.860	0.171
Residuals	34	9.82e-3	2.89e-4		
Selenium					
Station	1	0.156	0.156	1.051	0.312
Year	2	4.034	2.017	13.573	**<0.001**
Station *Year	2	0.024	0.012	0.082	0.922
Residuals	34	5.053	0.149		
Zinc					

Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
Station	1	1.225	1.225	0.136	0.715
Year	2	8.475	4.238	0.469	0.629
Station*Year	2	54.675	27.338	3.028	0.062
Residuals	34	307	9.029		
Notes: Bolded p-value denotes a significant result (α=0.05)					

Hydrocarbons in Hebron Platform and Reference Area Tissues

No hydrocarbons were detected in fillets taken from the Hebron Platform or Reference Area in 2019 (Table 6.7). However, nearly all liver composites from both stations contained hydrocarbons in the >C_{10}-C_{16}, >C_{16}-C_{21} and >C_{21}-C_{32} range (only 3 of 5 samples in the >C_{10}-C_{16} range were above RDL at the Reference Area; Table 6.8). Hydrocarbons in all three ranges did not differ between the Hebron Platform and Reference Area in 2019 (Table 6.8). All composites at both stations also contained unidentified compounds in the fuel/lube range (see Bureau Veritas report in Volume II).

In 2015 and 2018, hydrocarbons in the >C_{16}-C_{21} and >C_{21}-C_{32} ranges were also all above RDL and screened in for analysis (EMCP 2016b, EMCP 2019). However, >C_{10}-C_{16} hydrocarbons have not been screened in any previous EEM year though two samples in 2015 at the Reference Area were above RDL. Comparisons across stations and years is presented in Figure 6-9. Hydrocarbons in all three ranges significantly differed between years (Table 6.11), with >C_{10}-C_{16} and >C_{16}-C_{21} hydrocarbon concentrations higher in 2019 than either 2015 or 2018, and >C_{21}-C_{32} concentrations higher in 2019 compared to 2018, though values were similar to 2015 (Figure 6-9). As hydrocarbons within fish tissues at both stations are higher in 2019, this does not appear to be a project related effect (no significant interaction term).

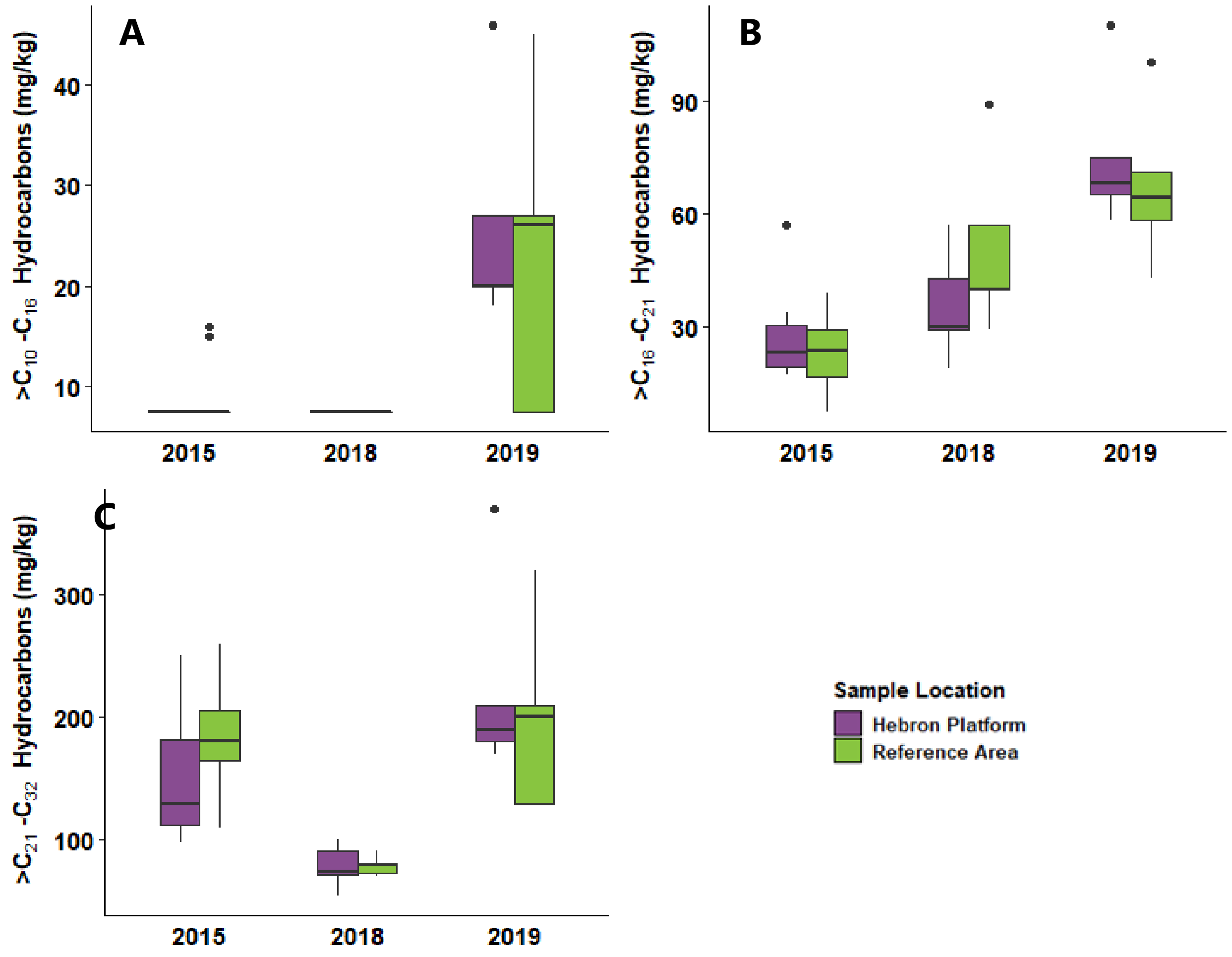


Figure 6-9 **Boxplots of (A) >C_{10}-C_{16} hydrocarbons, (B) >C_{16}-C_{21} hydrocarbons, and (C) >C_{21}-C_{32} hydrocarbons in American plaice liver composites from the Hebron Platform and Reference Area from 2015 to 2019.**

Table 6.11 Two-way ANOVAs for >C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32} hydrocarbon concentrations in liver composites from American Plaice collected from Hebron Platform and Reference Area, 2015 to 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
>C_{10}-C_{16} Hydrocarbons					
Station	1	0.1	0.10	0.002	0.964
Year	2	2013.0	1006.64	21.018	**<0.001**
Station *Year	2	45.1	22.55	0.471	0.629
Residuals	34	1628.4	47.89		
>C_{16}-C_{21} Hydrocarbons					
Station	1	0.9	0.9	0.004	0.953
Year	2	14519.7	7259.8	28.299	**<0.001**
Station *Year	2	844.4	422.2	1.646	0.208
Residuals	34	8722.4	256.5		
>C_{21}-C_{32} Hydrocarbons					
Station	1	1051	1051	0.392	0.536
Year	2	91739	45870	17.110	**<0.001**
Station *Year	2	6151	3076	1.147	0.330
Residuals	34	91149	2681		
Notes: Bolded p-value denotes a significant result (α=0.05).					

PAHs in Hebron Platform Tissues

No PAHs were detected in both fillet and liver samples from either the Hebron Platform or the Reference Area in 2019 (Table 6.7). In 2018, two compounds in liver composites were detected above their RDLs and screened in: acenaphthylene and fluorene. Some detections for fluorene were observed in 2015, through co-matrix interference has often resulted in an elevated RDL for fluorene. No co-matrix interference was noted in 2019.

Taste Panels

Due to laboratory closures from the COVID-19 pandemic, taste testing was postponed until it could be carried out safely. However, the cold storage for the fish fillets malfunctioned prior to tests being carried out and samples were no longer usable for sensory analysis. As such, no taste panel results will be included for the 2019 EEM program.

6.2.3 Fish Health Program

Maturity Stages

Sexual maturity stages and the frequency (percentage) of fish presenting in each category at both locations is presented in Table 6.12. During the 2019 EEM program, 13 males and 57 females were collected at the Hebron Platform, and 23 males and 47 females at the Reference Area. Fisher's exact test showed no difference in the ratio of male to female fish between stations (p=0.08). No difference was found between maturity stage frequency for males or females between stations, with the exception of codes Maturing A-P (520) and Maturing C-P (540) being significantly higher at the Reference Area (p=0.03 and <0.01, respectively) (Table 6.12).

Table 6.12 Frequencies (%) of maturity stages of male (top) and female (bottom) American plaice from the 2019 Hebron Platform 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)**
Hebron Platform	13	15	0	8	77	0	0	0
Reference Area	23	9	0	26	65	0	0	0
p-value		0.61	1.00	0.38	0.71	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)**
Hebron Platform	57	26	28	5	2	0	11	26	0	4
Reference Area	47	15	28	19	9	15	0	15	0	0
p-value		0.23	1.00	**0.03**	0.17	**<0.01**	0.06	0.23	1.00	0.50

Notes:
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)

Biological Characteristics

2019 Results

Some significant variations between stations existed for male and female American plaice sampled (Table 6.13). Male fish differed in liver weight (p=0.026) and hepatosomatic index (p=0.001). Female fish differed in liver weight (p=0.023), age (p=0.010), hepatosomatic index (p=0.002) and gonadosomatic index (p=0.001). 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 for by using analysis of co-variance (ANCOVA) of the regression of the variable of interest on its covariate, compared between stations. Male fish were found to still differ in liver weight when covaried on gutted weight, and female fish still differed in liver weight, and differed in gonad weight when covaried on gutted weight (Table 6.14).

Table 6.13 Averages and standard deviations of biological characteristics and condition indices of male (top) and female (bottom) American plaice from the Hebron platform and Reference Area in 2019.

Parameter	Hebron Platform	Reference Area	p-value
Male			
No. of Fish	13	23	
Length (cm)	332.0 ± 19.7	336.7± 23.4	0.553
Total Body Weight (g)	328.2 ± 62.4	316.0 ± 68.9	0.612
Gutted Body Weight (g)	280.8 ± 60.9	280.5 ± 59.5	0.989
Liver Weight (g)	5.20 ± 1.3	4.13 ± 1.3	**0.026**
Gonad Weight (g)	5.30 ± 2.8	5.43 ± 2.6	0.888
Age (years) [a]	9.4 ± 2.2	8.6 ± 2.0	0.211
Fulton's Condition Index [b]	0.75 ± 0.06	0.73 ± 0.06	0.161
Hepatosomatic Index [c]	1.85 ± 0.23	1.47 ± 0.32	**0.001**
Gonadosomatic Index [d]	1.90 ± 0.90	1.89 ± 0.75	0.990
Female			
No. of Fish	57	47	
Length (cm)	405.5 ± 47.9	395.7 ± 41.1	0.276
Total Body Weight (g)	629.7 ± 246.6	553.5 ± 195.0	0.092
Gutted Body Weight (g)	513.3 ± 189.8	457.7 ± 171.9	0.130
Liver Weight (g)	10.4 ± 4.9	8.11 ± 4.9	**0.023**
Gonad Weight (g)	24.92 ± 37.4	35.09 ± 31.3	0.145
Age (years) [e]	9.7 ± 1.8	10.1 ± 2.3	**0.010**
Fulton's Condition Index [b]	0.73 ± 0.06	0.71 ± 0.07	0.059
Hepatosomatic Index [c]	1.96 ± 0.39	1.67 ± 0.51	**0.002**
Gonadosomatic Index [d]	4.20 ± 4.25	8.42 ± 8.30	**0.001**

Notes: All data are expressed as average values ± standard deviation.

[a] For male age calculations, n=11 for the Hebron Platform and n=15 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=39 for the Hebron Platform and n=35 for the Reference Area.

* Bolded p-value denotes significant results (α=0.05).

Table 6.14 Adjusted p-values from ANCOVA analysis of gutted, liver, and gonad weight for male (top) and female (bottom) American plaice from the Hebron Platform and Reference Area in 2019.

Variable	Covariate	Adjusted p-value [a]
Male		
Gutted weight (g)	Length (mm)	0.095
Liver Weight (g)	Gutted weight (g)	**0.001**
Gonad weight (g)	Gutted weight (g)	0.861
Female		
Gutted weight (g)	Length (mm)	0.117
Liver Weight (g)	Gutted weight (g)	**0.024**
Gonad weight (g)	Gutted weight (g)	**0.036**

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 6.15). Significant results include male HSI being higher at the Hebron Platform compared to the Reference Area, and male GSI higher in 2019 compared to 2015 (Table 6.15, Figure 6-10). Female plaice had significant interaction terms for both HSI and GSI, indicating potential project related effects (Table 6.15, Figure 6-11).

Table 6.15 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 Hebron platform and Reference Area from 2015 to 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
MALE					
Fulton's Condition Index					
Station	1	0.0027	0.0027	0.3922	0.532
Year	2	0.0328	0.0164	2.3573	0.099
Station *Year	2	0.0077	0.0039	0.5532	0.576
Residuals	137	0.9537	0.0070		
Hepatosomatic Index					
Station	1	2.136	2.136	15.517	**<0.001**
Year	2	0.255	0.128	0.926	0.398
Station *Year	2	0.294	0.147	1.067	0.347
Residuals	137	18.857	0.138		
Gonadosomatic Index					
Station	1	0.038	0.038	0.062	0.803
Year	2	8.266	4.133	6.722	**0.002**
Station *Year	2	0.026	0.013	0.021	0.979
Residuals	137	84.226	0.615		
FEMALE					
Fulton's Condition Index					
Station	1	0.038	0.038	2.667	0.104
Year	2	0.072	0.036	2.512	0.083
Station *Year	2	0.016	0.008	0.570	0.566
Residuals	268	3.862	0.014		
Hepatosomatic Index					
Station	1	0.695	0.695	2.570	0.110
Year	2	1.490	0.745	2.757	0.065
Station *Year	2	1.867	0.934	3.454	**0.033**
Residuals	268	72.429	0.270		
Gonadosomatic Index					
Station	1	199.3	199.3	6.020	**0.015**
Year	2	61.7	30.8	0.931	0.395
Station *Year	2	245.5	122.7	3.707	**0.026**
Residuals	268	8872.7	33.1		
Notes: Bolded p-value denotes a significant result (α=0.05)					

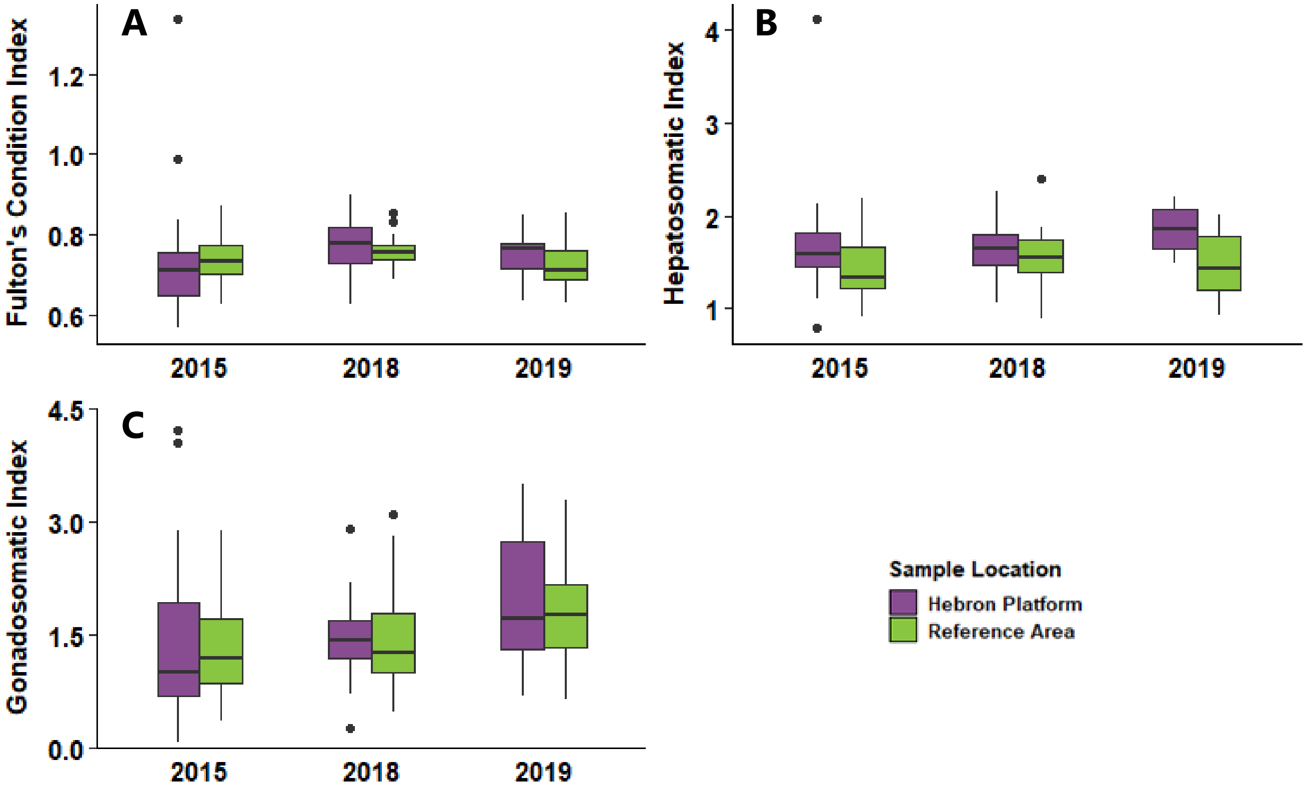


Figure 6-10 **Boxplots of Fulton’s condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for male American plaice sampled from the Hebron Platform and Reference Area from 2015 to 2019.**

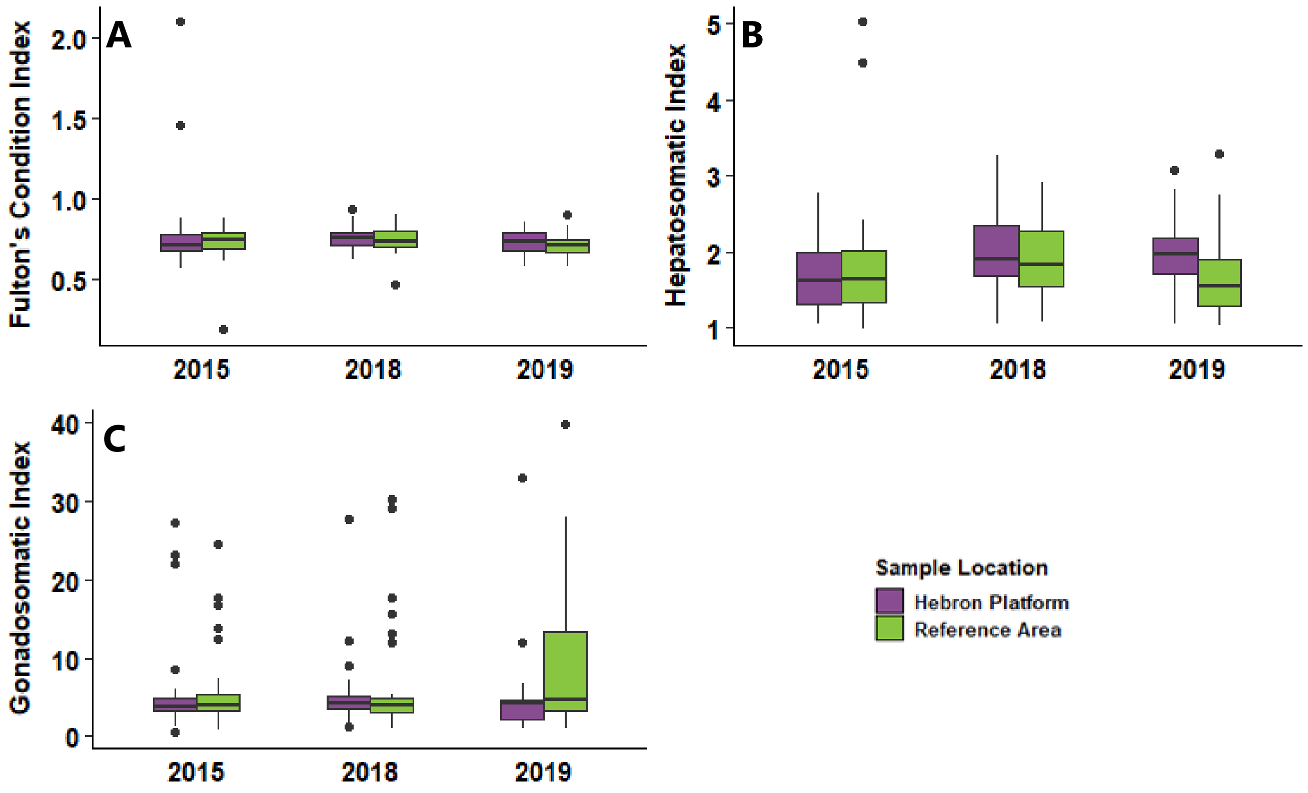


Figure 6-11 Boxplots of Fulton's condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for female American plaice sampled from the Hebron Platform and Reference Area from 2015 to 2019.

Gross Pathology

2019 Results

American plaice retained for fish health examination (≥300 mm) and tissue subsampling appeared overall in good condition at both the Hebron platform and Reference Area. Example pathologies observed during the biological survey are presented in Figure 6-12. Several minor conditions were noted including localized discolouration on the liver (such as bile accumulation in the anterior region of the liver; Figure 6-12A), mild skin and fin abrasion (likely associated with trawl collection; Figure 6-12B), thickening or scaring on gill filaments (not shown), and the presence of parasites in or on specimens (Figure 6-12A). These conditions and their prevalence at both stations are summarized in Table 6.16 for male and female plaice. There were no significant differences among any of the other parameters examined individually for males or females, aside from parasites for female plaice differing between stations (Table 6.16). The totals of fish health conditions were compiled and analyzed as the health assessment index (HAI; Table 6.16). Female plaice differed for both HAI and its first modification, but after parasites are removed (HAI2) it was not significant (Table 6.16). No other significant differences were observed for HAI.

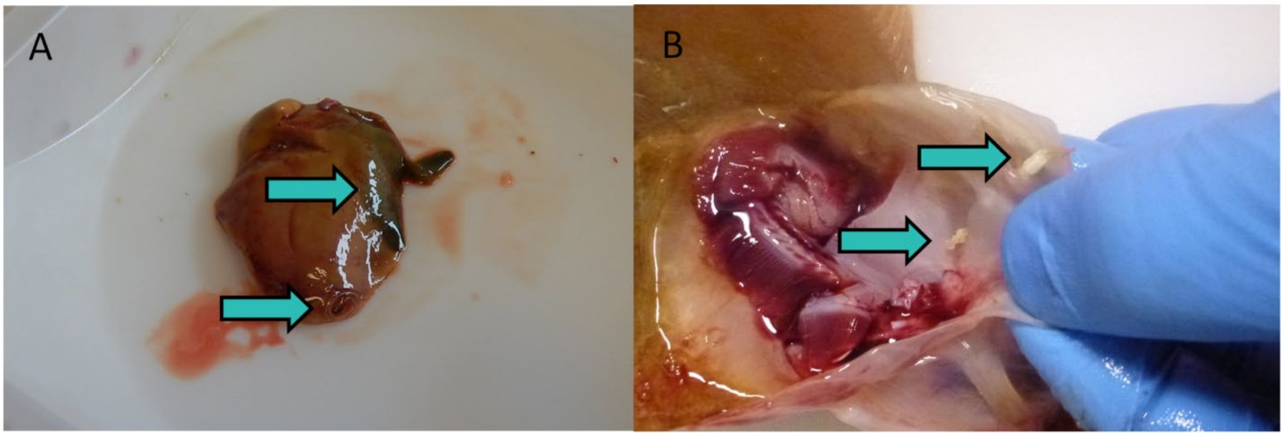


Figure 6-12 Examples of gross pathologies observed among American plaice from the Hebron platform EEM biological survey. A) nematode and green discolouration present on liver, B) parasitic copepod (*Acanthochondria* spp.).

Table 6.16 Pathologies and health assessment index of male (top) and female (bottom) American plaice from the Hebron Platform and Reference Area in 2019.

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Male	**Hebron Platform (n=13)**		**Reference Area (n=23)**			
Fins	1	8	1	4	1.00	Fisher's
Spleen	0	0	0	0	1.00	Fisher's
Hindgut	0	0	1	4	1.00	Fisher's
Kidney	0	0	0	0	1.00	Fisher's
Skin	0	0	1	4	1.00	Fisher's
Liver	7	54	17	74	0.28	Fisher's
Eyes	0	0	0	0	1.00	Fisher's
Gills	0	0	0	0	1.00	Fisher's
Parasites	9	69	16	70	1.00	Fisher's
Male	**Hebron Platform (n=13)**		**Reference Area (n=23)**		**p-value**	**Test used**
HAI	30.0 ± 19.1		36.1 ± 18.0		0.35	ANOVA
Modified.HAI.1	29.2 ± 20.2		35.2 ± 18.3		0.37	ANOVA
Modified.HAI.2	16.2 ± 15.6		22.6 ± 13.9		0.21	ANOVA
Female	**Hebron Platform (n=57)**		**Reference Area (n=47)**		**p-value**	**Test used**
Fins	4	7	0	0	0.12	Fisher's
Spleen	0	0	0	0	1.00	Fisher's
Hindgut	1	2	0	0	1.00	Fisher's
Kidney	0	0	0	0	1.00	Fisher's
Skin	0	0	1	2	1.00	Fisher's
Liver	31	54	25	53	1.00	Fisher's
Eyes	0	0	0	0	1.00	Fisher's
Gills	1	2	0	0	1.00	Fisher's
Parasites	42	74	21	45	**0.01**	Fisher's
Female	**Hebron Platform (n=57)**		**Reference Area (n=47)**		**p-value**	**Test used**
HAI	31.6 ± 17.7		24.0 ± 16.0		**0.03**	ANOVA
Modified.HAI.1	30.9 ± 17.7		23.8 ± 16.2		**0.04**	ANOVA
Modified.HAI.2	17.0 ± 15.2		16.0 ± 15.1		0.72	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 Hebron Platform and Reference Area across 2018 and 2019 (no gross pathology data available for 2015). No significant differences were found for male American plaice, but female fish differed between stations for the HAI and mod. 1, but not mod. 2 (Table 6.17, Figure 6-13, Figure 6-14).

Table 6.17 Two-way ANOVA for male and female American plaice comparing the three HAI modifications (HAI, mod. 1, and mod. 2) at the Hebron Platform and Reference Area for 2018 and 2019.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male American Plaice					
Health Assessment Index (HAI)					
Station	1	89.5	89.5	0.279	0.599
Year	1	1008.9	1008.9	3.141	0.081
Station *Year	1	458.8	458.8	1.428	0.236
Residuals	68	21842.8	321.2		
HAI Modification 1 (Removed skin and fins)					
Station	1	97.1	97.1	0.287	0.594
Year	1	857.4	857.4	2.533	0.116
Station *Year	1	407.0	407.0	1.203	0.277
Residuals	68	23016.2	338.5		
HAI Modification 2 (Removed skin, fins, and parasites)					
Station	1	5.1	5.1	0.021	0.885
Year	1	230.1	230.1	0.943	0.334
Station *Year	1	706.8	706.8	2.897	0.093
Residuals	68	16589.9	244.0		
Female American Plaice					
Health Assessment Index (HAI)					
Station	1	1916	1915.6	5.861	**0.016**
Year	1	9	8.7	0.027	0.870
Station *Year	1	106	105.9	0.324	0.570
Residuals	204	66676	326.8		
HAI Modification 1 (Removed skin and fins)					
Station	1	1746	1746.1	5.320	**0.022**
Year	1	40	39.6	0.121	0.729
Station *Year	1	73	72.8	0.222	0.638
Residuals	204	66952	328.2		
HAI Modification 2 (Removed skin, fins, and parasites)					
Station	1	384	384.0	1.526	0.218
Year	1	8	8.1	0.032	0.858
Station *Year	1	137	136.7	0.543	0.462
Residuals	204	51346	251.7		
Notes: Bolded p-value denotes a significant result (α=0.05)					

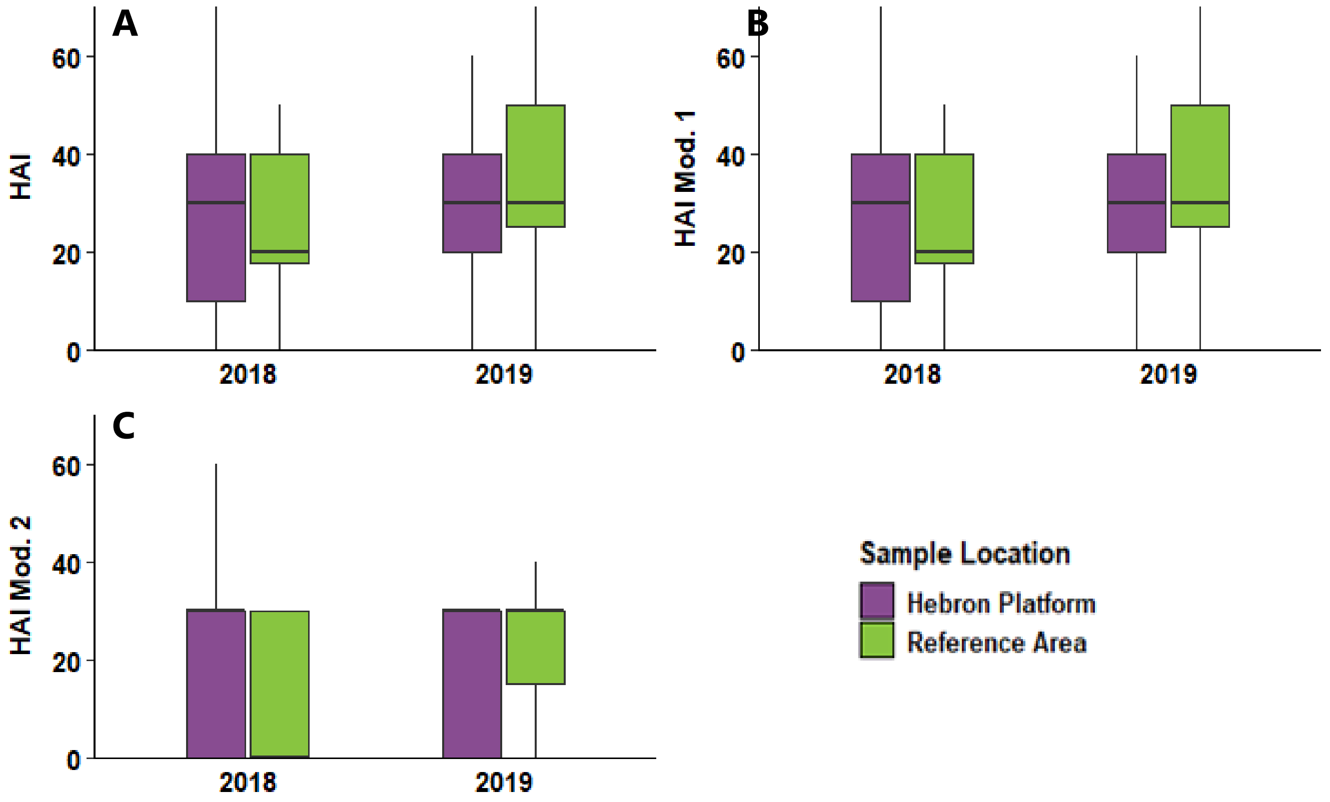


Figure 6-13 **Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for male American plaice sampled at the Hebron Platform and Reference Area in 2018 and 2019.**

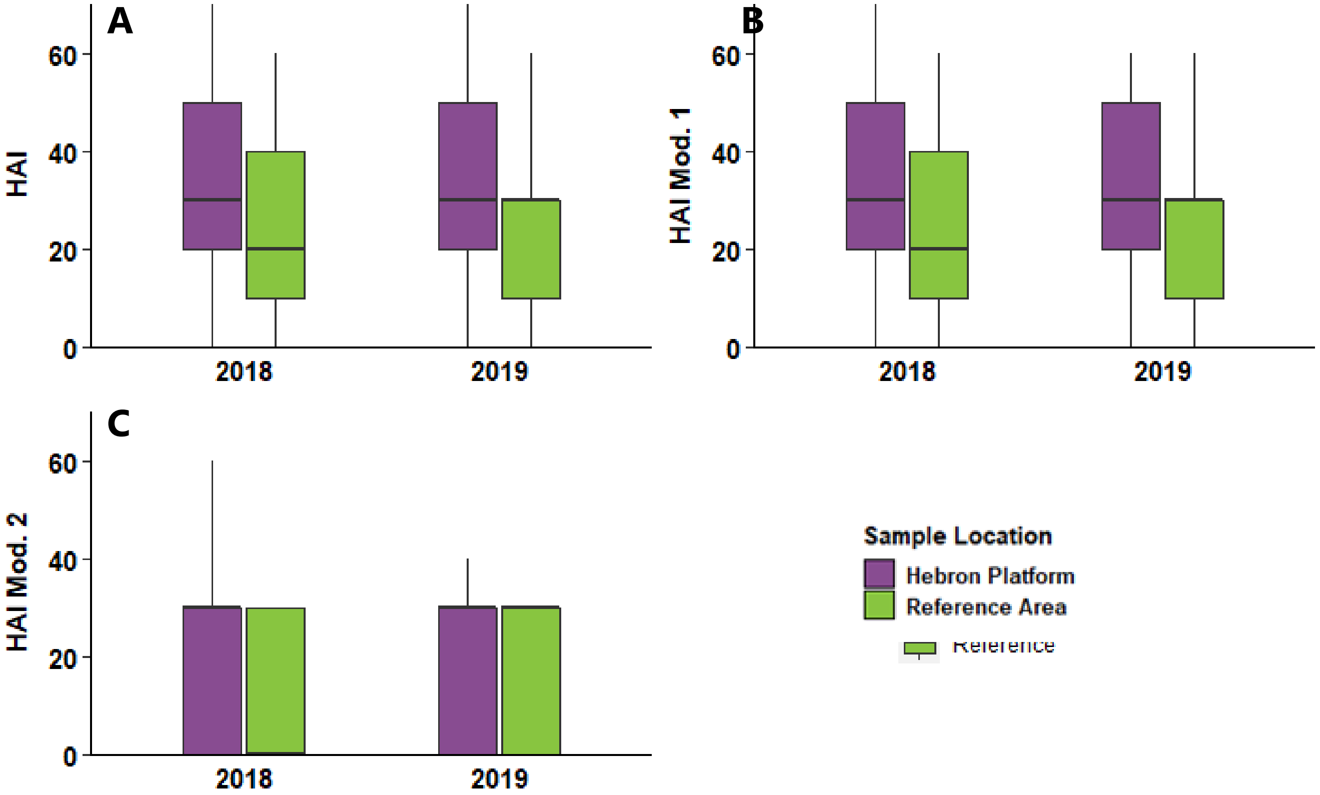


Figure 6-14 Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for female American plaice sampled at the Hebron Platform and Reference Area in 2018 and 2019.

Haematology

Blood smears were collected from 50 fish at both the Hebron Platform and Reference Area in 2019, and examples of each cell type can be found in Figure 6-15. These counts are used to prepare percentages of these cells in a minimum of 200 white blood cells.

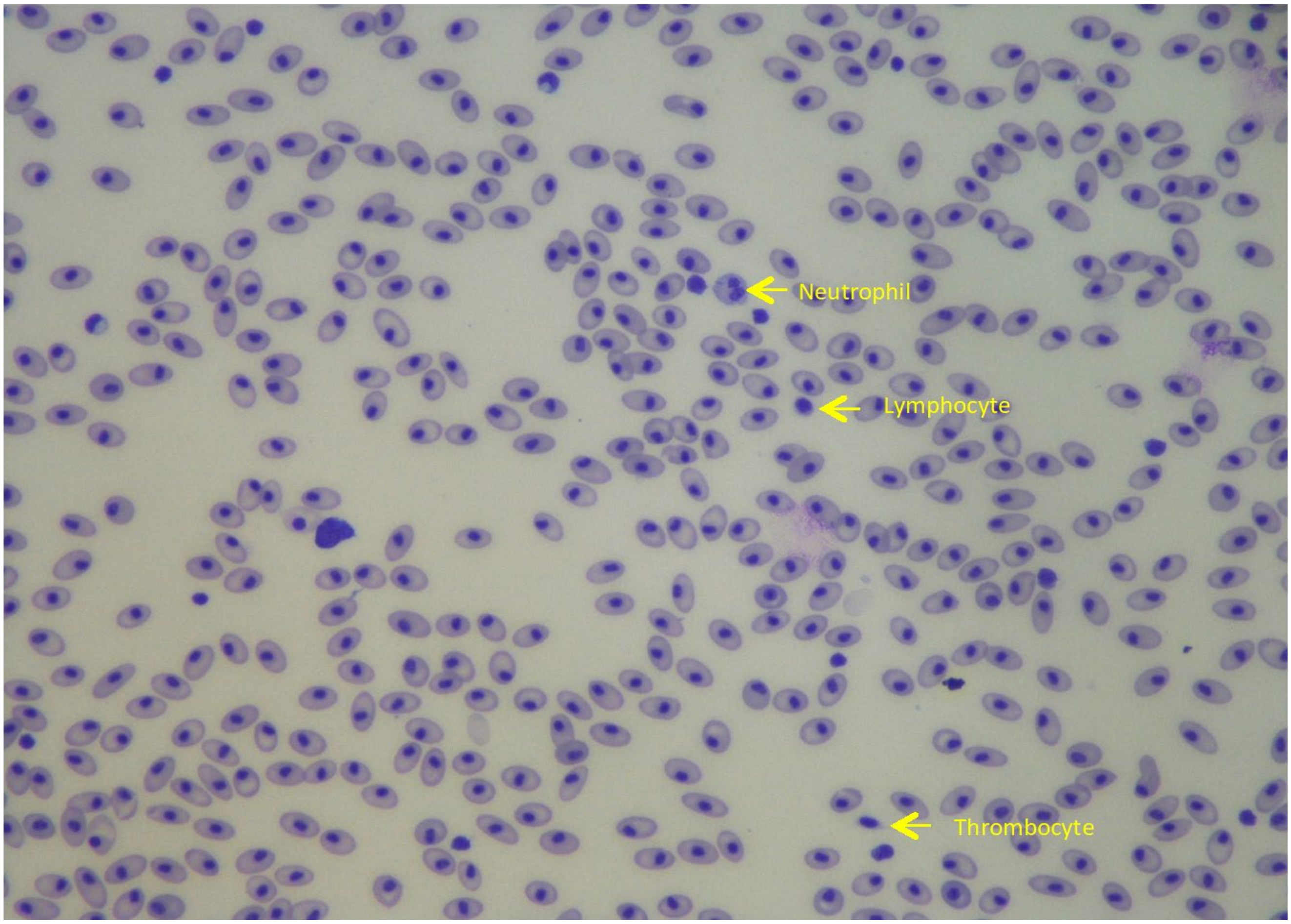


Figure 6-15 Example of cell types in blood smear from American plaice sampled during the Hebron EEM.Arrows indicate a neutrophil (top), lymphocyte (middle), and thrombocyte (bottom). Image provided by CDRF (MUN).

2019 Results

No significant differences were found between the Hebron platform and Reference Area for any blood cell type (neutrophils, lymphocytes, and thrombocytes; Table 6.18), however, neutrophils were near significance (p=0.051).

Table 6.18 Frequencies of blood cell types in American plaice from the 2019 Hebron biological survey.

Cell Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Lymphocytes (%)	95.1 ± 4.54	94.1 ± 5.48	0.321
Neutrophils (%)	0.96 ± 1.10	0.59 ± 0.75	0.051
Thrombocytes (%)	3.94 ± 4.37	5.31 ± 5.37	0.163

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 at the Reference Area in 2015 were not suitable for analysis, and so comparisons made here are by year (Hebron Platform only in 2015 compared to Hebron Platform/Reference Area combined in 2018 and 2019) and by station (Hebron Platform 2015 to 2019 combined compared to Reference Area for 2018 to 2019), with the interaction term only valid for the 2018 and 2019 data. Significant differences were found between stations for all three cell types (Table 6.19), with the Hebron Platform having a greater percentage of neutrophils and thrombocytes, and the Reference Area having a higher percentage of lymphocytes (Figure 6-16). Year was significantly different for neutrophils and for thrombocytes (Table 6.19), with 2015 having higher values for both cell types compared to 2018 and 2019 (Figure 6-16).

Table 6.19 Two-way ANOVA of the percent of neutrophils, lymphocytes, and thrombocytes from the blood smears of American plaice collected from the Hebron Platform and Reference Area from 2015 to 2019. No data exists for the Reference Area in 2015, and so interaction terms only apply to 2018 and 2019 data.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Neutrophils (%)					
Station	2	54.09	27.04	29.684	**<0.001**
Year	1	4.69	4.69	5.151	**0.024**
Station *Year	1	0.21	0.21	0.229	0.633
Residuals	244	222.31	0.91		
Lymphocytes (%)					
Station	2	1591.5	795.8	40.694	**<0.001**
Year	1	66.5	66.5	3.399	0.066
Station *Year	1	1.1	1.1	0.056	0.812
Residuals	244	4771.4	19.6		
Thrombocytes (%)					
Station	2	1121.0	560.51	31.082	**<0.001**
Year	1	106.5	106.48	5.905	**0.016**
Station *Year	1	0.4	0.35	0.020	0.889
Residuals	244	4400.1	18.03		
Notes: Bolded p-value denotes a significant result (α=0.05).					

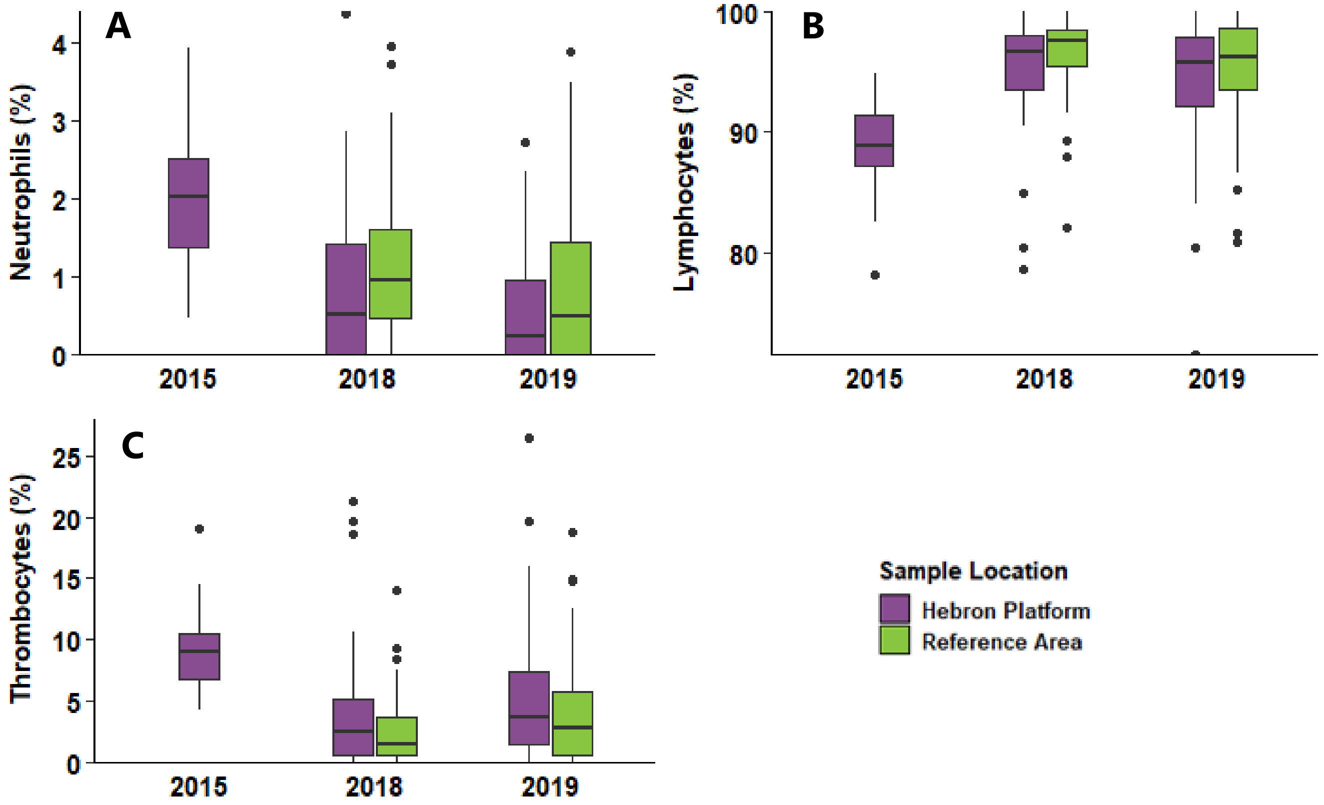


Figure 6-16 **Boxplots of the percentage of neutrophils (A), lymphocytes (B), and thrombocytes (C) from blood smears of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2019. No data exists for the Reference Area in 2015.**

Mixed Function Oxygenase Activity

2019 Results

A significant difference was found between female American plaice collected from the Hebron Platform and the Reference Area (p=0.03; Table 6.20). No difference was found for male fish between stations, though the p-value was near significance (p=0.070; Table 6.20).

Table 6.20 Mixed function oxygenase activity (pmol resorufin / mg protein / min) from male (top) and female (bottom) American plaice sampled from the Hebron platform and Reference Area in 2019.

Mixed Function Oxygenase (pmol resorufin / mg protein / min)			
Male	**Hebron Platform (n=13)**	**Reference Area (n=23)**	**p-value**
MFO (EROD)	93.9 ± 31.8	74.9 ± 18.6	0.070
Female	**Hebron Platform (n=57)**	**Reference Area (n=47)**	**p-value**
MFO (EROD)	76.2 ± 17.9	65.9 ± 20.5	**0.023**
Notes: All data expressed as mean percentage ± standard deviation Bolded p-value denotes significant result (α=0.05).			

Cross-year Comparison

Two-way ANOVAs were used to compare MFO activity across both stations (Hebron platform and Reference Area) and years (2015 to 2019) for male and female American plaice. Both analyses had significant results in their interaction terms and between years, indicating potential project effects (Table 6.21). Figure 6-17 shows the cause of the significant interactions, with much higher results in 2019 compared to 2015 and 2018, and variation in whether the Hebron Platform or Reference Area fish have a higher mean in a given year.

Table 6.21 Two-way ANOVA of mixed function oxygenase activity (pmol resorufin / mg protein / min) collected from American plaice at the Hebron platform and Reference Area from 2015 to 2019.

Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
Male					
Station	1	400	400	1.438	0.233
Year	2	80043	40021	144.021	**<0.001**
Station *Year	2	9157	4579	16.477	**<0.001**
Residuals	100	27789	278		
Female					
Station	1	209	209	1.255	0.264
Year	2	190233	95117	570.888	**<0.001**
Station*Year	2	2684	1342	8.055	**<0.001**
Residuals	187	31156	167		
Notes: Bolded p-value denotes a significant result (α=0.05).					

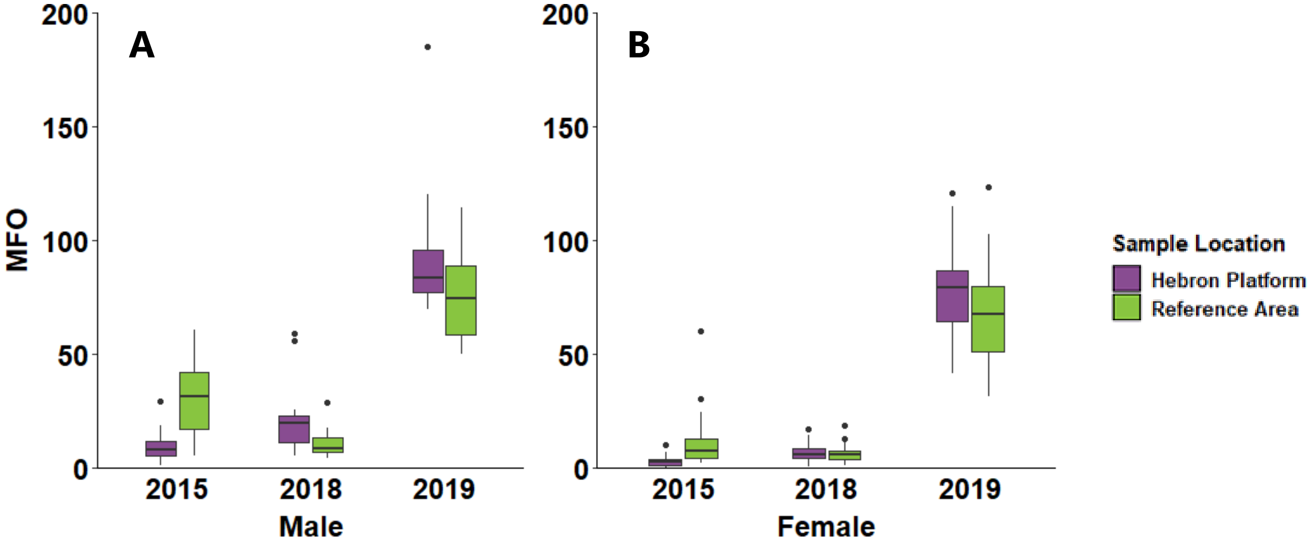


Figure 6-17 Boxplot of mixed function oxygenase (MFO) activity (pmol resorufin / mg protein / min) collected from male (A) and female (B) American plaice at the Hebron platform and Reference Area from 2015 to 2019.

Histopathology

Examples of liver pathologies is shown in Figure 6-18, and examples of gill pathologies in Figure 6-19.

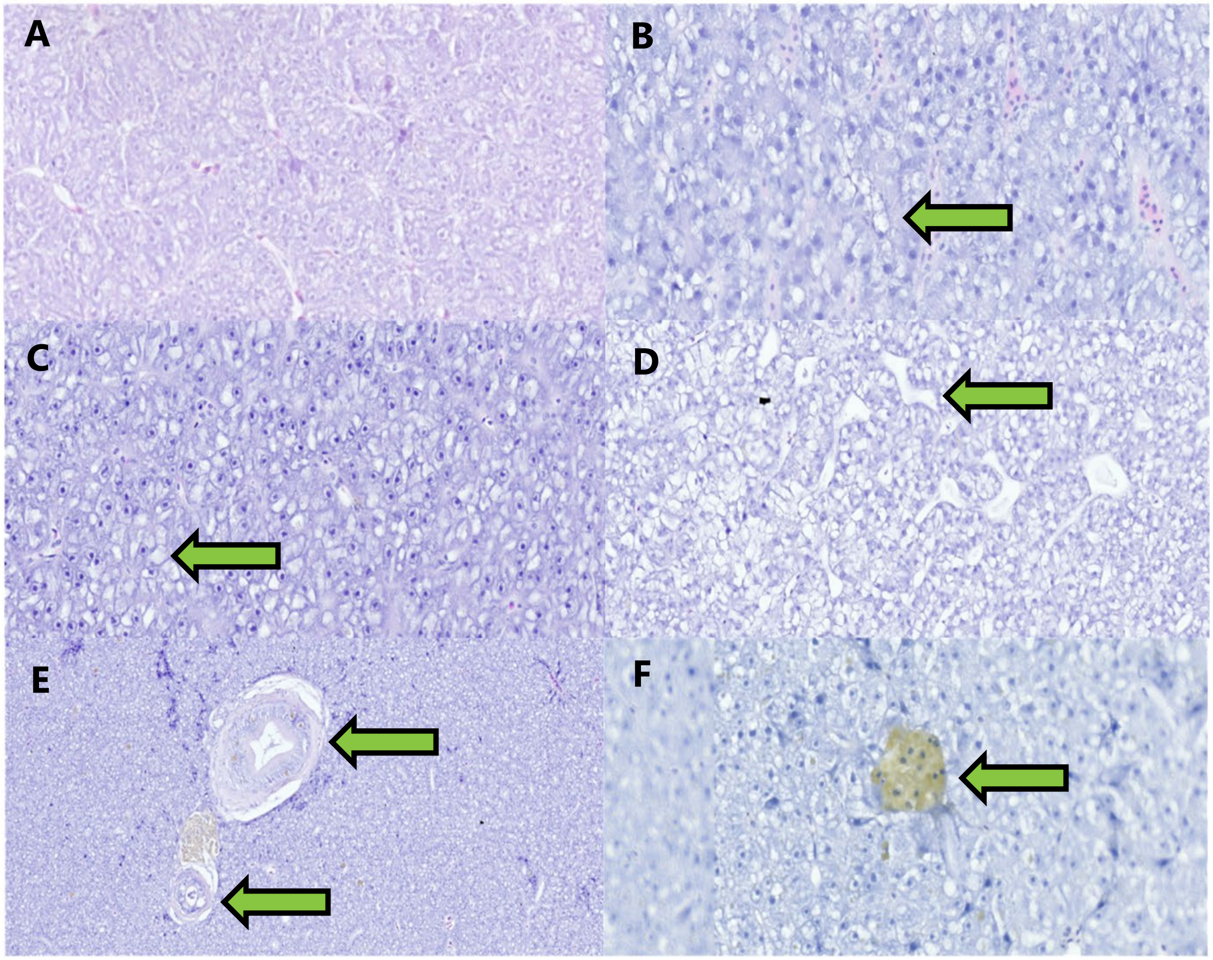


Figure 6-18 Examples of liver pathologies: A) normal liver tissue, B) small hepatocellular vacuoles, C) medium hepatocellular vacuoles, D) large hepatocellular vacuoles, E) bile duct hyperplasia, and F) macrophage aggregate. Images provided by the CDRF (MUN).

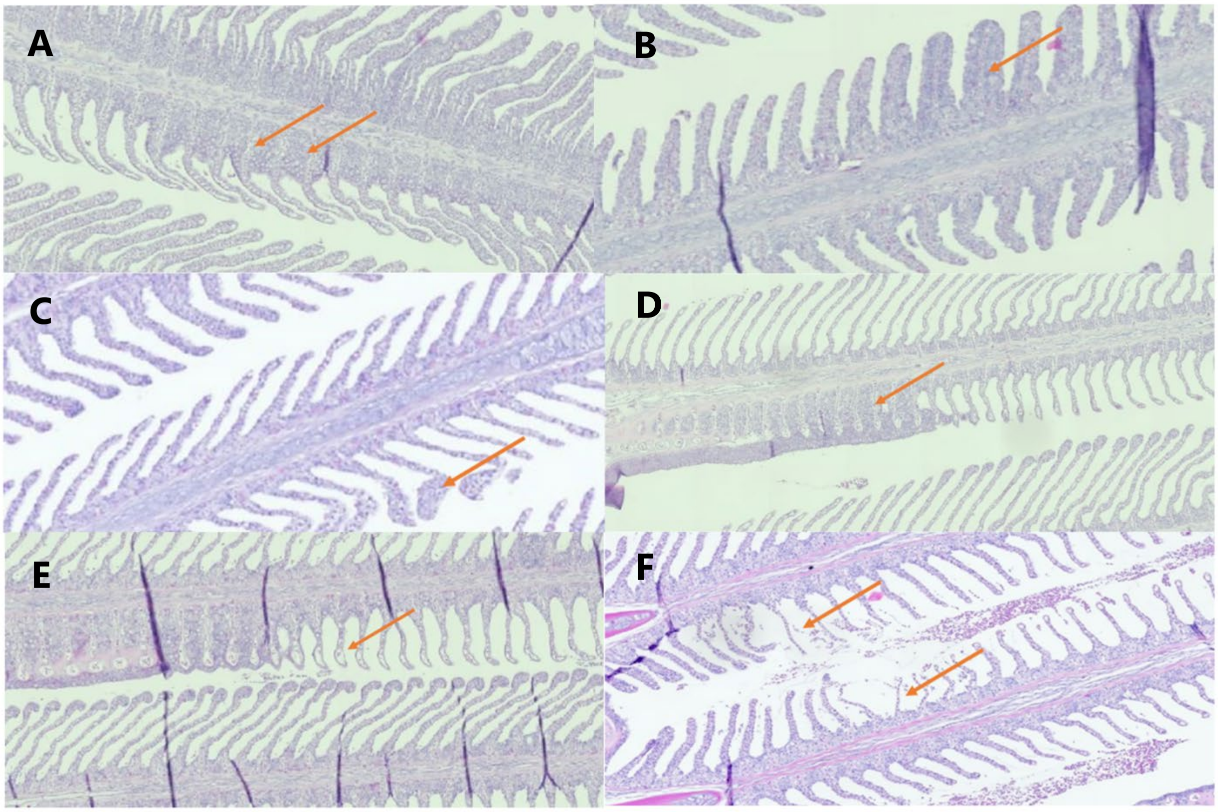


Figure 6-19 Examples of gill pathologies: A) basal hyperplasia, B) distal hyperplasia, C) tip hyperplasia, D) fusion, E) epithelial lifting, and F) thin filaments. Images provided by the CDRF (MUN).

2019 Results

Several hepatic lesions were observed in American plaice in 2019, including bile duct hyperplasia (Figure 6-18), hepatocellular carcinoma (not shown), macrophage aggregates (Figure 6-18), and hepatocellular vacuoles (Figure 6-18, Table 6.22). Three lesion types (hepatocellular carcinoma, small, and all hepatocellular vacuoles) significantly differed between the Hebron platform and the Reference Area (p=<0.001, 0.031, and 0.041, respectively; Table 6.22). Hepatocellular carcinoma had a significantly higher occurrence at the Reference Area, while small and all hepatocellular vacuoles had higher occurrences at the Hebron Platform.

Table 6.22 Number and frequency of American plaice with hepatic lesions from the Hebron Platform and Reference Area in 2019

Lesions	**Hebron Platform (n=50)**		**Reference Area (n=50)**		**p-value**
	Fish Affected	**Prevalence (%)**	**Fish Affected**	**Prevalence (%)**	
Normal	12	24	3	6	
Nonspecific necrosis	0	0	0	0	
Bile duct hyperplasia	20	40	22	44	0.840
Nuclear pleomorphism	0	0	0	0	1.000
Megalocytic hepatosis	0	0	0	0	1.000
Eosinophilic foci	0	0	0	0	1.000
Basophilic foci	0	0	0	0	1.000
Clear cell foci	0	0	0	0	1.000
Hepatocellular carcinoma	12	24	32	64	**<0.001**
Benign tumours	0	0	0	0	1.000
Cholangioma	0	0	0	0	1.000
Cholangiofibrosis	0	0	0	0	1.000
Increase in mitotic activity	0	0	0	0	1.000
Macrophage aggregates[a]	3	6	1	2	0.617
Macrophage aggregates[b]	0	0	0	0	1.000
Hydropic vacuolation	0	0	0	0	1.000
Hepatocellular vacuoles S	8	16	1	2	**0.031**
Hepatocellular vacuoles M	13	26	10	20	0.635
Hepatocellular vacuoles L	5	10	4	8	1.000
Hepatocellular vacuoles A	26	52	15	30	**0.041**

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).

Gills abnormalities were also observed in fish from both areas, with only one significant difference between the Hebron platform and the Reference Area (Table 6.23). Normal condition gills significantly differed between stations, with a higher incidence at the Hebron Platform (Table 6.23).

Table 6.23 Percentages of secondary lamellae affected by lesions, and scale of affected lesions in the gill tissues of American plaice from the Hebron Platform and Reference Area in 2019.

Lesion Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Percentage of Secondary Lamellae Affected by Lesions			
Normal	98.3 ± 1.88	97.0 ± 3.04	**0.012**
Tip Hyperplasia [a]	0.52 ± 0.77	0.79 ± 1.06	0.157
Basal Hyperplasia [b]	0.22 ± 0.59	0.22 ± 0.76	0.977
Distal Hyperplasia [c]	0.17 ± 0.40	0.28 ± 0.50	0.254
Fusion	0.80 ± 1.37	1.58 ± 2.89	0.092
Telangiectasia	0 ± 0	0.05 ± 0.28	0.196
Thin Lamellae	0 ± 0	0.08 ± 0.45	0.191
Epithelial Lifting	0.02 ± 0.12	0.04 ± 0.26	0.632
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.12 ± 0.38	0.10 ± 0.41	0.804

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)

Across-year Comparison

A MANOVA was performed using the factors listed in Table 6.22 that were detected in fish (i.e., excluding those with zero fish affected). This left seven 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 6.24 (top) presents the results of the MANOVA, with significant differences between station (p=0.003), year (p=<0.001), and the interaction term (p=<0.001). Two-way ANOVAs were then run on each individual factor to determine which are contributing to the significance in the MANOVA. Table 6.24 (bottom) shows the individual ANOVAs, with five factors having significant results: bile duct hyperplasia, hepatocellular carcinomas, macrophage aggregates (0-3), small hepatocellular vacuoles, and large hepatocellular vacuoles. The interaction term was significant for all factors analyzed except for bile duct hyperplasia.

Figure 6-20 shows each of the five factors with significant results found in Table 6.24. Bile duct hyperplasia significantly varied by year, with a higher incidence in 2019 compared to 2015 or 2018. Hepatocellular carcinoma has a significant interaction term, as incidence has increased at the Hebron Platform over time and not at the Reference Area. Macrophage aggregates and small hepatocellular vacuoles also had significant interactions terms, and both vary in whether the Hebron Platform or Reference Area has a higher value each year. For large hepatocellular vacuoles, higher prevalence was observed at the Hebron platform in 2015 and at the Reference Area in 2018 with lower values overall in 2019.

Table 6.24 MANOVA (six factor) and individual two-way ANOVAs of each factor of detected liver histopathologies from American plaice collected at the Hebron Platform and Reference Area from 2015 to 2019.

Factor	**Degrees of Freedom**	**Number of Degrees**	**Pillai's Trace**	**Approximate F Value**	**p value**
MANOVA (6 factors)					
Station	1	6	0.066	3.398	**0.003**
Year	2	12	0.348	10.194	**<0.001**
Station *Year	2	12	0.151	3.949	**<0.001**
Residuals	294				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
Individual Factor ANOVAS					
Bile duct hyperplasia					
Station	1	0.053	0.053	0.291	0.590
Year	2	3.860	1.930	10.547	**<0.001**
Station *Year	2	0.007	0.003	0.018	0.982
Residuals	294	53.800	0.183		
Hepatocellular carcinoma					
Station	1	2.613	2.613	14.281	**<0.001**
Year	2	4.560	2.280	12.460	**<0.001**
Station *Year	2	2.027	1.013	5.538	**0.004**
Residuals	294	53.800	0.183		
Macrophage aggregates (0-3)					
Station	1	0.120	0.120	1.460	0.228
Year	2	0.607	0.303	3.691	**0.026**
Station *Year	2	0.500	0.250	3.042	**0.049**
Residuals	294	24.160	0.082		
Hepatocellular vacuoles (small)					
Station	1	0.333	0.333	4.010	**0.046**
Year	2	0.007	0.003	0.040	0.961
Station *Year	2	0.607	0.303	3.649	**0.027**
Residuals	294	24.440	0.083		
Hepatocellular vacuoles (medium)					
Station	1	0.013	0.013	0.075	0.784
Year	2	0.047	0.023	0.132	0.877
Station *Year	2	0.447	0.223	1.261	0.285
Residuals	294	52.08	0.177		
Hepatocellular vacuoles (large)					
Station	1	0.003	0.003	0.020	0.889
Year	2	7.127	3.563	20.811	**<0.001**

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Station *Year	2	5.127	2.563	14.971	**<0.001**
Residuals	294	50.340	0.171		
Notes: Bolded p-value denotes a significant result (α=0.05)					

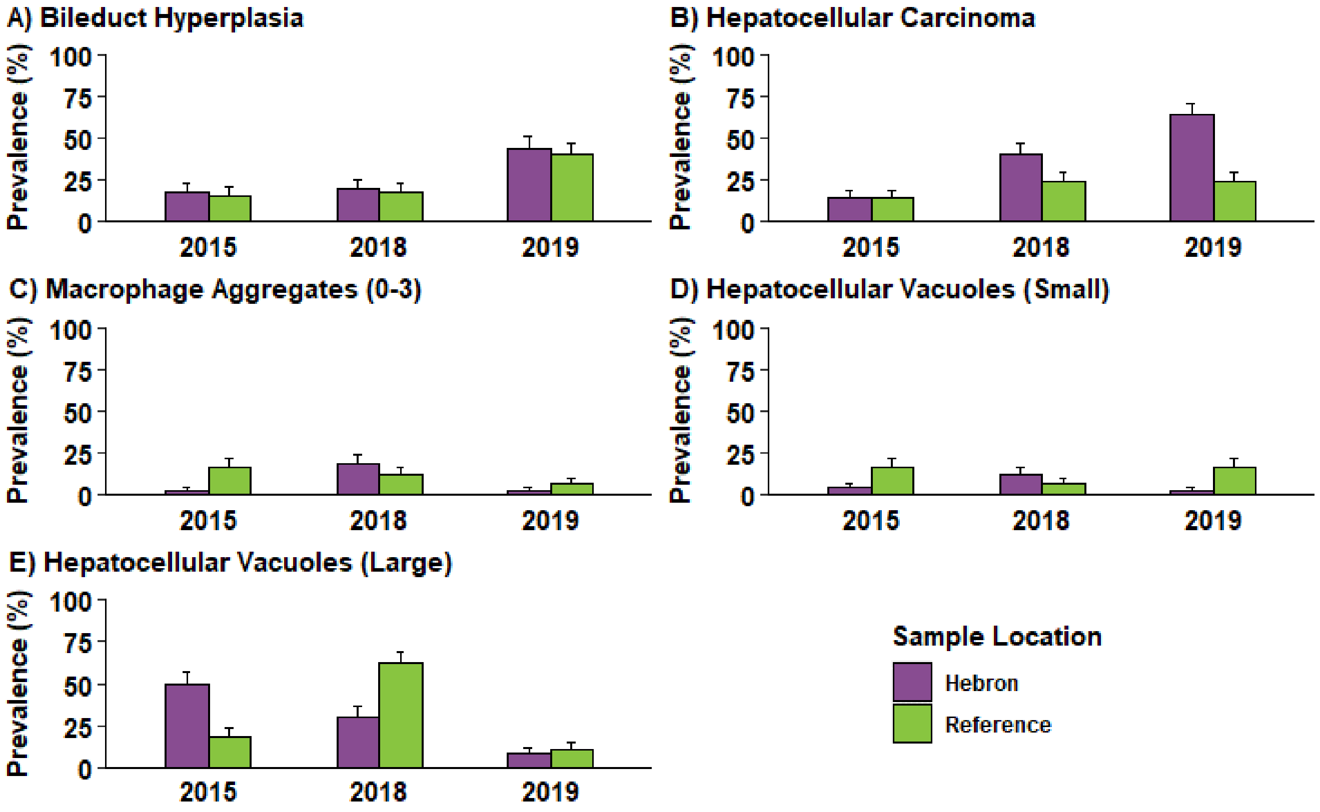


Figure 6-20 Bar graphs of the prevalence (%) of bile duct hyperplasia (A), hepatocellular carcinoma (B), macrophage aggregates (0-3) (C), small hepatocellular vacuoles (D), and large hepatocellular vacuoles (E) from livers of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2019. Bars indicate standard error.

Due to the large number of gill histology factors, a MANOVA was performed using the factors listed in Table 6.23 excluding oedema as it is a measure of the scale of affected lesions. This left seven factors: hyperplasia (tip, basal, and distal), fusion, telangiectasia, thin lamellae, and epithelial lifting. Table 6.25 (top) shows the results of the MANOVA, with significant differences between stations (p=0.006), years (p=<0.001) and the interaction term (p=0.050). Two-way ANOVAs were then run on each individual factor to determine which are driving the significance in the MANOVA. Table 6.25 (bottom) shows the individual ANOVAs, with five factors having significant results: tip, basal, and distal hyperplasia, fusion, telangiectasia, and thin lamellae.

Figure 6-21 shows each of the five factors with significant results found in Table 6.25. Tip hyperplasia had a significant interaction term, with incidence being higher at the Hebron Platform compared to the Reference Area, though 2019 values are similar to 2018. Basal and distal hyperplasia significantly differed between stations and years, with 2019 values lower than 2018, and higher at the Hebron Platform. Fusion significantly differed between years and was lower in 2019 compared to 2018. Telangiectasia significantly differed between stations and was higher at the Hebron platform compared to the Reference Area in all years.

Table 6.25 MANOVA (seven factor) and individual two-way ANOVAs of each factor of detected gill histopathologies from American plaice collected at the Hebron platform and Reference Area from 2015 to 2019.

Factor	**Degrees of Freedom**	**Number of Degrees**	**Pillai's Trace**	**Approximate F Value**	**p value**
MANOVA (7 factors)					
Station	1	7	0.066	2.873	**0.006**
Year	2	14	0.277	6.599	**<0.001**
Station *Year	2	14	0.080	1.710	**0.050**
Residuals	292				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
Individual Factor ANOVAS					
Hyperplasia (tip)					
Station	1	0.559	0.559	0.896	0.345
Year	2	11.140	5.570	8.926	**<0.001**
Station *Year	2	5.285	2.643	4.235	**0.015**
Residuals	292	182.210	0.624		
Hyperplasia (basal)					
Station	1	8.14	8.14	4.848	**0.028**
Year	2	84.44	42.22	25.147	**<0.001**
Station *Year	2	5.74	2.872	1.711	0.183
Residuals	292	490.25	1.679		
Hyperplasia (distal)					
Station	1	6.85	6.848	4.827	**0.029**
Year	2	19.55	9.773	6.889	**0.001**
Station *Year	2	7.11	3.554	2.506	0.083
Residuals	292	414.24	1.419		
Fusion					
Station	1	7.98	7.98	1.104	0.294
Year	2	234.47	117.23	16.212	**<0.001**
Station *Year	2	16.44	8.22	1.137	0.322
Residuals	292	2111.49	7.23		
Telangiectasia					
Station	1	0.451	0.451	8.32	**0.004**

Factor	**Degrees of Freedom**	**Number of Degrees**	**Pillai's Trace**	**Approximate F Value**	**p value**
Year	2	0.088	0.044	0.807	0.447
Station *Year	2	0.067	0.034	0.621	0.538
Residuals	292	15.839	0.054		
Thin lamellae					
Station	1	0.027	0.027	0.196	0.658
Year	2	0.117	0.059	0.432	0.650
Station *Year	2	0.667	0.334	2.453	0.088
Residuals	292	39.709	0.136		
Epithelial lifting					
Station	1	0.233	0.233	1.000	0.318
Year	2	0.512	0.256	1.097	0.335
Station *Year	2	0.238	0.119	0.511	0.601
Residuals	292	68.068	0.233		
Notes: Bolded p-value denotes a significant result (α=0.05).					

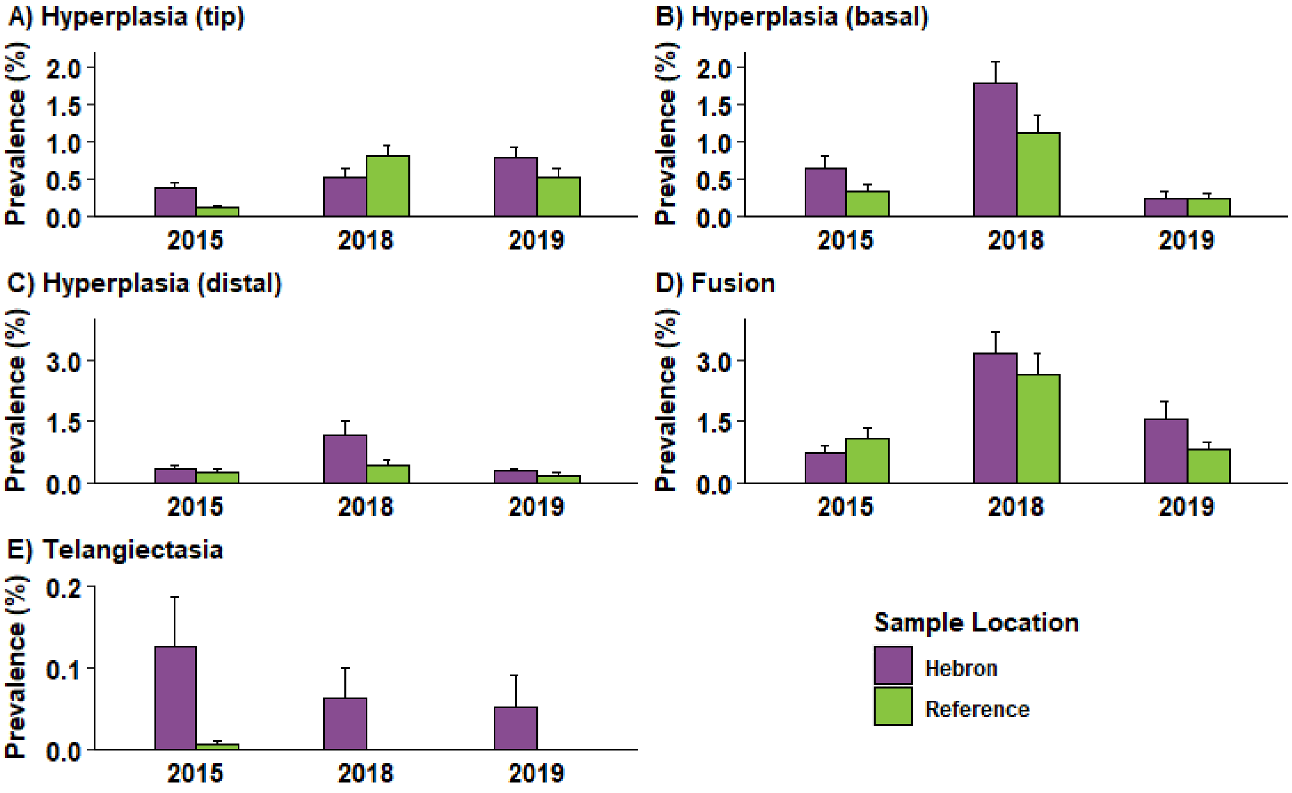


Figure 6-21 **Bar graphs of the prevalence (%) of hyperplasia - tip (A), basal (B), and distal (C), fusion (D), and telangiectasia (E), from livers of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2019. Bars are standard error.**

6.3 Summary of Results

6.3.1 Summary of Chemical Profiles of American Plaice

Consistent with past EEM years, composite American plaice tissue sampled at the Hebron Platform and Reference Area in 2019 had arsenic, mercury, and zinc above their RDLs in all samples. Comparison across EEM years found a significant difference for zinc, with higher values in 2015 compared to 2018. For liver composites, eight metals have been consistently detected in all EEM years, with three other metals occasionally above their RDLs. Arsenic, copper, and selenium were significantly different between years, with copper and selenium decreasing from 2018 to 2019, and arsenic increasing from 2018 to 2019 (though still lower than 2015). Cadmium and iron were significantly different between stations and both were higher at the Reference Area across years. Manganese significantly differed for both station and year with higher levels in 2018 and 2019 than in 2015, and higher at the Hebron Platform compared to the Reference Area. Hydrocarbons in all three ranges (>C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32}) were screened in for 2019, and no significant differences were detected between the Hebron Platform and Reference Area. Hydrocarbons in all three ranges significantly differed between years, with >C_{10}-C_{16} and >C_{16}-C_{21} hydrocarbon concentrations higher in 2019 than either 2015 or 2018, and >C_{21}-C_{32} concentrations higher in 2019 compared to 2018, though values were similar to 2015. No PAHs were detected in any liver composites in 2019, though acenaphthylene and fluorene were screened in for analysis in 2018.

6.3.2 Summary of Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2019 (Table 6.26).

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2019 for the first and third of the three maturing codes (Mat A-P, code 520; and Mat C-P, code 540) stage, both of which had higher proportions at the Reference Area. For biological characteristics, male fish significantly differed for liver weight and the hepatosomatic index, and female fish differed in liver weight, age, the hepatosomatic index, and the gonadosomatic index between stations. After accounting for covarying factors using ANCOVAs, male and female liver weight, and female gonad weight significantly differed. Cross-year comparisons across all EEM years for three indices (Fulton's condition index (FCI), hepatosomatic index (HSI), and gonadosomatic index (GSI)) had significant results for male HSI (higher at the Hebron Platform compared to the Reference Area) and male GSI (higher in 2019 compared to 2015). Female plaice had significant interaction terms for both HSI and GSI.

For gross pathology, no significant differences were found in 2019 for male American plaice. However, female American plaice had a higher incidence of parasites at the Hebron Platform compared to the Reference Area. Additionally, female fish had significantly higher health assessment index (HAI) values at the Hebron Platform for the original HAI and the first modification of the HAI (removal of skin and fins).

For haematology, no differences were detected in the 2019 EEM program. For the cross-year comparison, significant differences were found between stations for all three cell types, with the Hebron Platform having a greater percentage of neutrophils and thrombocytes, and the Reference Area having a higher percentage of lymphocytes. Year was significantly different for neutrophils and for thrombocytes, with 2015 having higher values for both cell types compared to 2018 and 2019.

For MFO, female fish significantly differed between the Hebron Platform and Reference Area in 2018. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, the Hebron platform and Reference Area significantly differed for hepatocellular carcinoma, large, and all hepatocellular vacuoles in 2019. A MANOVA with eight liver histology factors showed significant differences between stations, years, and in the interaction term. Bile duct hyperplasia significantly varied by year, with a higher incidence in 2019 compared to 2015 or 2018. Hepatocellular carcinoma, macrophage aggregates, and small and large hepatocellular vacuoles all had significant interactions terms.

For gill histopathology, only the incidence of normal condition fish differed in 2019 with a higher incidence at the Hebron Platform. However, a MANOVA for seven gill histology factors detected significant results across station, year, with a significant interaction term. Significant differences between stations was largely due to basal and distal hyperplasia (both higher at the Hebron platform), and telangiectasia (higher at Hebron platform). Significant differences between years was driven by distal and basal hyperplasia and fusion (higher in 2018 compared to 2015 or 2019), and tip hyperplasia (higher in 2018 and 2019 compared to 2015). Only tip hyperplasia had a significant interaction term.

Table 6.26 Summary of significant results between the Hebron Platform and Reference Area within each EEM year.

Indicators	**2015 Fish Characterization**	**2015 (EEM ref. area) [a]**	**2018**	**2019**
Maturity Stages	-	Yes	Yes	Yes
Fish length	Yes	No	Yes	No
Fish weight	No	No	Yes	No
Liver weight (post-ANCOVA)	-	Yes	No	Yes
Gonad weight (post-ANCOVA)	-	No	No	Yes
Age	-	No	Yes	Yes
Hepatosomatic Index	No	Yes	No	Yes
Gonadosomatic Index	No	No	No	Yes
Mixed-function oxidase	Yes	Yes	Yes	Yes
Liver Histopathology	Yes	Yes	Yes	Yes
Gill Histopathology	Yes	Yes	No	No

Notes:

[a] See 2018 EEM report comparing Hebron Platform 2015 results with EEM Reference Area, and description of the differences between the fish characterization and EEM reference area data from 2015

- Indicates a lack of results for comparisons (too few male fish or no comparison made)

7.0 DISCUSSION AND INTERPRETATION

To detect changes in the surrounding environment that may be attributed to operation activities, the Hebron Project is committed to conducting an EEM program (EMCP 2017). The Hebron EEM program consists of assessments on a sediment quality triad, and commercial fish health, size, and body burden chemistry (as per Table 7.1). Hebron also includes a water sampling component to assess the chemistry of water quality.

Table 7.1 Hebron Platform Program sediment, water and biological sampling program component parameters and analysis.

Program Component	Parameters	Analysis
Sediment Quality Triad	Chemistry	Particle size, organic and inorganic carbon, metals, hydrocarbons, ammonia, and sulphide concentrations
	Toxicity	Amphipod survival
	Benthic Community	Benthic invertebrate community sampling
Water Quality	Chemistry	Metals, hydrocarbons
	CTD	Dissolved oxygen, temperature, salinity, and pH profiles
Commercial Fish (American plaice)	Tissue Chemical Profiles	Body burden (metals, hydrocarbons)
	Sensory Evaluation	Taint / taste testing (Triangle Test and Hedonic Scaling)
	Health Indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity

7.1 Sediment Quality Component

7.1.1 Physical and Chemical Characteristics

A total of 19 analytes were screened-in for further analysis. Mean increases (as compared previous surveys) were observed in gravel, barium, iron, manganese, TOC, C_{10}-C_{21}, C_{21}-C_{32}, redox potential, and ammonia. Of the screened-in analytes for 2019, four of whichc were not screened-in in 2018 (chromium, strontium, uranium, vanadium). Analyte concentrations were influenced by several factors including other analytes and distance from the Hebron GBS. Analytes can be correlated with each other which increases in one resulting in increases of another. Increases in percent fines were correlated with increases in hydrocarbons, barium, sulphide, and sulphur. Similarly, increases of barium were significantly correlated to hydrocarbons, sulphide, and sulphur.

Distance to the GBS was a key factor in differentiating analyte concentrations between stations. Several, analytes were correlated with distance to the GBS and several were negatively correlated. A negatively correlated relationship in this instance means there was a decrease in analyte concentration with increasing distance from the GBS which is what would be predicted in a project-level effect. Barium, total organic carbon, C_{10}-C_{21} hydrocarbons, C_{21}-C_{32} hydrocarbons, sulphide, and sulphur were negatively correlated with distance from the

Hebron GBS. These changes occurred within 1,000 m of the GBS. These changes in concentrations are mainly driven by changes occurring at station 8-250. Station 8-250 sediment samples had the highest concentrations of barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons, moisture, sulphide, sulphur, and relatively higher concentrations of iron, lead, chromium, vanadium. Threshold regression models found a distinct threshold at 500 m from the platform. Percent fines was two standard deviations above 2014 levels at 8-250 and many analytes (particularly barium and hydrocarbons) cling to the more ionically charged finer particle sizes. The Hebron GBS cuttings disposal discharge points (cuttings chute) is located to the northwest of the GBS directly across from this station. Thus, increases from analytes at this station is an expected project-related effect. While highest concentration of barium occurred at station 8-250, it is a decrease from 2018. This trend could continue and should continue to be monitored.

Stations greater than 3,000 m also had increases in certain analytes. Gravel was positively correlated with distance with several stations to the northeast of the GBS reporting increases. The distribution and increase in percent gravel concentration is unlikely to be a project effect. All other screened-in analytes concentrations were not statistically significant with distance. However, there were also relatively high concentrations of iron, lead, manganese, chromium, strontium, uranium, and vanadium observed at stations to the northeast of the Hebron GBS. The highest concentrations of uranium occurred at B-250, strontium occurred at B-1250, and vanadium, manganese, and iron occurred at 2-6000. These stations are more than 6,000 m to the northeast of the Hebron GBS and increases from these analytes are unlikely project related.

Other observed changes occurred in redox potential values. This is the first instance of negative redox potential values across the three survey years. Of the eight negative readings, seven occurred to the northeast of the GBS with the lowest reading occurring at A-1000. Negative redox readings could indicate a reducing environment or anoxic conditions in the sediment. Oxygen penetration and consumption is generally deeper in sandy sediments than in fine-grained sediments (Andersen and Hilder, 1987). This trend will continue to be observed and changes in benthic fauna will be monitored. Due to the stations distance from the GBS, the negative redox potential values are unlikely a result of project related effects.

7.1.2 Toxicity

Rises in analytes did not however, correspond to the sediment being identified as toxic. The screening threshold for a sample to be tested for toxicity is a PetroTox level of 150 mg/kg C10-C21. No sample in 2019 was near this threshold. Obligatory testing occurs for stations within 500 m from the GBS. None of these samples (including 8-250) were deemed toxic. Although no sediments evaluated were deemed toxic, there were statistically significant changes in analyte concentration with respect to distance from the GBS.

7.1.3 Benthic Community Structure

Analysis of benthic community structure is the final component of the sediment triad and may give further indications of any project-related environmental changes. Overall, decreases were detected in all six of the benthic community monitoring variables compared to baseline levels (except for biomass which was not recorded for baseline levels). Polychaetes are a major component of the marine benthic community (Dean 2008) and are well known indicators of pollution (Diaz and Reish 2009) including tolerant families such as Capitellidae and Spionidae (Pocklington and Wells 1992) and intolerant species such as *Exogone* spp., *Harmothoe* spp., and *Polycirrus* spp. (Hiscock 2004). The Capitellidae, the most commonly used indicator of marine pollution world-wide, were not abundant in 2019 (n=70) or 2018 (n=61). Similarly, in 2014, Capitellidae were also not a top ten taxa contributing to the variation in assemblages between stations. In 2018, species from this family were found mainly in stations more than 3,000 m from the GBS but in 2019 this family was present at stations within 1,000 m from the GBS. The station with the highest concentrations of several analytes was 8-250 is located closest to the GBS outflow and would likely experience changes from the GBS before other stations. The pollution indicator species *Capitella capitata* was not present at station 8-250 in 2018 but is present in 2019 (n=6).

Other polychaete species used for environmental monitoring include transitional zone (i.e. areas between polluted and unpolluted) indicator species *Tharyx* sp. and *Exogone hebes* (Word et al. 1977; Mair et al. 1987; Dean 2008). These species were observed throughout the survey area being in 31 of the 35 samples. This is similar to 2018 where these species were observed at 33 of the 36 stations respectively. At station 8-250, *Tharyx* sp. and *Exogone hebes* abundance slightly increased between 2019 (n=26, n=12 respectively) and 2018 (n=14, n=10). The increase of transitional zone species, new appearance of a pollution tolerant species, and increase in barium and C_{10}-C_{21} hydrocarbons indicate changes at 8-250. Due to the close proximity to the discharge chute, these changes were predicted in the CSR and are expected project-related effects and will continue to be monitored.

Several stations to the northeast of the GBS had relatively high abundances of clitellates. This annelid class is recognized as an opportunist re-colonizer and the high abundance values may indicate altered or highly organic areas. Within the class Citellata is the family Naididae which are often used as indicators of pollution (Behling 2013); however, they should be identified to the species level to estimate pollution levels (Rodriguez and Reynoldson 2011). In 2019 several organisms could be identified as Naididae but could not be taken to the species level.

Distributions of crustacean, mollusc, and echinoderm populations can be significantly reduced by hydrocarbon contamination (Blackburn et al. 2014). Percent abundance contribution for annelids, arthropods, molluscs, and echinoderms were similar between 2018 and 2019. Additionally, the bivalve family Hiatellidae, which inhabits deep waters throughout the Grand Banks of Newfoundland, contributed 3.24% to the similarity of stations 1,000 m to 2,000 m from the GBS. This species was not noted as a contributor to similarity in either the 2014 baseline survey or the 2018 EEM year one survey. Hiatellidae has been observed at Terra Nova in previous years (Paine et al. 2014).

7.2 Water Quality Component

The water sampling/monitoring program at Hebron is designed to assess the potential effects of produced water and other liquid discharges discussed in Section 5. Water samples were tested for metals and hydrocarbon. None of the metal analyte concentrations detected at any sampling area exceeded CCME marine water guidelines (CCME 2001). Petroleum hydrocarbons (e.g., C_6 to $<C_{32}$, BTEX, TPH) were not detected in any water samples. The metals concentrations with distance from the platform were mixed with few discernible patterns but in general, there were varied elevated concentrations of aluminum, arsenic, calcium, copper, molybdenum, nickel, strontium, sulphur and zinc towards the east and/or north closer to the produced water outlet (≤100 m) relative to the farther sampling stations (500 m) (Tukey HSD $p<0.05$).

Produced water modelling indicated under average low currents in August, dilution factors of 300 for oil to reach 0.1 ppm could be reached out to 352 m (Amec 2010), however, hydrocarbons were not detected in any water samples. These results indicate that the produced water appears to dilute rapidly once discharged. Elevated barium in water samples collected near the bottom may be reflective of discharged cuttings near the seafloor. All these results indicate that their potential for the water columns discharges having a deleterious biological effect is likely minimal.

7.3 Commercial Fish Program

7.3.1 Chemical Profiles of American Plaice

American plaice is a species of commercial importance in the Newfoundland offshore region that are monitored in all EEM programs in the Newfoundland Offshore. Section 6 seeks to describe project effects on body burden of metals, hydrocarbons, and PAHs, as well as reporting catch numbers and species for trawls. Note that no taste testing took place for the 2019 EEM as those samples were lost (see Section 6.1). Several statistically significant differences were found in the 2019 data, and in comparisons to past EEM years. The 2015 fish characterization had several methodological differences compared to the 2018 and 2019 EEM programs, and so greater weight in this discussion was given to differences from 2018 to 2019.

Twenty-seven different taxa were caught as part of the 2019 Hebron environmental effects monitoring (EEM) program (Table 6.3). No difference was observed for catch per unit effort (CPUE) for all species across either year or between the Hebron Platform and Reference Area (Table 6.6). The most commonly caught fish species were sand lance followed by American plaice, and the most common invertebrate was northern shrimp (Figure 6-3). Similar catch results were observed in the both the 2015 and 2018 programs (EMCP 2016b, EMCP 2019). CPUE for American plaice had a significant interaction term between station and year (Table 6.6). American plaice CPUE was consistent between stations in 2015 but was higher at the Hebron Platform in 2018 and 2019. This may be early evidence of American plaice congregating near the Hebron platform due to a release from fishing pressure and the concrete GBS acting as an artificial reef and source of food for plaice. Nogueira et al. (2016) surveyed American plaice biomass from 2002 to 2014 on the Grand Banks and reported high fluctuations between years. A longer time series of CPUE at these stations may yield better insights.

For American plaice fillets, three metals were detected above their RDLs in the 2019 EEM program: arsenic, mercury, and zinc (Table 6.7). No significant difference was detected in these metals between the Hebron platform and Reference Area in 2019 (Table 6.7). No hydrocarbons or PAHs were above their RDLs in fillets in 2019. This is consistent with 2015 and 2018 results, with the same three metals detected. Cross-year comparison showed no significant difference between stations or years for arsenic or mercury, but zinc had a significant difference across years (Table 6.9, Figure 6-7). Zinc in fillets was lower in 2018 and 2019 compared to 2015, but without a significant interaction term, no project related effects are apparent in American plaice fillet tissues. These analytes are also consistent with other platforms, including Terra Nova (DeBlois et al. 2014) and Hibernia (HMDC 2017, 2019). These values appear steady across years and stations and are likely natural levels of these metals.

In American plaice liver composites, eight metals and three hydrocarbon groups were detected above their RDLs in the 2019 program (Table 6.8). Within the 2019 program, only copper significantly differed between the Hebron Platform and Reference Area and was higher at the Reference Area. No difference between years, stations, or station-year interaction was observed for mercury or zinc (Table 6.10). For metals in liver with significant results across either station or year, many were not indicative of a project related effect (higher at the reference area or in past EEM years), and these include cadmium, copper, iron, and selenium (see Section 6.2.2.1.2). Arsenic significantly differed between years and increased from 2018 to 2019 (though still lower than 2015 concentrations). Manganese significantly differed for both station and year (Table 6.10) with higher levels in 2018 and 2019 than in 2015, and higher at the Hebron Platform compared to the Reference Area. Hydrocarbons in all three ranges (>C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32}) were screened in for 2019, but no difference was detected between stations (Table 6.8). Hydrocarbons in all three ranges significantly differed between years (Table 6.11), with >C_{10}-C_{16} and >C_{16}-C_{21} hydrocarbon concentrations higher in 2019 than either 2015 or 2018, and >C_{21}-C_{32} concentrations higher in 2019 compared to 2018, though values were similar to 2015. No PAHs were above RDL in 2019, though two (acenaphthylene and fluorene) were screened in for 2018. There are; however, two analytes in American plaice liver composites that will continue to be observed in future monitoring studies to further assess their current trends: an increase in manganese levels at the Hebron Platform and across years, an increase in all three hydrocarbon ranges in 2019.

These results for American plaice livers closely match results from the 2018 EEM program, with the exception of PAHs being screened in for analysis. Manganese was elevated in 2018 compared to 2015, and values in 2019 are slightly elevated compared to 2018, though the difference is slight. Manganese has also consistently been elevated at the Hebron Platform compared to the Reference Area, even in the 2015 fish characterization study. Sediment data collected in 2019 does not show any significant increase in manganese levels in any of the near-field stations around the Hebron platform (Figure 4.10). Manganese has been consistently detected in fish at other platforms including Hibernia but varies significantly between years with no particular trend (HMDC 2017). Data from 2018 and 2019 is also comprised of five composite samples as compared to ten composites in 2015. This smaller sample size may be contributing the detected significance, as there is less variance for the test to act on, in addition to making the test uneven. Taking more samples in the future could help increase statistical power. Longer term monitoring for this variable is needed to determine any persistent trends as well.

An increase was observed in the sediment data for hydrocarbons in both the fuel and lube range, with one station directly northeast of the Hebron Platform showing higher hydrocarbon values in both 2018 and 2019 (Figures 4.15 and 4.16). This sediment station is the closest to the cuttings disposal chute, which has fuel range (>C_{10}-C_{21}) hydrocarbons as a tracer (EMCP 2016b). Both fuel and lube range hydrocarbon concentrations decreased with distance from the Hebron Platform in 2019 (Table 4-4). However, these values are changing evenly between years at the Hebron Platform and Reference Area fish livers. These results are similar to those in 2018, but unlike the previous EEM, hydrocarbons in the lower fuel range (>C_{10}-C_{16}) and lube range (>C_{21}-C_{32}) increased in American plaice livers in 2019. For sediment, levels of lower fuel range hydrocarbons have been steadily increasing since 2015 at several stations (Figure 4.15). The greatest increases were within 500 m of the Hebron Platform, but elevated levels are noted out to 1,250 m (Figure 4.15). Similar to the discussion above for manganese, only five liver composite samples were taken in 2018 and 2019, which may be influencing the detected difference. Hydrocarbons in these ranges are consistently reported at other production operations and may also simply be natural hydrocarbon compounds (DeBlois et al. 2014). Analysis of chromatographs from the hydrocarbon sampling in livers showed compounds were biogenic in origin (pers. comm. Bureau Veritas). Longer term monitoring of these variables is needed to capture potentially natural variation before any further recommendations can be made.

The PAHs acenaphthylene and fluorene were novel detections in the 2018 EEM commercial fish program, but no samples in 2019 had either PAH above its RDL. Neither PAH was detected above its RDL in the sediment program in any monitoring year (Table 4-3). Though it was not above its RDL in 2015, fluorene typically experiences an elevated RDL value due to matrix or co-extractive interference during lab analysis. However, no co-matrix interference was reported in 2019. PAHs are a component in most hydrocarbons, and may be present near the Hebron Platform in drilling muds, raw oil, or produced water (Harman et al. 2009). Both compounds in

2018 were detected at the Hebron Platform and the Reference Area and may represent natural variations due to oil seeps or other hydrocarbon sources on the Grand Banks. PAHs are occasionally detected in the Hibernia EEM program, though typically only a few samples exceed their RDL (HMDC 2017). Terra Nova reported some American plaice with PAHs present in 2012, but attributed these findings to contamination on deck and have otherwise never reported any PAHs (Suncor Energy 2017).

7.3.2 Fish Health Program

American plaice were chosen as the focus of the fish health program for the Hebron EEM program. A broad variety of biological factors were analyzed based on current literature revolving around the effects of oil platforms on fish. Factors analyzed include general biological characteristics, gross pathology of organs, white blood cell counts, and histopathology of the gills and livers.

No difference was found in the ratio of male and female fish between the Hebron Platform and Reference Area in 2019. Male and female fish were assigned maturity codes based on their condition using the index provided in Templeman et al. (1978). No difference was detected between male maturity codes at the two stations, but female fish differed in the maturing in current year (A) (Mat. A-P, code 520) and maturing in current year (C) (Mat. C-P, code 540) maturity codes, with higher incidences at the Reference Area for both (Table 6.12). Maturity codes A-P, B-P, and C-P are different progress stages towards full maturity in the present year (Templeman et al. 1978). Though not significantly different, the Hebron platform has a greater number of fish in the partly spent and spent in current year categories. Delayed maturity is expected when fish are exposed to contamination such as spilled oil (Sol et al. 2000), but for 2019 it appears that fish in the Reference Area are still maturing while fish at the Hebron Platform may have already spawned. Additionally, no differences were detected in hydrocarbon levels between the Hebron Platform and Reference Area fish in the 2019 EEM program. As determining maturity stages can be subjective on the part of individual biologists, this alone is not evidence of any project related effect.

Certain biological characteristics were found to differ between stations in the 2019 EEM program. Male American plaice had significantly higher liver weight and HSI at the Hebron Platform compared to the Reference Area (Table 6.13). After adjusting the p-value by compensating for co-varying measures (e.g., liver weight and total body weight) liver weight remained significantly different (Table 6.14). Female plaice had significantly higher values at the Hebron platform for liver weight and HSI, and higher values at the Reference Area for age and the GSI, with FCI near significance (Table 6.13). Similar adjustment of p-values for co-variates had liver and gonad weight remain significant (Table 6.14). This may point to the Hebron platform acting as a reef or shelter for larger and older fish, due to the lack of fishing pressure and addition food sources, though older female fish at the Reference Area would appear to contradict this. 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, Sargent et al. 2006, Macreadie et al. 2011, Claisse et al. 2014). Hibernia has similar findings in most EEM years, though exceptions do exist (2000, 2004, and 2011; HMDC 2017). Higher liver weight and HSI values at the Hebron Platform would indicate greater healthier energy reserves in fish near the platform (Jan and Ahmed 2016), while variations in gonad weight and the gonadosomatic index may be due to differences in maturity phases in each area.

Comparisons across EEM years for the three indices (FCI, HSI, and GSI) had some significant results. HSI for male plaice varied across stations (higher at the Hebron Platform), while GSI varied among years (higher in 2019 compared to 2015 and 2018) (Table 6.15, Figure 6-10). Both HSI and GSI had a significant interaction term across station and year for female fish (Table 6.15, Figure 6-11). Similar results were found for the 2018 EEM program, with significantly higher HSI values for male fish at the Hebron Platform. However, the 2018 EEM found significant differences for FCI which were not found in 2019 and found no significant differences for GSI (EMCP 2019). EEM results from Hibernia occasionally find difference in biological characteristics, but they were not significant in the most recent published report (HMDC 2017). Longer term monitoring for these variables is needed to see if these trends continue over time or simply represent natural variation.

Significant results were found in 2019 for gross pathology and health assessment index (HAI) values (Table 6.16). While no differences were found for male American plaice, female fish had significantly higher parasite loading at the Hebron Platform compared to the Reference Area. HAI modifications that include parasites (HAI and HAI modification 1) were also significantly higher at the Hebron Platform, but the 2nd HAI modification that excludes parasites was not significantly different (Table 6.16). No significant results were detected between the Hebron Platform and Reference Area in 2018 and no results are available from 2015 for gross pathology. The three HAI indices were compared across years (excluding 2015), as they incorporate all gross pathologies with scores given for severity of various pathologies (Goede and Barton 1990, Adams et al. 1993). No significant differences were detected for male American plaice, but female fish had significantly higher HAI and HAI mod. 1 value at the Hebron Platform compared to the Reference Area (Table 6.17). However, no significant differences were detected for HAI mod. 2 across years, indicating that parasite loading is the cause for this significant difference as the removal of parasites is the only change from the HAI mod. 1 to mod. 2. Mathieu et al. (2011) report very few, if any, gross pathologies in American plaice taken as part of the Terra Nova EEM program. Hibernia reports similar pathologies, and incidence rates are also similar to those in this study, with parasites typically as the most common incidence (HMDC 2017). Parasite loading can be a difficult environmental indicator, as increased loading can be due to exposure to contaminants or stress response, but a higher parasite load can also cause a stress response and lead to false positives (Khan 1990, Marcogliese et al. 1998, Sures 2004). Additionally, a higher parasite load is typical of larger and older fish (Lo et al. 1998), though in 2019 the Reference Area had significantly older female fish. Longer term monitoring for gross pathology is needed to verify if these trends are consistent over time.

Blood haematology had no significant differences in the 2019 EEM for neutrophils, lymphocytes, or thrombocytes, through neutrophils was very near significance (Table 6.18). Cross-year comparisons were made using data only from the Hebron platform in 2015, as Reference Area samples were discarded that year. Significant results were found between stations for all three blood cell types, as well as differences between years for neutrophils and thrombocytes (Table 6.19). Neutrophils and thrombocytes were higher at the Hebron platform, while lymphocytes were higher at the Reference Area. Neutrophils and thrombocytes were higher in 2015 compared to 2018 or 2019. The majority of these significant results are likely driven by the 2015 data, as it differs greatly from 2018 and 2019 for all three cell types, while 2018 and 2019 data appear similar for all three. Lymphocytes help fight infections, and a decrease in the number of lymphocytes is generally considered to be a stress response (Chen et al. 2002). Thrombocytes are used in blood clotting, and a decrease typically indicates poor fish health (Corrêa et al. 2016). Though the proportion of lymphocytes was lower at the Hebron Platform in 2019, neutrophils and thrombocytes were higher. No difference was detected between stations in the 2018 or 2019 program, and so this finding may simply be a regional pattern in this area of the Grand Banks. As these proportions are related to each other, clear long-term trends will take longer to identify.

Mixed function oxygenases (MFOs), in particular EROD, is 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 2019 EEM, female plaice had significantly higher EROD values at the Hebron Platform compared to the Reference Area, while males did not (though it was near significance) (Table 6.20). Cross-year comparisons showed a significant difference between years, and a significant interaction term, for both sexes, indicating a potential project effect (Table 6.21). Both sexes had a higher value in 2019 compared to 2015 and 2018, and the interaction term points to the trend changing as the higher MFO results varies from being at the Hebron Platform or at the Reference Area in different years (Figure 6-17). Similar results were noted in the 2018 EEM with significant interaction terms for both sexes. The elevation in MFO activity at both the Hebron Platform and Reference Area may point to natural fluctuations in the area, though the Hebron Platform values being higher for females and nearly significantly higher for males in 2019 may indicate a project related effect. Both Terra Nova and Hibernia have found differences in some years between platform and reference stations, but there is no clear pattern as the reference station is as likely to be higher as the platform (Mathieu et al. 2011, HMDC 2017). Longer term monitoring at the Hebron Platform is needed to clarify if this is a project related trend.

Of the 19 different liver histopathology lesions tested for, significant differences between stations was detected for hepatocellular carcinoma (higher at the Reference Area) and both small and all hepatocellular carcinomas (both higher at the Hebron Platform) (Table 6.22). A MANOVA comparing across stations and years found a significant difference across stations and years, with a significant interaction term (Table 6.24). Each term in the MANOVA was subjected to a two-way ANVOA, and one term varied across years and four terms had significant interaction terms, indicating a potential project effect (Figure 6-20). Bile duct hyperplasia had significantly higher prevalence in 2019 compared to 2018 and 2015. Hepatocellular carcinoma, macrophage aggregates (0-3), and both small and large hepatocellular vacuoles had significant interaction terms, with varying trends between years indicating a potential project effect (Table 6.24, Figure 6-20). Hepatocellular vacuoles is the accumulation of fluid, typically lipids, in the cells of the liver, and is regarded as pre-neoplastic change (Feist et al. 2004). 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 Hebron Platform was observed. A separate analysis (not reported here) for both sexes comparing carcinoma incidence and age using a one-way ANVOA found no significant difference across all years. A longer time series will allow for better comparisons across years. The same laboratory does liver histopathology for the Hibernia Platform EEM, and very similar pathologies and incidence rates were observed in the 2016 and 2018 programs (HMDC 2019, Unpublished Data), though these rates are elevated compared to past Hibernia EEM programs and Terra Nova 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 2018 EEM. The only significant difference was a higher incidence of normal condition fish at the Hebron Platform (Table 6.23). A seven factor MANOVA was used to compare the stations between years, and a significant difference was found between stations, years, as well as the interaction term indicating a potential project effect (Table 6.25). Two-way ANOVAs for each factor were used to see which factors contribute to the differences. Tip hyperplasia had a significant interaction term (potential project effect), with incidence being higher at the Hebron Platform compared to the Reference Area, though 2019 values are similar to 2018. Basal and distal hyperplasia significantly differed between stations and years, with 2019 values lower than 2018, and higher at the Hebron Platform. Fusion significantly differed between years and was lower in 2019 compared to 2018. Telangiectasia significantly differed between stations and was higher at the Hebron platform compared to the Reference Area in all years. In fish, the gills are a major uptake station 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 Hebron Platform and Reference Area had 98.3 percent and 97.0 percent of fish present normal gill histologies, respectively (Table 6.23). Though some histologies were higher in 2019 and at the Hebron Platform, many also had significant interactions terms with shifting trends between years (some higher at the Hebron Platform in one year and higher at the Reference Area in the next, and vice versa) (Figure 6-21). A longer time series is needed to verify the direction of these changes and further define discernible project related trends.

Histopathology results for the Hebron 2019 EEM program for both liver and gill are similar to findings from the Hibernia and HSE EEM results in 2016 and 2018 (HMDC 2019, Unpublished Data). 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 (HMDC Unpublished Data, 2017, Wolf et al. 2015). Hebron and Hibernia have both used the same laboratory for gill and liver histopathology since 2015 and therefore have more comparable results.

7.5 EEM Interpretation

The design of the EEM program is that critical elements of the receiving marine environment are being monitored to provide timely and beneficial information to detect any potential deleterious effects to the marine environment (EMCP 2017).

7.5.1 Sediment Component

With respect to sediment quality, the generic monitoring hypothesis is:

> *H_0 = Approved discharges from the Project will not induce changes in the receiving environment that may be distinguished statistically, as being more severe in outcome than predicted in the CSR.*

The effects predicted in the CSR include increased fine class sediments close to the installed platform and increases in certain metals (barium) and hydrocarbons from the drill cuttings near the discharge point. These results found a decrease in analyte concentration with increasing distance from the Hebron Platform which is what would be predicted in a project-level effect. Barium, total organic carbon, $>C_{10}$-C_{21}, $>C_{21}$-C_{32}, sulphide, and sulphur were negatively correlated with distance from the Hebron Platform. These changes, however, occurred within 1,000 m of the Hebron Platform which was predicted in the CSR. No statistical differences were noted for PetroTox or amphipod survival. Differences were noted between years for benthic community with some more pollution -tolerant species increasing in abundance in near-field stations (especially 8-250m, that station closest to the cutting discharge chute) and some other significant changes in assemblages of crustaceans, molluscs, and echinoderms, but all of these changes are within 1,000 m of the platform and therefore aligned with the predictions in the CSR. Therefore, the sediment quality null hypothesis is not rejected for the 2019 EEM program.

7.5.2 Water Quality Component

Generic monitoring hypotheses for the water quality component are:

> *H_0: Distribution of approved produced water discharges from the Project will not differ from the zone of influence as predicted in the CSR.*

Predictive modelling of the produced water plume in the CSR (EMCP 2011) indicated that effects resulting from the discharge of produced water are expected to be undetectable further than 500 m from the Hebron Platform. Hydrocarbons were not detected in any water samples. Based on other analytes, the results also indicate detection of the produced water plume within 50-100 m of the discharge outlet with decreasing concentrations with distance and not statistically elevated at the 500m stations. Therefore, the water quality null hypothesis is not rejected for the 2019 EEM program.

7.5.3 Commercial Fish Component

Generic monitoring hypotheses for the commercial fish component are:

> *H_0: Approved solid and liquid project discharges from Hebron's production and drilling operations will not result in taint of American plaice resources at the Hebron Project area relative to Reference Area(s), as measured using taste panels.*

> *H_0: Approved solid and liquid project discharges from Hebron's production and drilling operations will not result in adverse effects to American plaice health at the Hebron Project area relative to Reference Area(s), as measured through assessment of biomarkers and general health indices.*

As there were no taste testing this year, the first commercial fish null hypothesis could not be tested. However, the levels of chemical analytes in American plaice fillets were not significantly different between sites in 2019. Therefore, the first commercial fish null hypothesis is not rejected for the 2019 EEM program but not fully assessed for the 2019 program due to lack of the taste testing component.

No significant differences were seen for most of the chemical profiles of American plaice between stations, though some variation existed between years; the exception being cadmium, iron, and manganese with only manganese higher at the Platform. Larger female fish were caught at the Hebron Platform and male fish tended to be larger at the Reference Area, but this is not an adverse effect and is may be due to an artificial reef effect from the physical structures at the platform. Female fish had elevated EROD concentrations at Hebron Platform, but this is likely natural variation as other platforms note shifts from year to year with MFO often higher at the reference area or the platform. There was some variation and differences in the some of the health indices between stations but those results appear to have higher indices at the platform station. A longer time series is needed for any definitive proof of an adverse effect; therefore, the second commercial fish null hypothesis is not rejected for the 2019 EEM program.

8.0 RECOMMENDATIONS

8.1 Sediment Component

As more EEM years are added to the data set the statistical power for analysis increases with the addition of more samples. The northeast cluster of stations is outside the drill cutting footprint and are not expected to be influenced by operation activities from the Hebron Platform. These stations were original developed as they related to a potential drill centre and tieback that was never developed. We therefore recommend revising the EEM to remove the high density of stations sampled in the northeast cluster in subsequent EEM years.

9.0 CLOSURE

This report on the Hebron 2019 EEM has been prepared for the exclusive use by EMCP. 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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