EXXONMOBIL CANADA PROPERTIES

HEBRON PLATFORM ENVIRONMENTAL EFFECTS MONITORING PROGRAM (2020)

VOLUME I - INTERPRETATION

MARCH 21, 2023

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FINAL

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

VERSION TRACKING

Version	Date (dd-mmm-yyyy)	Managing Author	Reviewer Name	Status and Comments
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EXECUTIVE SUMMARY

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. This report presents the results of the 2020 monitoring program for the Hebron Platform.

SEDIMENT COMPONENT

In 2020, the Hebron Platform was the single point source for discharges in the area. Sediment samples were collected from predetermined stations at varying distances on radii originating from the Hebron Platform. A total of 36 stations were sampled for sediment quality triad analyses (physical/chemical characteristics, toxicity, and benthic community). The results of the 2020 EEM survey were compared to results from all EEM survey years.

Physical and Chemical Characteristics

A total of 20 analytes were screened-in for further analysis in 2020. There was a statistically significant difference between EEM years and baseline. Several analytes were negatively correlated to distance from the Hebron Platform including barium, fuel and lube range hydrocarbons, and sulphur. Statistically higher concentrations of barium, C_{10}-C_{21} hydrocarbons, and C_{21}-C_{32} hydrocarbons occurred within 500 m of the Hebron Platform. This is aligned with CSR drilling waste fate modelling which predicted highest levels of drill solids deposition to occur within 500 m. All other screened-in analytes concentrations were not statistically significant with distance. Station 8-250 sediment had the highest reported concentrations of ten analytes including barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons, sulphur, and several metals. This is similar to previous EEM survey years (2018 and 2019). Also, as in previous EEM surveys, the highest concentrations of gravel, precent fines, TOC, ammonia, and moisture occurred at stations more than 6,000 m from the Hebron Platform.

Toxicity

All Hebron EEM Year Three sediment samples were deemed non-toxic based on Environment Canada Guidelines. This includes sediments collected at Station 8-250 which contained the highest level of hydrocarbons recorded to date at 432 mg/kg. Samples taken more than 500 m from the Platform were all below the no-effect PetroTox threshold and only obligatory samples (i.e., samples within 500 m of the platform) were sent for further testing.

Benthic Community Structure

There was little overall change in community parameters compared to the three EEM years (2018-2020). The means for three of the parameters have slightly increased in 2020 from baseline levels; number of taxa, evenness, and Shannon-Weiner diversity index. In 2020, of the six monitoring parameters, the stations with the lowest values were mainly found in the Near-field while those with the highest were found in the Far-field. This trend was also observed in previous EEM years. However, in the baseline survey while the highest values were mainly in the Far-field, the lowest values for the number of taxa, abundance, and species richness were distributed throughout all distances from the Platform. As in previous survey years and baseline, polychaetes were the most abundant taxa observed (42 percent). Disturbance tolerant polychaetes (e.g., Capitellidae and Spionidae) were observed in relatively low abundances throughout the survey area with the highest abundances occurring at stations more than 2,000 m from the Hebron Platform. Transition and intolerant species (e.g., *Tharyx* sp. and *Exogone hebes*) were observed through out the survey area with the highest abundances observed more than 1,000 m from the Platform. The benthic communities at stations within 1,000 m from the Platform were statistically different from those at greater distances by the presence of Clitellata taxa, *Tharyx* sp., and *Exogone hebes*. At stations more than 1,000 m from the Platform, arthropods and other species of annelids contributed more to the community structure. From multivariate analysis, concentrations of gravel, and fuel and lube range hydrocarbons were key variables in explaining variance in community structure between stations.

WATER QUALITY COMPONENT

The water sampling/monitoring program at Hebron is designed to assess the potential effects of produced water and other liquid discharges. Water samples were collected from predetermined stations at varying distances from the Hebron Platform and at two reference stations. Water samples were tested for metals and hydrocarbons. 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. Boron was the only analyte with levels that were significantly different among Sites, with higher levels at the Hebron Platform relative to the Reference Site. However, Site differences are not likely to be a project-induced change based on relatively low boron levels in produced water prior to discharge.

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 NW 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, total metals and hydrocarbons (including polycyclic aromatic hydrocarbons [PAHs]), and taint testing 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 2020 consistently showed the presence of arsenic, mercury, and zinc. No hydrocarbons were detected in fillets. Significantly higher concentrations of mercury and zinc were detected at the Hebron Platform. Comparison across EEM years found a significant difference for zinc, with lower values in 2018 and higher values in 2020 though generally similar to 2015 results. 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 2020, or lower at the Hebron Platform, with the exception of manganese and zinc had significant interaction terms, indicating a potential project-induced change. Hydrocarbons in all three ranges were screened in for 2020, with significantly higher values at the Reference Area for $>C_{10}$-C_{16} and $>C_{21}$-C_{32} hydrocarbons. Hydrocarbons in all three ranges have been steadily increasing at both sites since 2015. Additionally, hydrocarbons in the $>C_{10}$-C_{16} range had a significant interaction term indicating a potential project-induced change.

Sensory Evaluation

For the 2020 EEM program, no significant difference was detected between the Hebron Platform and the Reference Area in either the triangle test or the hedonic scaling. These results are consistent with findings in 2015 and 2018 (no taste panels were completed for the 2019 EEM).

Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American Plaice surveyed in 2020. As few male fish were caught in 2020, statistical comparisons were not completed due to the small sample size.

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2020 for the maturing in present year codes (530) and spent in present year (560), with code 530 higher at the Reference Area and 560 higher at the Hebron Platform. For biological characteristics, female fish significantly differed in all biological characteristics with the exception of age with all those that differed higher occurred at the Hebron Platform compared to the Reference Area. 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 including male HSI differing between sites (higher at the Hebron Platform) and years (higher in 2020 compared to past years), and GSI differed between years, with higher values in 2019 compared to other EEM years. Female plaice significantly differed between sites and years for FCI and had significant interaction terms for both HSI and GSI, indicating a potential project-induced change.

No significant differences were found between the areas for any pathology in female fish (males not statistically compared in 2020). Female American Plaice 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), but not the second modification (removal of skin, fins, and parasites).

For haematology, no differences were detected in the 2020 EEM program. For the cross-year comparison, significant differences were found between sites 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. The interaction term was significant for thrombocytes, indicating a potential project-induced change.

For MFO, no significant differences were found between sites for MFO activity for male (low statistical power due to low catch number) or female fish. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, there were no significant differences in the occurrence of hepatic lesions between Hebron platform and Reference Area in 2020. 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 other monitoring years. Medium hepatocellular vacuoles varied significantly by year with a higher incidence in 2020 compared to other years. Hepatocellular carcinoma, macrophage aggregates, and small hepatocellular vacuoles all had significant interactions terms. 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 and 2020.

For gill histopathology, no conditions significantly differed in 2020. However, a MANOVA for seven gill histology factors detected significant results across site, year, with a significant interaction term. Significant differences between sites was largely due to basal and distal hyperplasia, telangiectasia, and epithelial lifting (all higher at the Hebron platform). Significant differences between years was driven by tip (lower in 2020), basal (higher in 2020), and distal hyperplasia (lower in 2020), fusion (lower in 2020), and epithelial lifting (higher in 2020). Tip and distal hyperplasia had significant interaction terms.

CONCLUSION

Overall, project-induced changes 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, and sulphur) were higher in the near-field, especially at the site closest to the drill cuttings chute. For the water component, only boron was found to differ between sites in 2020. Potential effects on the environment may be highly localized, variable, and are within the CSR predictions. The results of the commercial fish component in 2020 found significant differences in mercury and zinc fillet concentrations with higher levels detected from Hebron Platform samples. Hydrocarbons were not detected in fillet samples from either location. Liver composite analyses found significant differences in arsenic, cadmium, copper, manganese, selenium, zinc, C_{10}-C_{16} and C_{21}-C_{32} hydrocarbon between Reference Area and the Hebron with all concentrations higher at the Reference Area in 2020. There were no significant differences between haematology, MFO, liver histopathology or gill histopathology between the Hebron Platform and the Reference Area in 2020. These findings are not consistent across EEM years and may be associated with naturally occurring factors. 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 2020 EEM survey.

ACKNOWLEDGEMENTS

The 2020 Hebron EEM program was conducted under contract to ExxonMobil Canada Properties Ltd. (EMCP) under the guidance of Mike Quilty and Mitchell Wiseman, Environmental Advisors for EMCP, and managed by Kevin Baldwin as Associate / Program Manager, Met-Ocean Services, at WSP E & I Canada Limited (WSP), formerly Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited, in St. John's, Newfoundland and Labrador Canada.

The biological survey program was conducted aboard the the Motor Vessel (MV) *Aqviq* with Captain Lloyd Price and crew. Fish processing and sampling was conducted by Michael Teasdale, Justin So, Shaun Garland, Kyle Millar, and Ashton Verge from WSP and Julek Chawarski from Edgewise Environmental. Fish health samples (MFO, haematology, gill histopathology) were processed and analyzed by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University and managed by Stephen Hill. Liver histopathology analysis was conducted by by Dr. Rasul Khan. Aging of American Plaice otoliths were conducted by Mark Gautreau from the Canadian Rivers Institute, University of New Brunswick (Fredericton, New Brunswick). Fish fillet taint testing was conducted by the Marine Institute of Memorial University and managed by Kim Snelgrove and Heather Burke (St. John's, Newfoundland and Labrador).

The sediment sampling program was conducted aboard the Offshore Support Vessel (OSV) *Avalon Sea* with the assistance of her crew. Fugro GeoSurveys provided geopositional services for sediment collections by Andrew Walsh and Kelly Power. Narcissus Walsh (Narwhal Environmental Consulting Services, St. John's, Newfoundland and Labrador) provided logistical expertise and help with the mobilization. WSP sampling crew included Michael Teasdale, Andrew Peddle, Kyle Millar, Brett Barter, Lara Miles, and Justin So.

Laboratory quantification of chemical analytes in sediment and tissues as well as particle size analysis was conducted by Bureau Veritas and managed by Heather Macumber (Bedford, Nova Scotia). Sediment toxicity assays were performed by Avalon Laboratories and managed by Suzette Winter and Jennifer Mews (St. John's, Newfoundland and Labrador). Benthic invertebrate community analysis was conducted by Jo-Anne Monahan from BioTech Taxonomy (Smithtown, New Brunswick).

Data analysis and reporting was conducted by WSP. Sediment quality, toxicity, and benthic community data were analyzed by Lara Miles and Steven Beale for the sediment quality component. Water quality data was analyzed by Justin So and Kyle Millar for the water quality component. Fish tissue (body burden) and fish health parameters were analyzed by Kyle Millar and Matt Gosse for the commercial fish component. GIS technical support was provided by Juanita Abbott. The Volume I Interpretation report was written by Lara Miles, Kyle Millar, Steven Beale, Shaun Garland, Michael Teasdale, and Justin So. The Volume II Methods and Results was compiled by Shaun Garland and Justin So. Senior Independent Review was conducted by James McCarthy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
CAPP	Canadian Association of Petroleum Producers
CEAA	Canadian Environmental Assessment Act
CCME	Canadian Council of Ministers of the Environment
CDRF	Cold-Ocean Deep-Sea Research Facility
C-NLOPB	Canada-Newfoundland and Labrador Petroleum Board
CPUE	Catch per unit effort
CRI	Cutting 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
EA	Environmental Assessment
ECCC	Environment and Climate Change Canada
EEM	Environmental Effects Monitoring
EMCP	ExxonMobil Canada Properties
EROD	ethoxyresorufin-O-deethylase
FCI	Fulton's condition index
FPSO	Floating production storage and offloading
GBS	Gravity-based structure
GSI	Gonadosomatic index
HAI	Health assessment index
H'	Shannon-Wiener Diversity Index
H_0	Null hypothesis
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 Hebron Platform
MUN	Memorial University of Newfoundland
MV	Motor Vessel

NAF	Non-aqueous fluid (synonymous with SBM)
NEB	National Energy Board
MS	Mean square
N/n	Abundance/number
NB	New Brunswick
NL	Newfoundland and Labrador
nMDS	Non-metric multidimensional scaling
NS	Nova Scotia
OCI	Ocean Choice International
OCNS	Offshore Chemical Notification Scheme
OLS	Offshore loading system
OSV	Offshore support vessel
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 (synonymous with NAF)
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 Baseline
WBM	Water-based mud
WSP	WSP E & I Canada Limited
Y3	Year 3 (of the monitoring program)

Units

%	Percent
°C	Degrees Celsius
cm	Centimetre
Eh	Redox potential
g	Grams
kg	Kilograms
km	Kilometre
L	Litre
m	Metre

mg	Milligrams
mV	Millivolts
µg	Microgram
mm	Millimetre

1.0 INTRODUCTION

ExxonMobil Canada Properties (EMCP) is committed to conducting an environmental effects monitoring (EEM) program to detect potential project-induced changes from the Hebron offshore platform. The results will enable an assessment of the need for additional mitigations (EMCP 2017a). This report presents the results of the 2020 field program for the Hebron Platform based on the approved methods and plans from the Hebron Offshore EEM Plan (EMCP 2017a). For the Hebron Platform, the 2020 program represents the 3rd Production-Phase EEM field program.

1.1 Report Structure

The Hebron EEM Program report (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, 2013, 2017b). A plain language summary of results is presented at the end of individual component sections. The discussion section provides an overall assessment of the potential project-induced changes 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 m (mean sea level) (Figure 1-1). The Hebron oil field is in proximity to three other offshore oil and gas drilling and production 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 Cenovus 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 1-2). 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.

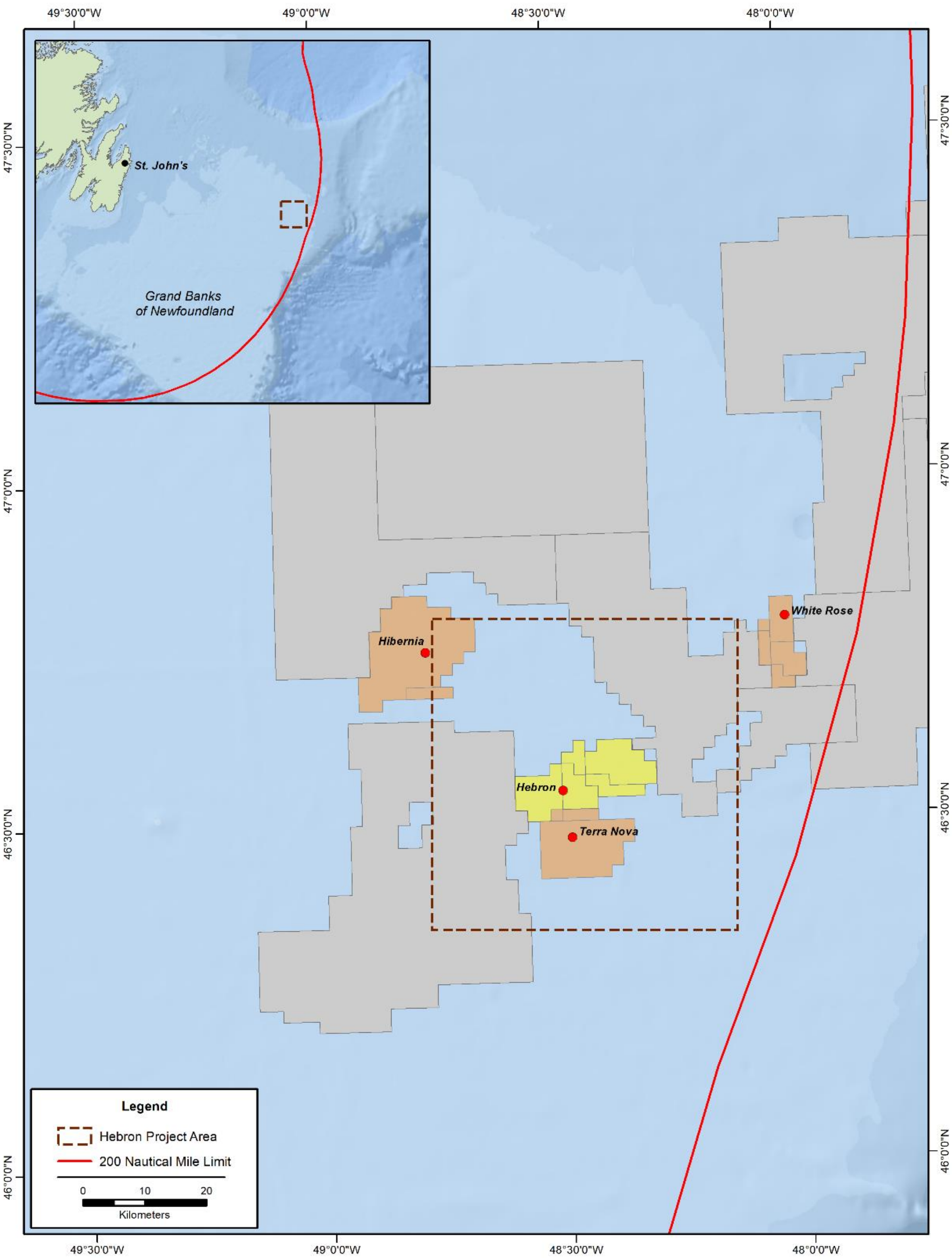


Figure 1-1 Location of the Hebron oil field in relation to St. John's, Newfoundland and Labrador, and proximity to other offshore production operations on the Grand Banks.

Figure 1-2 Hebron Platform with the OSV *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 2017a). 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 2017a). The purpose of this EEM is to validate the Hebron Project Comprehensive Study Report (CSR) predictions that are relevant to effects related to marine discharges (EMCP 2017a). 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) (NEB et al. 2010). The OWTG are applicable to waste materials including effluents, emissions and solid wastes with discharge limits defined in an offshore operator's Environmental Protection Plan. Discharges are monitored according to Paragraph 9(j) of the Drilling and Production Regulations (NEB et al. 2010). Operations at Hebron are required to comply with discharge levels and volumes 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.

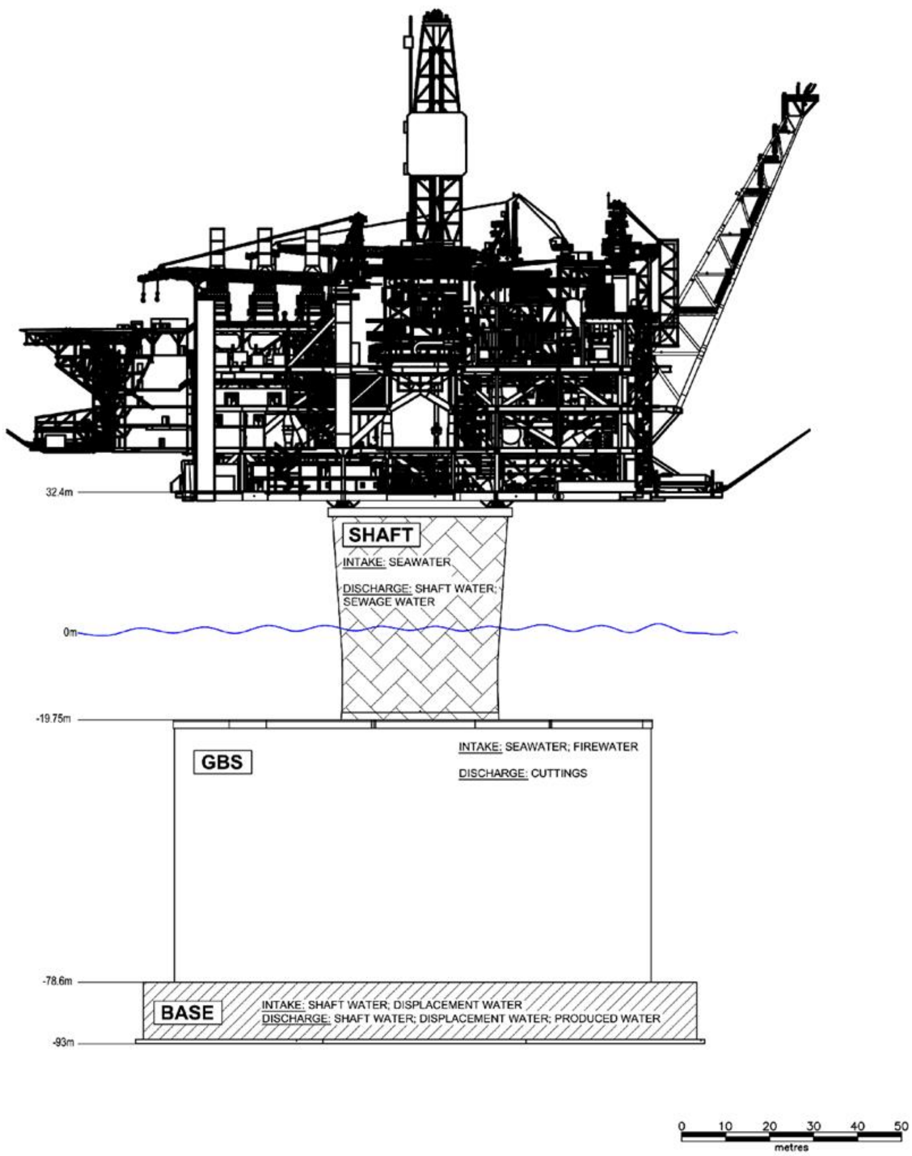


Figure 2-1 Intake and discharge vertical locations for the Hebron Platform; modified from EMCP (2017a). All discharges are below the water line.

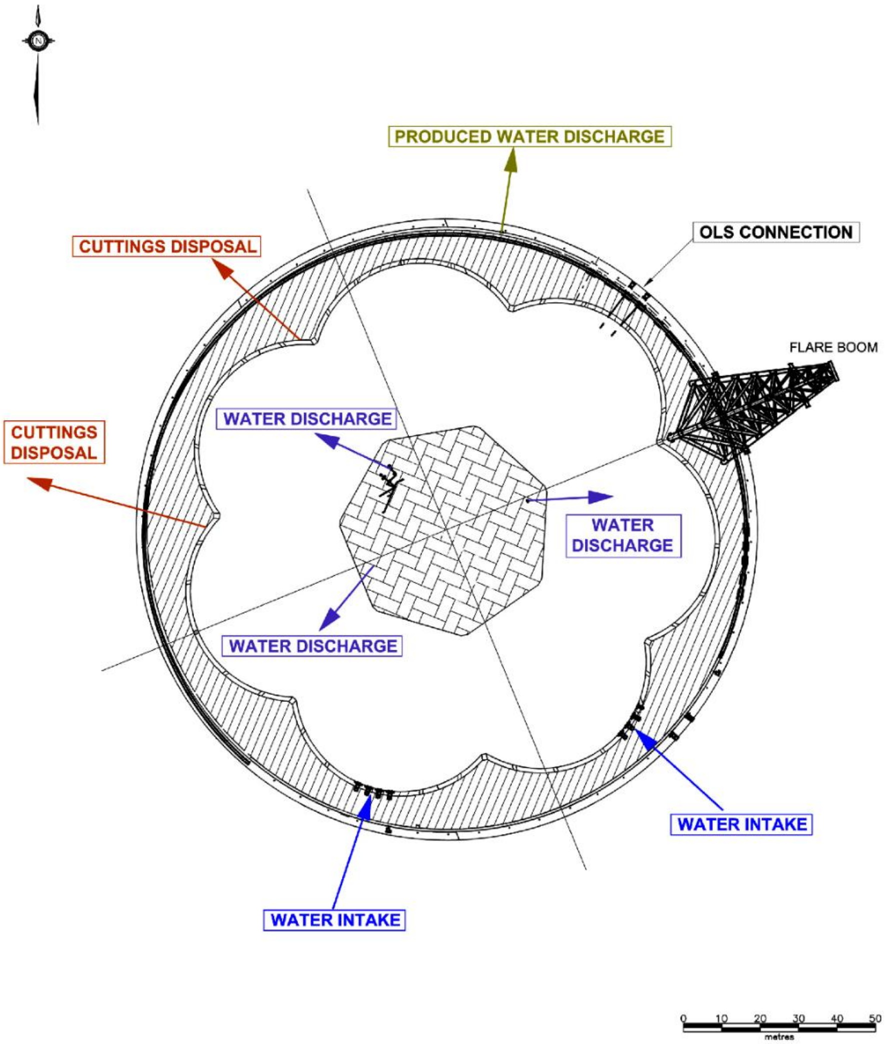


Figure 2-2 Discharge orientations for the Hebron Platform. All discharges are below the water line. Purple discharges are from shaft and rest are from GBS itself or the base. Modified from EMCP (2017a).

2.1 Construction and Operation Activities

Construction and operation activities may have potential project-induced changes on the environmental components assessed as part of the EEM program. The Hebron Platform has been operational since 2017 with ongoing discharges of produced water and other authorized waste discharges. The majority of synthetic-based mud (SBM) drill cuttings from the platform are reinjected into the formation. Vessel traffic in the Project Area is from standby, supply, and servicing and environmental monitoring activities. There have been no construction activities since 2017.

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 managed prior to discharge once the drilling mud is returned to surface 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 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 for hole stabilization, lubricity, and cooling capabilities.

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. 2014a). Depending on the composition of the bedrock formation being drilled, various salts and organic gels may also be added (Trefry et al. 2013). 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 2017a).

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 2017a), 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 2017a). It is composed of aliphatic hydrocarbons in the fuel range (>C_{10}-C_{21}) and contains no aromatic hydrocarbons (DeBlois et al. 2014a). Puredrill IA-35LV is also rated as a Category E product (least hazardous) in the Offshore Chemical Notification Scheme (OCNS) (NEB et al. 2009, DeBlois et al. 2014b).

For Hebron Platform drilling, SBM cutting re-injection (CRI) equipment is currently operating with a majority of SBM drill cuttings and solids being reinjected into the formation. Limited discharges of SBM cuttings occurs occasionally 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 (EMCP 2017b). Table 2.1 lists the SBM discharges for 2019-2020 from the Hebron Platform.

Table 2.1 Synthetic-based mud drill cuttings discharges from the Hebron Platform (2019-2020).

Discharge Period		Oil on Cuttings Concentration (%)	Calculated Oil Released (m^3)	Discharged Wet Solids (tonne)	Total Injected Volume (m^3)
Dec 23, 2019	Feb 3, 2020	11.32	1.13	8.24	7733
Feb 4, 2020	Mar 18, 2020	15.81	2.39	12.47	7250
Mar 19,2020	Apr 25, 2020	14.04	2.78	16.36	6320
May 7, 2020	Jun 25, 2020	12.90	1.10	7.06	8505
Apr 26, 2020	Jul 30, 2020	15.85	2.55	13.29	8358
Aug 1, 2020	Aug 26, 2020	11.63	3.21	22.75	6058
Aug 27, 2020	Oct 13, 2020	11.56	2.28	16.25	14984
Oct 14, 2020	Nov 25, 2020	12.00	9.51	65.4	13087
Project Total (2019-2020)			24.95	161.82	72295

Notes:
2020 EEM sampling was completed in July and September for Biological (fish sampling) and Physical (sediment and water sampling) 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 were continuous in 2020 with occasional intermittent periods when no produced water was released (Figure 2-3, Figure 2-4, Table 2.2). Produced water discharges have increased relative to 2019 discharges (Figure 2-4).

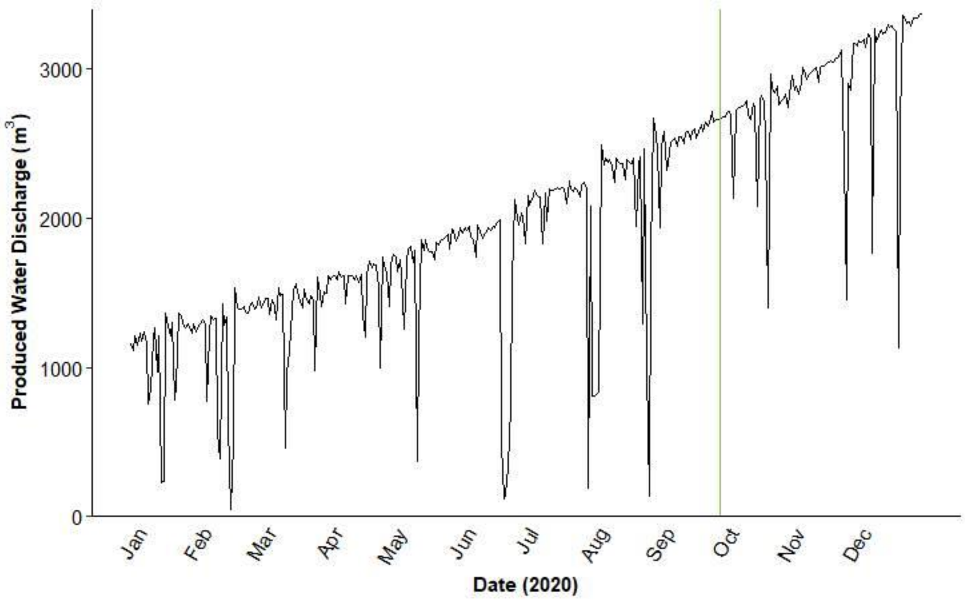


Figure 2-3 Daily average produced water discharges between January and December 2020.

Note: Green line indicates timing of Hebron 2020 EEM water quality component sampling.

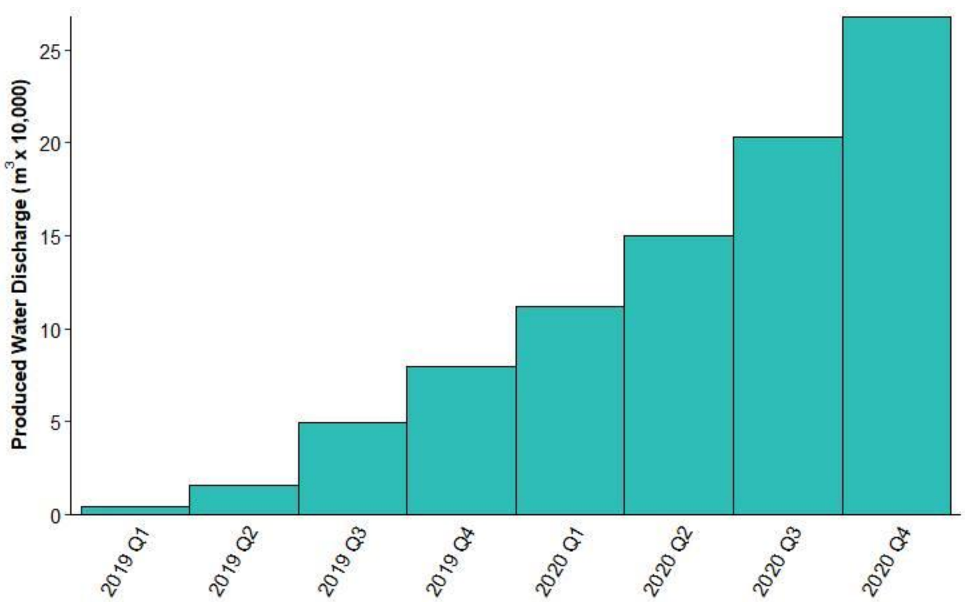


Figure 2-4 Quarterly produced water discharges.

Table 2.2 Summary of 2020 oil in water (Produced) concentration.

Discharge Period (2020)	Monthly Mean 24-hour Oil Concentrations* (mg/L)	Monthly Mean of 30-Day Rolling Average Oil Discharge** (mg/L)
January	6.6	6.6
February	6.5	7.7
March	10.2	6.7
April	6.6	10.0
May	7.3	6.7
June	4.7	6.4
July	6.6	6.1
August	5.9	6.0
September	6.9	7.4
October	6.0	5.5
November	7.6	7.5
December	8.1	7.4

Notes:
2020 EEM sampling was completed in July and September for Biological (fish sampling) and Physical (sediment and water sampling) cruise, respectively
* Midnight to midnight measurement (0000-0000 hr). 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 for tanker loading. 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 crude storage cell 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 monitored to verify oil in water concentrations are within the regulatory allowable limit of 15mg/L on an instantaneous basis. 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 2020 oil concentration and flow rates for Hebron Storage Displacement Water Discharges.

Table 2.3 2020 Storage displacement water oil in water concentrations and flow.

Month (2020)	Oil Concentration (mg/L)*		Daily Average Effluent Flow (m^3/day)	
	Average	Range	Average	Range
January	0.8	0.0 - 9.2	21847	3190 - 25941
February	0.9	0.0 - 8.7	23142	8910 - 25703
March	0.8	0.0 - 2.2	23777	16325 - 26241
April	1.2	0.0 - 9.9	24099	19214 - 25236
May	2.5	0.0 - 10.8	24424	20467 - 27618
June	0.5	0.0 - 2.2	23225	14040 - 25502
July	1.2	0.0 - 13.7	24751	10517 - 26149
August	0.2	0.0 - 1.4	23468	13127 - 25390
September	0.3	0.0 - 1.2	21270	16987 - 23732
October	0.4	0.0 - 1.6	21343	13879 - 23706
November	0.5	0.0 - 1.6	21024	14754 - 22448
December	0.5	0.0 - 2.5	22881	12848 - 26754

Notes:
2020 EEM sampling was completed in July and September for Biological (fish sampling) and Physical (sediment and water sampling) 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 (NEB et al. 2010). Deck drainage discharge may contain various substances such as cleaning detergents, and small amounts of hydrocarbons (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 treatment systems.

The Process Area drains collect all drainage on the platform not directly related to drilling. They can contain both hazardous areas (high-pressure systems; typically related to crude processing) and non-hazardous areas (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 and receiver as well as drainage 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 to prevent jet fuel from entering the drain system (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 2017a). The Drilling

Area non-hazardous drain effluent consists of sea water, minimal hydrocarbons, and mud components (EMCP 2017a). The daily mean oil concentrations and flow for process area drain water are presented in Table 2.4; note that there was no Drilling Area drain discharges in 2020, drilling area drain effluent was reinjected.

Drainage from the helideck and helifuel tank storage areas are routed directly overboard to prevent the helifuel from entering the drains system and from creating standing pools on the helideck.

Table 2.4 Process Area Drainage water discharges (2020).

Month (2020)	Oil Concentration (mg/L)*		Daily Average Effluent Flow (m^3/day)	
	Average	Range	Average	Range
January	3.1	0.6 - 19.5	212.5	123.2 - 335
February	3.3	0.4 - 8.7	165.4	121.8 - 288.4
March	4.8	2.0 - 10.9	208.1	134.9 - 275.6
April	3.1	0.8 - 13.3	194.6	0.3 - 313.4
May	2.8	1.0 - 7.5	182.1	63.7 - 312.1
June	4.7	1.0 - 13.3	184.1	0.0 - 423.1
July [a]	2.2	0.6 - 5.3	117.0	54 - 201.7
August	2.9	1.2 - 5.4	109.9	48.2 - 190
September [b]	3.1	0.8 - 6.6	151.6	66.7 - 273.7
October	2.7	0.6 - 4.8	222.4	125.2 - 369.1
November	3.7	1.3 - 7.0	221.5	139.1 - 405.4
December	3.8	1.0 - 6.6	203.6	147.2 - 354

Notes:
2020 EEM sampling was completed in July and September for Biological (fish sampling) and Physical (sediment and water sampling) cruise, respectively
* Regulatory Daily Limit is 15 mg/L

2.4.3 Seawater Return

Cooling water consists of sea water that has been pumped onto the platform, chlorinated 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 instantaneous limit of 2.0 mg/L (EMCP 2017b). Table 2.5 presents the mean residual chlorine concentrations of the seawater return discharge and monthly range for 2020.

Table 2.5 2020 Sea water return residual chlorine concentrations.

Month (2020)	Daily Residual Chlorine Concentration (mg/L)*	
	Average	**Range**
January	1.6	1.1 - 1.8
February	1.5	1.2 - 1.6
March	1.5	1.3 - 1.8
April	1.6	1.3 - 1.7
May	1.6	1.4 - 1.9
June	1.6	1.5 - 2.3
July	1.5	0.7 - 1.9
August	1.5	0.4 - 1.9
September	1.5	1.3 - 1.7
October	1.6	1.3 - 1.7
November	1.7	1.3 - 1.9
December	1.7	1.1 - 1.9

Notes:
2020 EEM sampling was completed in July and September for Biological (fish sampling) and Physical (sediment and water sampling) 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). Sanitary and domestic wastes must be macerated to a particle size of six mm or less (NEB et al. 2010). Domestic effluents are also treated to remove grease and screened to remove plastic and metals (EMCP 2017a).

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 chapters.

3.0 ENVIRONMENTAL EFFECTS MONITORING SUMMARY

3.1 Program Objectives

The ultimate purpose of the EEM program is to validate the Hebron 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 (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 CSR (EMCP 2011); 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 drilling operations at Hebron will alter near-field sediment physical and chemical characteristics within the vicinity of drilling related discharges in particular cuttings and solids recovered from the mud recovery system. Direct changes to fish populations as a result of drill cuttings discharge were expected to be unlikely, whereas changes 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.

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 km² 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 km² of seafloor area around the platform could be affected by project activities (pg. 7-100 of CSR) (EMCP 2011, 2017). 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 Plan (EMCP 2017b) has taken these conclusions and predictions into consideration by emphasizing sediment sampling within 2 km from the platform (primary) with some farther afield (>2 km) 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., >2 km from the platform) (EMCP 2011).

3.2.1 Water Quality Prediction and Assessment

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 project-induced changes 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).

3.2.2 Commercial Fish Prediction and Assessment

The CSR predicted that there will be no significant effect on commercial fisheries (CSR; Section 8.5.5) (EMCP 2011). 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.

3.3 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 Hypothesis

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 Water Quality Hypothesis

As outlined in the Hebron EEM Plan (EMCP 2017b), 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.*

3.4.3 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 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.*

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 4	-
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	September 29 - October 2	July 28 - 29
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 2019-2020.			

3.5.2 Parameters

The EEM program consists of sediment, water and commercial fish sampling components (Table 7-1) 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 2017a).

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

Program Component	Parameters	Analyses
Sediment Quality	Chemistry	General parameters (e.g., particle size, sulphide, redox potential), metal and hydrocarbon concentrations
	Toxicity	PetroTox threshold, Amphipod bioassay
	Benthic Community Structure	Species richness, abundance, biomass
Water Quality*	Chemistry	Metal and hydrocarbon concentrations
Commercial Fish (American Plaice)	Body Burden	Metal and hydrocarbon concentrations
	Sensory Evaluation	Triangle Test, hedonic scaling
	Fish Health	General parameters (e.g., size, weight, sexual maturity, condition indices), haematology, histopathology, stress enzyme activity
Note: *CTD profiles are used for assessment of sampling depths in the field using dissolved oxygen and pH profiles.		

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 <500 m, 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 Fulton's Condition index (gutted weight) Hepatosomatic index Gonadosomatic index
	Stress Enzyme Activity	Mixed Function Oxygenase (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	Lead Manganese

Variable Type	Commercial Fish Component	Specific Constituents
		Cadmium Chromium Copper Iron Mercury Selenium Zinc
	Hydrocarbons	<u>Total Petroleum Hydrocarbons (C_{10}-C_{32})</u> C_{10}-C_{21} (Fuel Range) C_{21}-C_{32} (Lube Range) <u>Polycyclic Aromatic Hydrocarbons</u> 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

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. The cluster of sediment sampling stations northeast of the Hebron Platform were established related to a potential drill centre and tieback that was never developed. These stations are outside the drill cutting footprint (EMCP 2017a, 2017b).

Table 3.6 Field distance definitions for sediment sampling.

Field Distance Descriptors	Distance from Hebron Platform	Prefixes	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

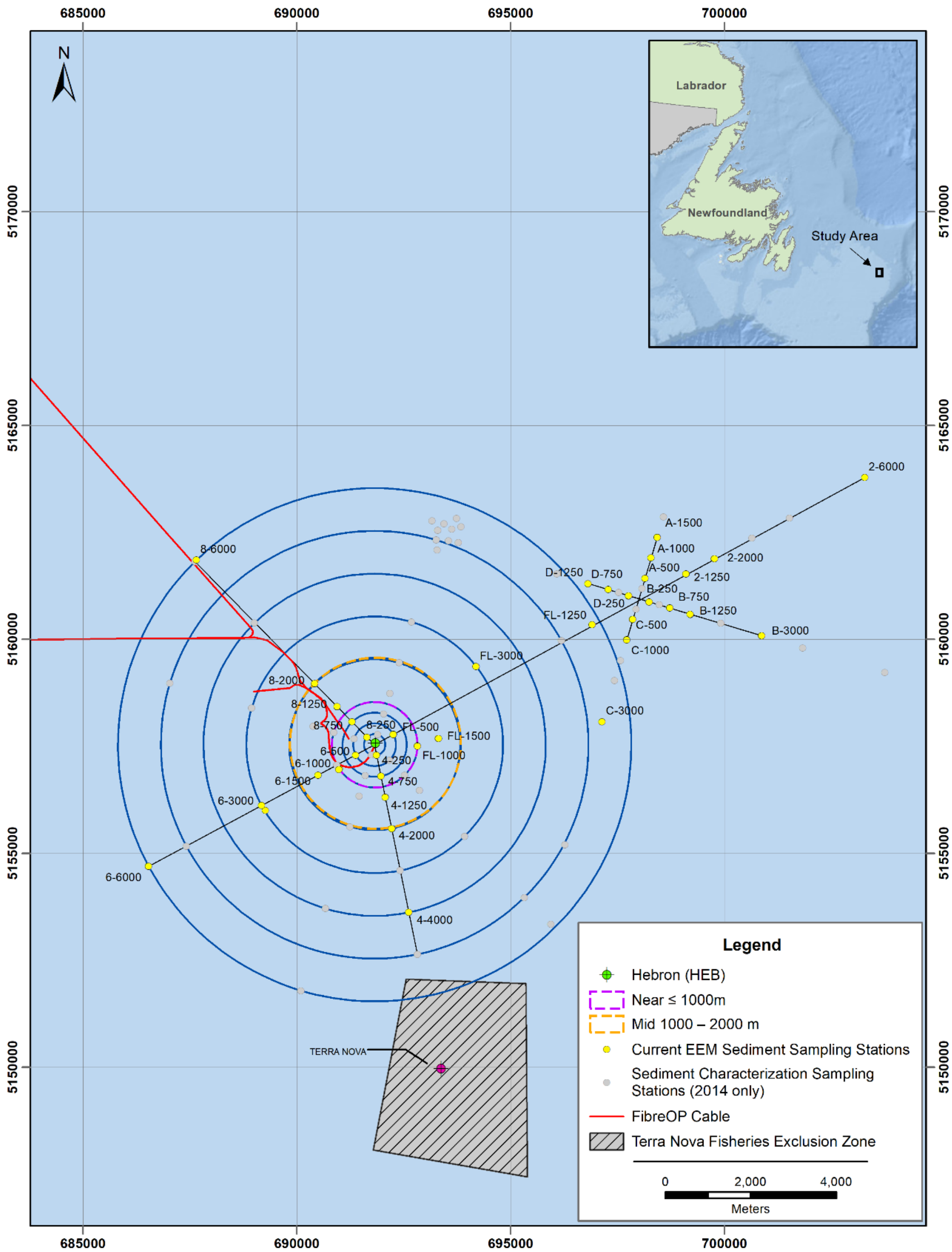


Figure 3-1 Sediment quality sampling stations for Hebron baseline and operational EEM.

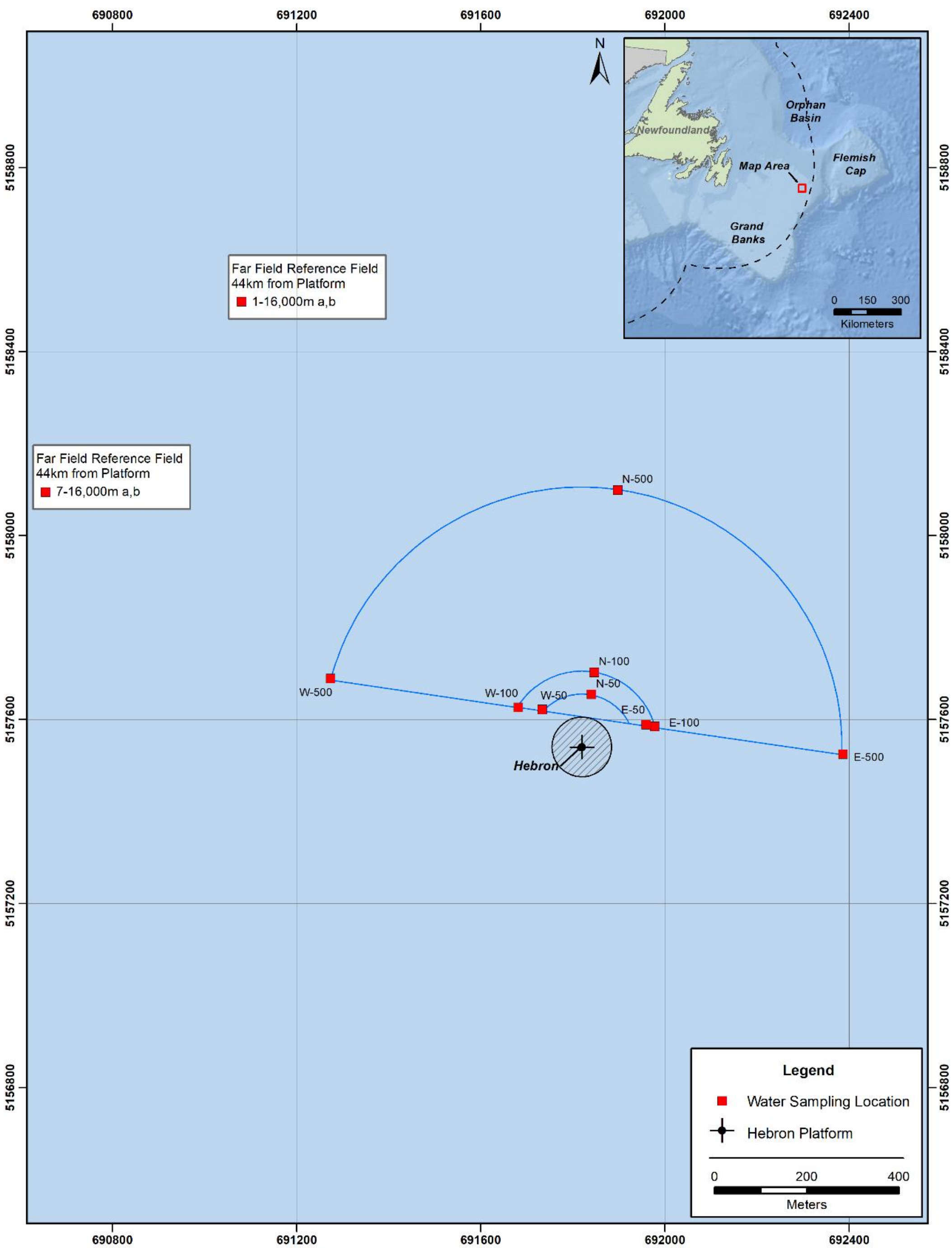


Figure 3-2 Water quality sampling stations for Hebron EEM.

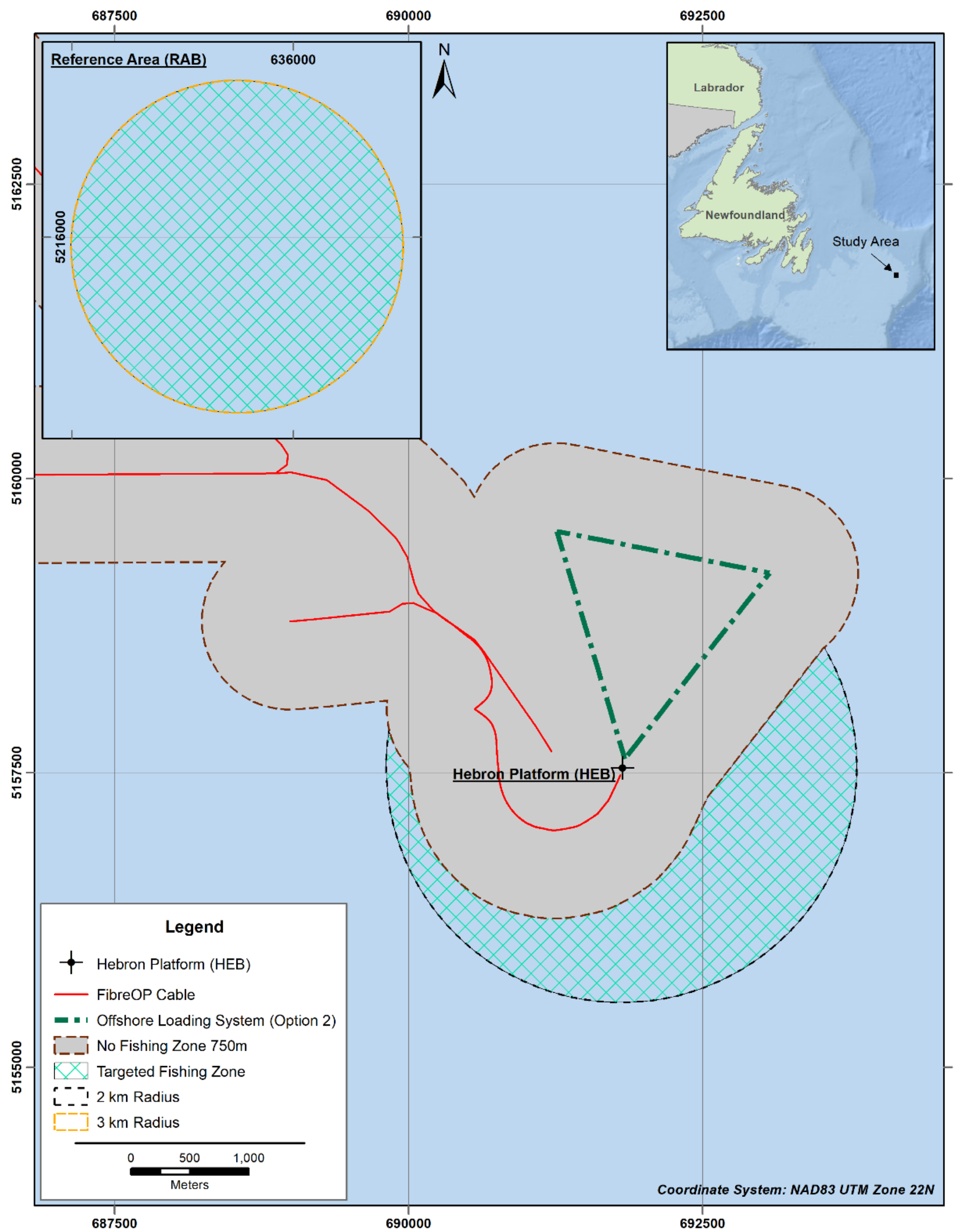


Figure 3-3 Commercial fishing areas for Hebron EEM.

4.0 SEDIMENT COMPONENT

Sediment samples have been collected in the Hebron Production Field annually for the first three years (2018, 2019, and 2020) and will be collected every subsequent two years with next sampling program scheduled for 2022. Below is a brief history of the Hebron EEM sediment program as of 2020 (Table 4.1).

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 Platform
2019	18	-	18	-	First year of Produced Water sampling
2020	18	-	18	-	
2021	-	-	-	-	As per agreement with CNLOPB (July 7, 2021), EEM will be executed on a two-year basis
2022**	18	-	18	-	As the potential tie back area is no longer needed, samples in the Northeast Cluster will be removed pending design plan revision, submission and approval form C-NLOPB.

Notes:

*The Northeast Cluster was a series of stations around a potential tieback that has not been developed.

** Northeast Cluster removal was not approved prior to the start of the 2022 EEM program.

4.1 Field Collection

The 2020 sediment sampling program is the third sediment operational sampling survey for the EEM program around the Hebron Platform. Sediment sampling was conducted by WSP field staff from September 29th to October 2nd aboard the offshore support vessel (OSV) *Avalon Sea*, under contract to EMCP.

Sediment sampling occurred at 36 sampling stations arranged at varying distances on radii surrounding the Hebron Platform. Coordinates for the established sediment sampling stations are outlined in the Hebron EEM Design Plan (EMCP 2017a). The actual sample positions were logged by onboard surveyors (Fugro GeoSurveys) who were contracted to position the sampling equipment on the seafloor and record locations. The positioning of box corer deployment was coordinated through the WSP team leader and a offshore surveyor.

Two sediment samples were collected at each station, one for physical/chemical analysis and the other for benthic community analysis. An additional sample was collected at stations 8-250, 4-2000, 6-6000, A-

1000, and C-1000 for QA/QC purposes. Two sample locations (6-1000 and 8-6000) were revised prior to the start of the field program to ensure a 150 m buffer from subsea infrastructures (Fibre optic cable).

An ultra-short baseline (USBL) device was used to track the positioning of the box corer on the seabed. Table 4.2 presents the coordinates (proposed and USBL actual) for 2020 Hebron sediment sampling locations. Actual sample locations were generally located within 10 m from the proposed sampling stations (except for the two stations noted above).

Sediment samples were collected on a 24-hour rotation when weather was suitable, and the vessel was not required for higher priority operations, therefore, two complete (three-person) WSP teams were required. The vessel's crew and the WSP team worked in a complimentary fashion with the ship's watch system. The vessel's crew worked 6-hour shifts; the WSP crews worked 12-hour shifts. Each 12-hour shift was directed by the WSP team leader. A toolbox safety meeting was conducted at the start of every 12-hour shift and the Vessel Master had final authority on safety matters. Sediment samples were collected using a large-volume box corer (Figure 4-1, A). 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, A). 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-core samples and data recording. Figure 4-1, B shows an example of a sediment sample recovered with the box corer.

Table 4.2 Coordinates (proposed and actual) for 2020 Hebron sediment sampling locations

Station ID	Station Type	Proposed: Easting	Proposed: Northing	Station Order	Actual: Easting	Actual: Northing
2-1250	Primary	699103	5161535	37	699105.03	5161531.57
2-2000	Primary	699768	5161890	38	699769.78	5161888.07
2-6000	Secondary	703285	5163791	39	703284.86	5163787.95
4-250	Primary	691868	5157299	16	691871.25	5157299.97
4-750	Primary	691968	5156809	19	691967.94	5156807.63
4-1250	Primary	692071	5156315	20	692068.54	5156315.57
4-2000	Primary	692220	5155580	25	692225.01	5155580.12
4-2000 QA	Primary	692220	5155580	26	692223.47	5155578.29
4-4000	Secondary	692620	5153620	24	692623.24	5153617.55
6-500	Primary	691379	5157299	15	691382.00	5157299.09
6-1000 [1]	Primary	690985	5156957	21	690987.42	5156961.45
6-1500	Primary	690501	5156830	22	690503.08	5156829.18
6-3000	Secondary	689179	5156121	23	689180.98	5156122.46
6-6000	Secondary	686535	5154701	40	686528.83	5154700.57
6-6000 QA	Secondary	686535	5154701	41	686527.89	5154694.70
8-250	Primary	691643	5157718	13	691644.35	5157714.14
8-250 QA	Primary	691643	5157718	14	691646.12	5157713.87
8-750	Primary	691293	5158081	12	691298.49	5158080.93

Station ID	Station Type	Proposed: Easting	Proposed: Northing	Station Order	Actual: Easting	Actual: Northing
8-1250	Primary	690942	5158431	11	690944.09	5158430.74
8-2000	Primary	690417	5158970	10	690419.26	5158973.77
8-6000 [1]	Secondary	687695	5161897	9	687696.27	5161896.29
A-500	Primary	698142	5161432	4	698146.65	5161431.65
A-1000	Primary	698284	5161911	2	698288.65	5161910.52
A-1000 QA	Primary	698284	5161911	3	698288.05	5161909.57
A-1500	Primary	698430	5162390	1	698436.01	5162389.73
B-250	Primary	698240	5160880	34	698240.99	5160880.94
B-750	Primary	698720	5160741	35	698723.48	5160745.29
B-1250	Primary	699199	5160590	36	699203.82	5160588.42
B-3000	Secondary	700872	5160089	8	700871.33	5160090.21
C-500	Primary	697854	5160472	33	697852.01	5160471.70
C-1000	Primary	697718	5159992	30	697716.70	5159995.28
C-1000 QA	Primary	697718	5159992	31	697717.99	5159995.32
C-3000	Secondary	697136	5158081	29	697136.87	5158081.09
D-250	Primary	697763	5161022	7	697765.50	5161019.44
D-750	Primary	697286	5161171	6	697287.93	5161170.26
D-1250	Primary	696810	5161309	5	696816.28	5161307.73
FL-500	Primary	692260	5157781	17	692260.87	5157780.27
FL-1000	Primary	692821	5157510	18	692820.13	5157509.05
FL-1250	Primary	696904	5160350	32	696900.91	5160352.17
FL-1500	Primary	693315	5157690	27	693317.46	5157691.15
FL-3000	Secondary	694196	5159371	28	694194.70	5159369.24

Notes:

[1] Stations 6-1000 and 8-6000 were moved prior to departure to maintain minimum 150 m buffer from subsea infrastructure.

All coordinates presented in UTMs, Zone 22 N, NAD83

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

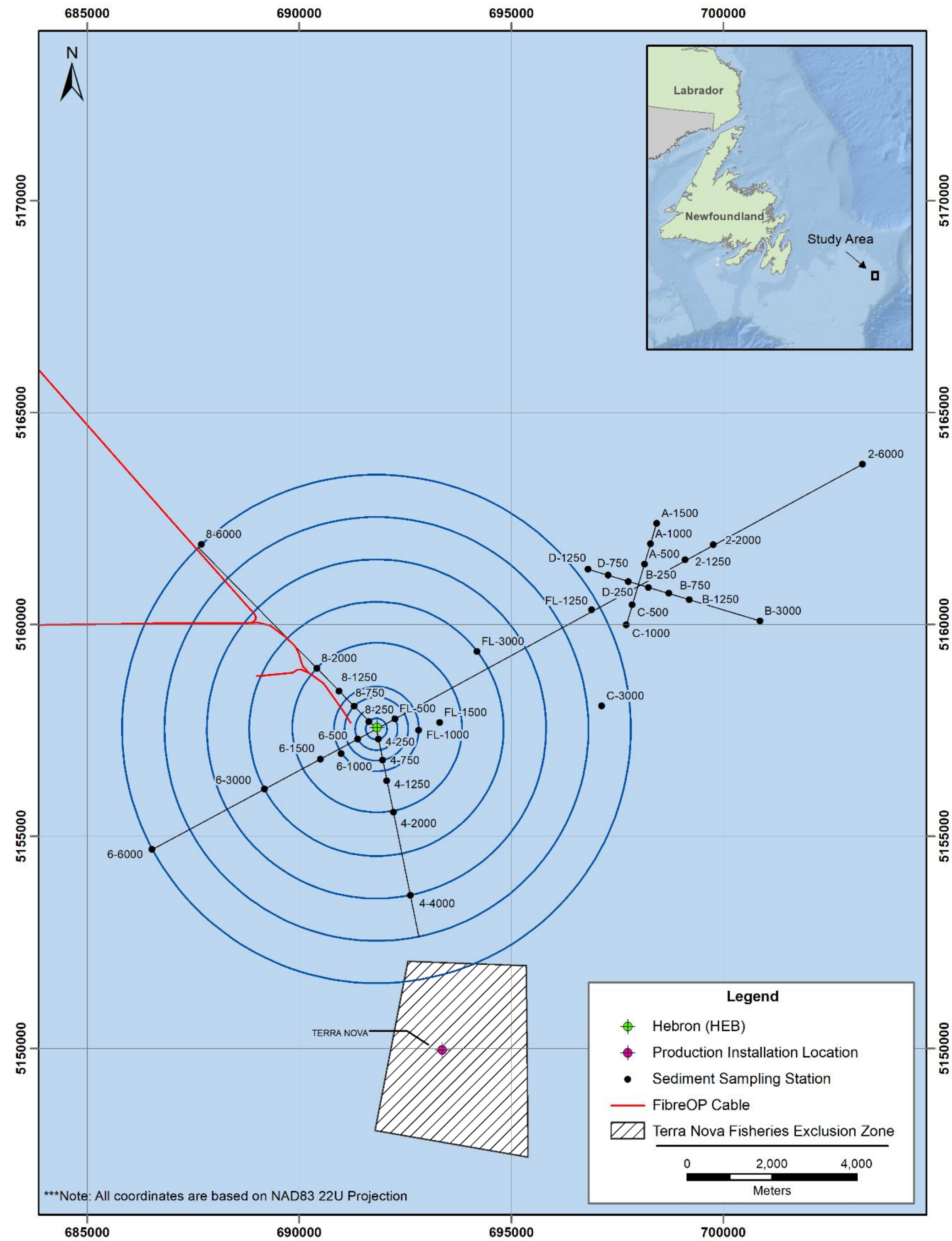


Figure 4-2 Hebron Production Field 2020 sediment sampling stations.

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 physical/chemical (trace metals, polycyclic aromatic hydrocarbons (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 of 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.

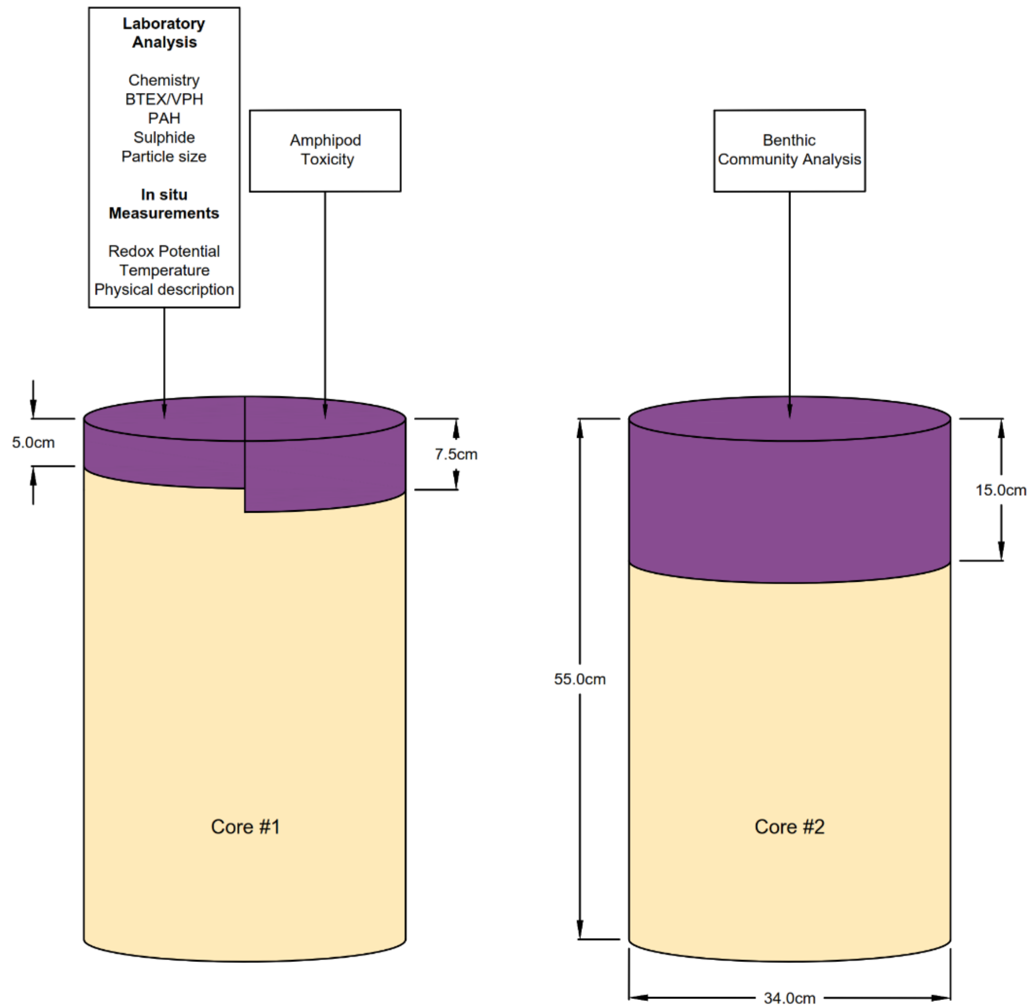


Figure 4-3 Sediment sub-sample collection diagram for each recovered box core sample

4.2 Laboratory and Statistical Analyses

The collected sediments were analyzed to determine the presence of potential project-related substances in sediment. 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 were compared to baseline (EMCP 2016a) results and previous EEM sampling years. The primary and supporting monitoring variables for the sediment quality component are listed below.

Table 4.3 Sediment quality component primary and supporting monitoring variables

Variable Type	Primary Variables	Supporting Variables
Sediment Chemistry	Barium and >C_{10}-C_{21}Hydrocarbons	Particle size Sulphides Redox Potential Organic carbon Ammonia Metals other than Barium Other hydrocarbons
Sediment Toxicity	Amphipod Toxicity Petrotox	
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 (Bedford, NS). Sediment samples were analyzed for the following analytes:

- Sediment Particle Size,
- Barium,
- Fuel and Lube Range Hydrocarbons,
- Total Petroleum Hydrocarbons (TPH),
- Metals (other than Barium),
- PAHs and alkyl PAHs,
- Total Organic Carbon (TOC),
- Sulphides,
- Sulphur,
- Ammonia (as nitrogen, -N),
- Moisture,
- Redox Potential.

Laboratory results from all analytes were screened-in for analysis if they met the following criteria:

- 75 percent of samples for a given analyte were above the reportable detection limit (RDL),
- Occur 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
- A natural analyte that could potentially be affected by the Hebron Platform (e.g., sulphides).

Screened-in analytes are summarized in Table 4.4 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 (CCME) 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 for subsequent statistical analysis (EMCP 2017a).

Spatial and temporal trends of screened-in analytes were examined through exploratory and statistical analysis (EMCP 2017a). Spatial trends were visually assessed with 2-D plots of screened-in analyte concentrations per station in relation to the Hebron Platform. These plots were used for illustrating patterns of changing analyte concentrations over successive survey programs only and no statistical inferences were made. For screened-in analytes, concentrations less than the RDL were expressed as RDL (for visualization purposes only). Plots were generated using R statistical software (R Core Team 2018). The Hebron Platform 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 were used to display analyte concentrations at each sampling station. 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 2020 screened-in analytes with distance from the Hebron Platform and the Terra Nova floating production storage offloading (FPSO) facility area (the Terra Nova FPSO was not in operation in 2020). Scatterplots of each screened-in analyte were visually assessed and presented to examine these relationships. Parametric analysis was conducted to compare between EEM 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 primary variables (barium, and fuel and lube range hydrocarbons). An analysis of covariance (ANCOVA) was performed on all sampling years (2020, 2019, 2018, and baseline). Only analytes measured in all four years were analyzed (e.g., sulphide was only measured in two out of four years and was removed from analysis). Spatial trends were analyzed with 'Year' as a factor and distance from the Hebron Platform (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). The analysis compares amphipod survivability in screened-in Hebron sediment samples compared to a laboratory control which results in a binary result ("toxic" or "non-toxic"). EEM sediment samples were screened-in for toxicity testing if they met any of the below criteria:

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

Stations at or within 500 m from the active drill center may experience project-induced changes due to their proximity and are automatically screened-in (EMCP 2017a). The PetroTox model was used to predict the aquatic toxicity of petroleum substance composition (Redman et al. 2012). PureDrill IA 35-LV is the drilling mud (i.e., base fluid) used at Hebron and other drilling platforms on the Grand Banks of Newfoundland (ECMP 2017a). HMDC undertook a risk assessment of PureDrill IA 35-LV in the environment using the PetroTox model (Stantec 2013). From the risk assessment, the PetroTox model found a no-effects concentration threshold of 150 mg/kg for PureDrill IA 35-LV. The hydrocarbons in the C_{10}-C_{21} range are used as a marker for PureDrill 1A 35-LV (EMCP 2017a). All samples above the no-effects threshold of 150 mg/kg hydrocarbons C_{10}-C_{21} hydrocarbons were screened-in for toxicity testing.

Amphipod bioassays assess the survival rate of individuals cultured in EEM sediment samples 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.

Each screened-in sediment sample (test sample) is divided into five replicate containers with 20 amphipods (*Rhepoxynius abronius*) each. The control sediment used for statistical comparisons was sediment from which the amphipods were collected. The amphipods were exposed for ten days, after which the percent survival between the test and control samples 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 were submitted for processing to Envirosphere Consultants (Windsor, NS). Samples were collected and processed in accordance with the Standard Methods 10200 (APHA 1995). This included preserving samples in the field in 11 L buckets containing 10 percent buffered formalin for shipment to the lab. Sample containers were checked for any leaks and labels checked against the chain-of-custody form accompanying the shipment. Below is a brief description of the sample processing and sorting.

In accordance with the above methods, sediment sample processing included removing the formalin and washing each sample through a 0.5 mm sieve. This sieve size was not selected to target a specific species. Samples were portioned onto a gridded petri plate and examined with a dissecting microscope under 6.4X magnification. All organisms (including fragments) were removed from the petri plate. When the plate was clear, it was re-examined under 16X magnification. The organisms sorted from each sample were blotted with paper towels to remove surface water, placed into vials, weighed to the nearest mg, and preserved with 70 percent isopropanol. Samples were then sent to BioTech Taxonomy (Smithtown, NB) for taxonomic identification and enumeration.

All 2020 samples were completely sorted, and 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 400x 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 2020 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 (S) indicates the number of species found at each station sample. Total abundance is the number of individuals (all taxa) found at each station. Biomass is the total wet weight of all individuals per station. Species richness (d) considers the number of taxa (S) and number of individuals (N) present in a sample; a higher value (d) indicates greater species 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 station. The Shannon-Wiener diversity index (H') is a measure of both abundance and evenness of species present at each station. A high value (H') indicates a highly diverse and equally distributed community where no one taxa is dominant.

Benthic community data was compared to results from the baseline survey and previous EEM years. Analyses focused on changes in the main indices of community structure (described above) as a measure of change 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 transformed data at the family level. 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. To examine the influence of distance from the Platform 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 Hebron Platform was treated as a categorical variable with stations falling into one of three distance bins ≤1,000 m (Near-field), 1,000 m to 2,000 m (Mid-field), and stations >2,000 m (Far-field).

Multivariate analysis to detect statistically significant relationships between benthic assemblage structure (at the family taxonomic level) and screened-in analytes as predictor variables was 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 20 analytes were included for further analysis. Table 4.4 presents the screened-in 2020 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 CCME ISQG) and PEL. The following section examines trends present in the screened-in analytes for the 2020 sediment samples and compares the findings to previous EEM years, sediment toxicity, and benthic community structure.

Table 4.4 Summary of screened in analytes from the 2020 Hebron EEM sediment samples

Station ID	RDL	Units	No.	No. >RDL	No.=RDL	No.<RDL	Mean	St. Dev.	Median	Min	Max	ISQG[1]	PEL[2]	Petrotox
PARTICLE SIZE ANALYSIS														
Gravel	0.1	%	36	18	1	17	2.63	4.65	0.14	0.1	20	-	-	-
Sand	0.1	%	36	36	0	0	95.22	5.48	99	77	99	-	-	-
Percent Fines	0.1	%	36	36	0	0	2.28	2.81	1.145	0.85	12	-	-	-
TOTAL EXTRACTABLE METALS														
Barium	5	mg/kg	36	36	0	0	475.58	1976.30	140	46	12000	-	-	-
Iron	50	mg/kg	36	36	0	0	1414.72	748.47	1200	680	4900	-	-	-
Lead	0.5	mg/kg	36	36	0	0	85.84	499.58	2	1	3000	30.2	112	-
Manganese	2	mg/kg	36	36	0	0	38.53	21.10	32.5	16	100	-	-	-
Aluminum	10	mg/kg	36	36	0	0	5777.78	1359.86	5500	2900	10000	-	-	-
Chromium	2	mg/kg	36	35	0	1	3.23	1.07	3.1	2	8.7	52.3	160	-
Strontium	5	mg/kg	36	35	0	1	178.14	826.84	35.5	15	5000	-	-	-
Uranium	0.1	mg/kg	36	36	0	0	0.15	0.04	0.15	0.11	0.32	-	-	-
Vanadium	2	mg/kg	36	36	0	0	4.68	1.90	4.25	2.6	14	-	-	-
TOTAL INORGANIC CARBON/TOTAL ORGANIC CARBON (TIC/TOC)														
TOC	500	g/kg	36	35	1	0	1.02	0.65	0.845	0.5	4.1	-	-	-
HYDROCARBONS														
C_{10}-C_{21} Hydrocarbons	0.25	mg/kg	36	18	0	18	14.03	72.01	0.28	0.25	432	-	-	150
C_{21}-C_{32} Hydrocarbons	0.25	mg/kg	36	16	0	20	0.83	2.28	0.385	0.25	14	-	-	-
OTHER														
Moisture	1	%	36	36	0	0	16.78	1.20	17	15	19	-	-	-
Redox Potential	1	mV	36	36	0	0	192.25	48.52	201.5	58	297	-	-	-
Sulphide	0.5	µg/g	36	20	1	15	2.43	4.40	0.7	0.5	18	-	-	-
Sulphur	0.001	%	36	1	0	35	0.03	0.04	0.0235	0.01	0.24	-	-	-
Ammonia	0.3	mg/kg	36	36	0	0	3.50	2.87	2.85	1.2	18	-	-	-

[1] ISQG: Interim Sediment Quality Guidelines [2] PEL: Probable effect levels

4.3.1 Physical and Chemical Characteristics Results

To detect spatial variations or patterns in screened-in analytes for the 2020 EEM samples, analyte concentrations per station are represented in two-dimensional scatter plots. Station locations 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. Outliers are represented by a black dot with the concentration above the station location. For the 2D plots, analyte values below RDL were expressed as RDL for visualization purposes only. These plots are for illustrating distribution patterns of analyte concentrations only. No statistical inferences were made from these plots.

Results-Spatial

Particle Size

Changes in particle size concentrations or distributions could affect the benthic environment (many species inhabit specific substrates) or distribution of other analytes. The primary particle size for all stations was sand with concentrations ranging between 77 to 99 percent while secondary particle size varied per sample. Of the secondary substrates, gravel ranged between 0.1 to 20 percent and fines ranged between 0.85 to 12 percent. Spatial distributions of particle size compositions are depicted in Figure 4-4 to Figure 4-6 in decreasing particle size. Higher concentrations of gravel (>4 percent) were mainly found in the northeast cluster of stations with the highest occurring at station B-1250 (Figure 4-4). Sand was the primary substrate across all stations of which 19 had a composition of 99 percent. The lowest percent sand concentration was also located at B-1250 (Figure 4-5). The mean percent fines concentration was 2.28 percent and the station with the highest reported concentration was B-750 (Figure 4-6).

Distributional patterns of particle size concentrations observed the 2020 EEM were visually similar to those observed in previous EEM years and baseline. Gravel concentrations have also mainly been higher in the northeast cluster rather than near the Hebron Platform. Reported percent fine mean concentration in 2020 was an increase from previous survey levels (EEM years and baseline). Percent fines at Station B-250 and B-750 were more than two standard deviations above 2014 levels which can be expected when releasing water-based mud and cuttings. In pervious EEM survey years only station 8-250 was two standard deviations above 2014 levels. for percent fines.

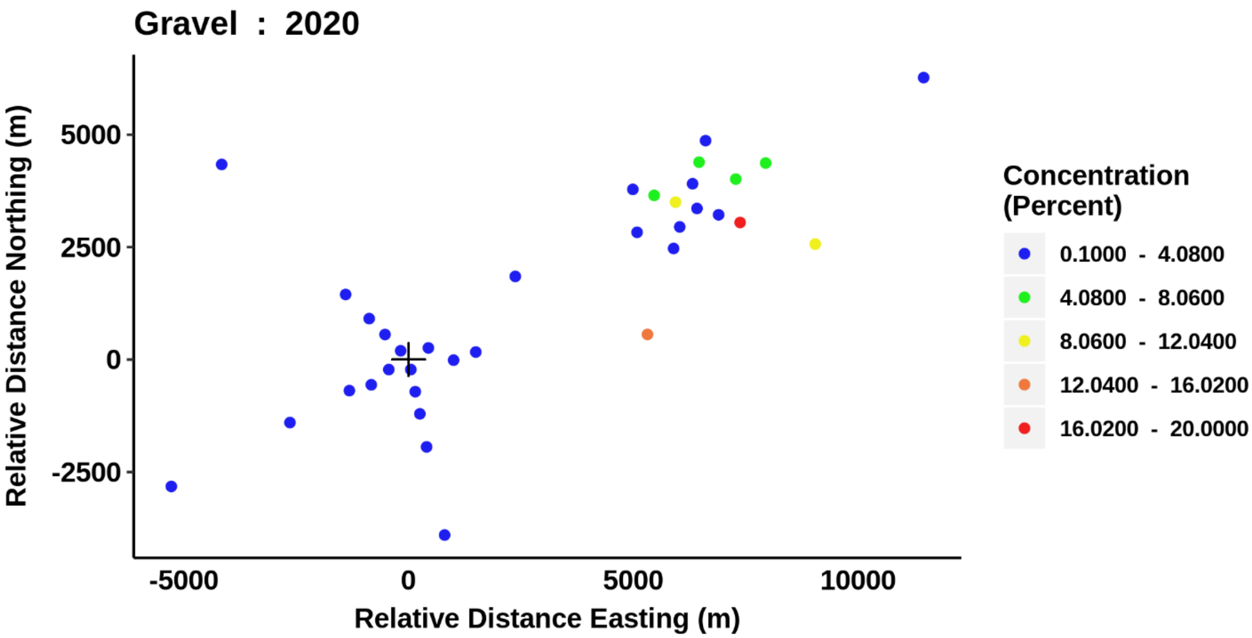


Figure 4-4 Spatial pattern of gravel (percent concentration) from 2020 EEM samples within the survey area around the platform (cross). When detected (82% of samples) the average percent composition of 2014 baselines samples was 4.11% gravel.

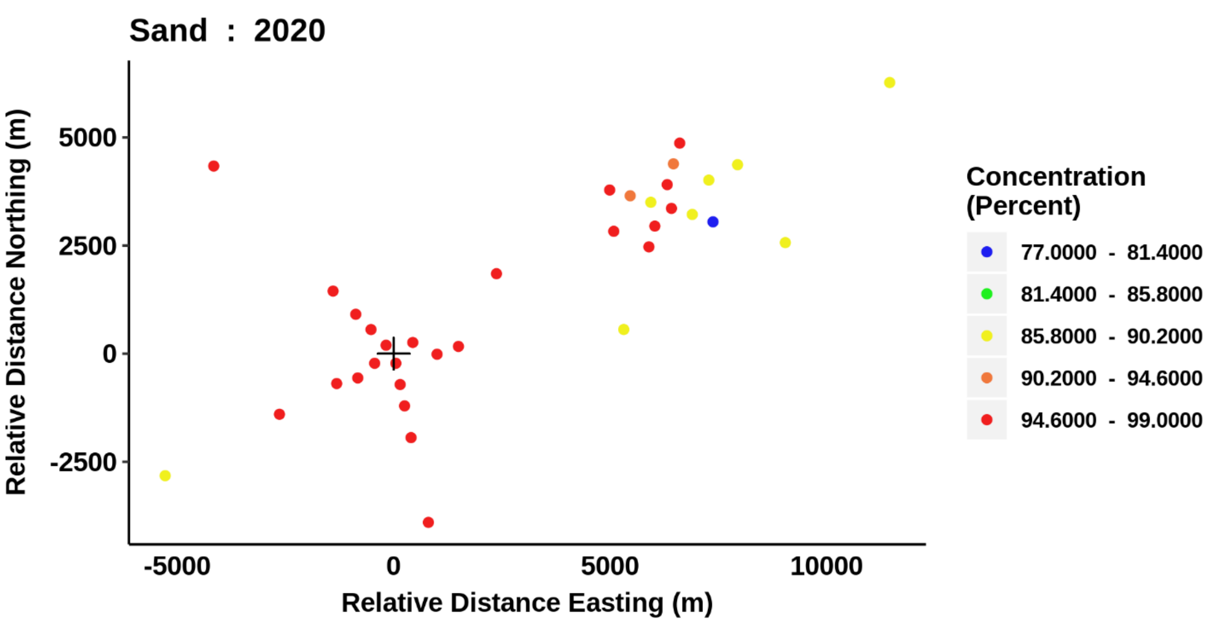


Figure 4-5 Spatial pattern of sand (percent concentration) from 2020 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with sand comprising on average 93.64% of each sample.

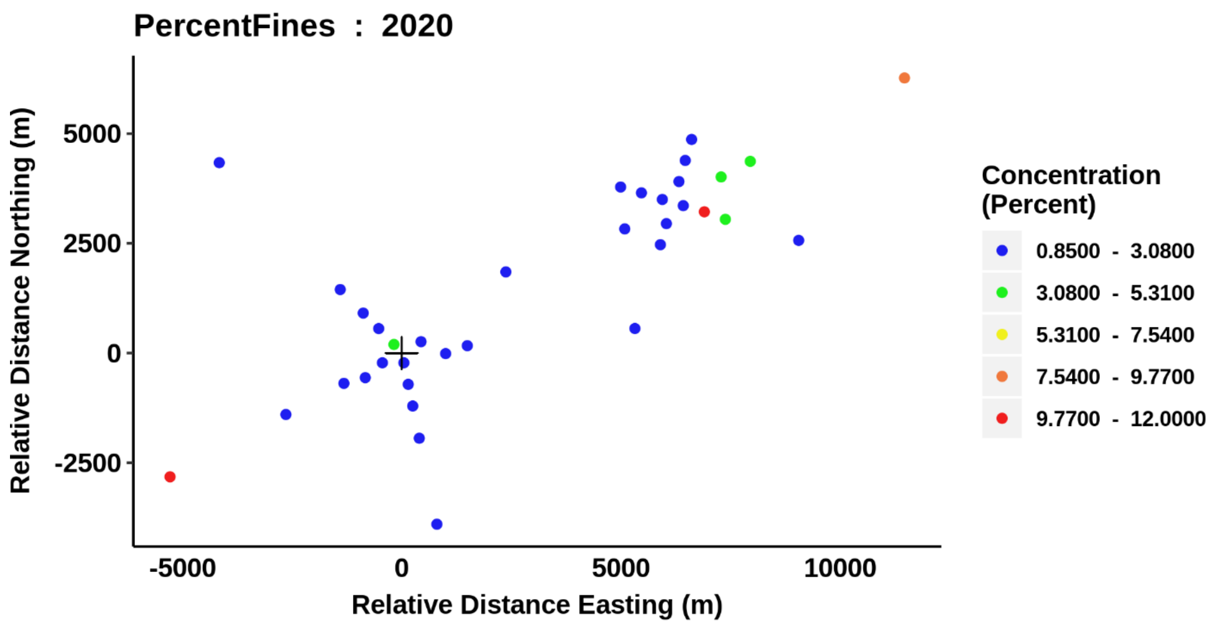


Figure 4-6 Spatial pattern of percent fines (percent concentration) from 2020 EEM samples within the survey area around the platform (cross). All 2014 baseline samples were above the detection limit with fines comprising on average 1.18% of each sample.

Total Extractable Metals

Spatial distributions for the nine extractable metals analyzed are presented in Figure 4-7 to Figure 4-15. Barium concentrations ranged between 46 to 12000 mg/kg. Barium is monitored because it is a substantial component of drilling mud and serves as a tracer to the estimated drill mud dispersion. As expected, the highest concentration of barium occurred at station 8-250 (Figure 4-7). The barium concentration at this station in 2020 was the highest observed compared to previous EEM survey years (2014: 99 mg/kg, 2018: 1100 mg/kg, 2019: 990 mg/kg). Station 8-250 was an outlier compared to other stations, barium concentrations at other stations ranged between 46 mg/kg (B-250) and 300 mg/kg (4-250). The highest concentrations of barium (230 mg/kg to 12000 mg/kg) were all within 750 m from the Hebron Platform. Of the other eight extractable metals analyzed, station 8-250 had the highest concentrations of iron (4900 mg/kg, Figure 4-8), manganese (100 mg/kg, Figure 4-10), aluminum (10000 mg/kg, Figure 4-11), chromium (8.7 mg/kg, Figure 4-12), strontium (5,000 mg/kg, Figure 4-13), uranium (0.32 mg/kg Figure 4-14), vanadium (14 mg/kg, Figure 4-15), and the second highest lead concentration (23 mg/kg, Figure 4-9). The highest concentrations of lead occurred at 6-6000 (3000 mg/kg). These metals also occurred at relatively high concentrations at stations more than 3,000 m from the Hebron Platform and in the northeast cluster. In previous EEM years, concentrations of extractable metals were also higher at station 8-250 and within the northeast cluster.

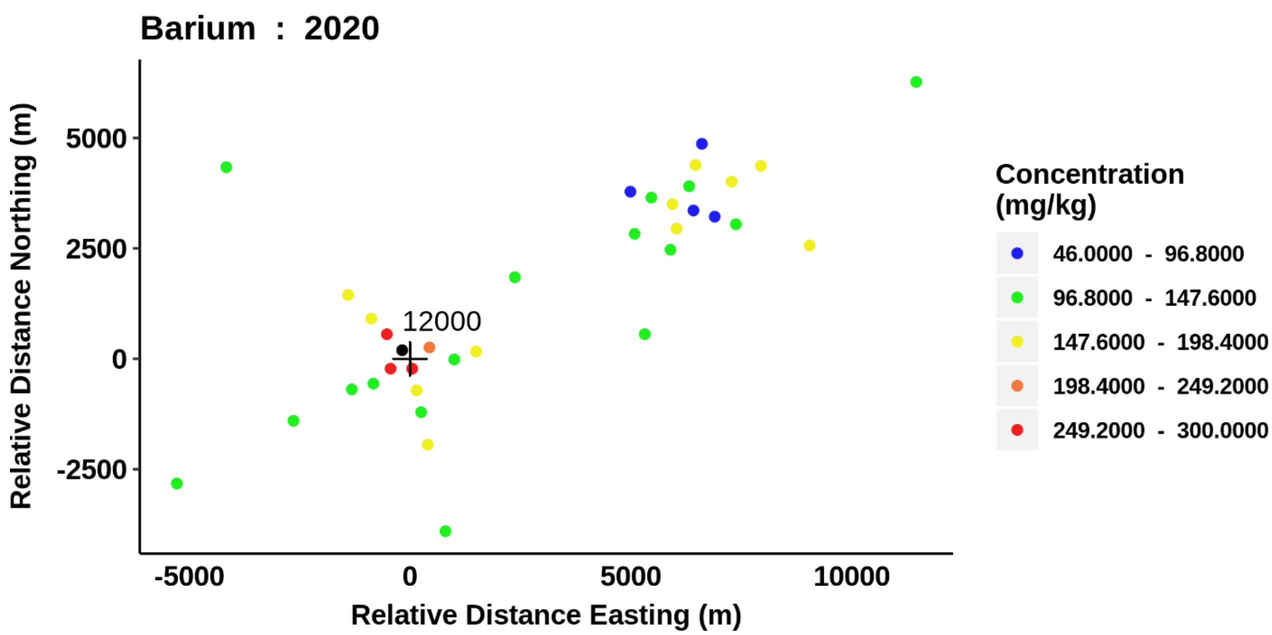


Figure 4-7 Spatial pattern of barium (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Largest concentration outlier represented by a black dot with the concentration noted next to it. Average baseline concentration 110 mg/kg.

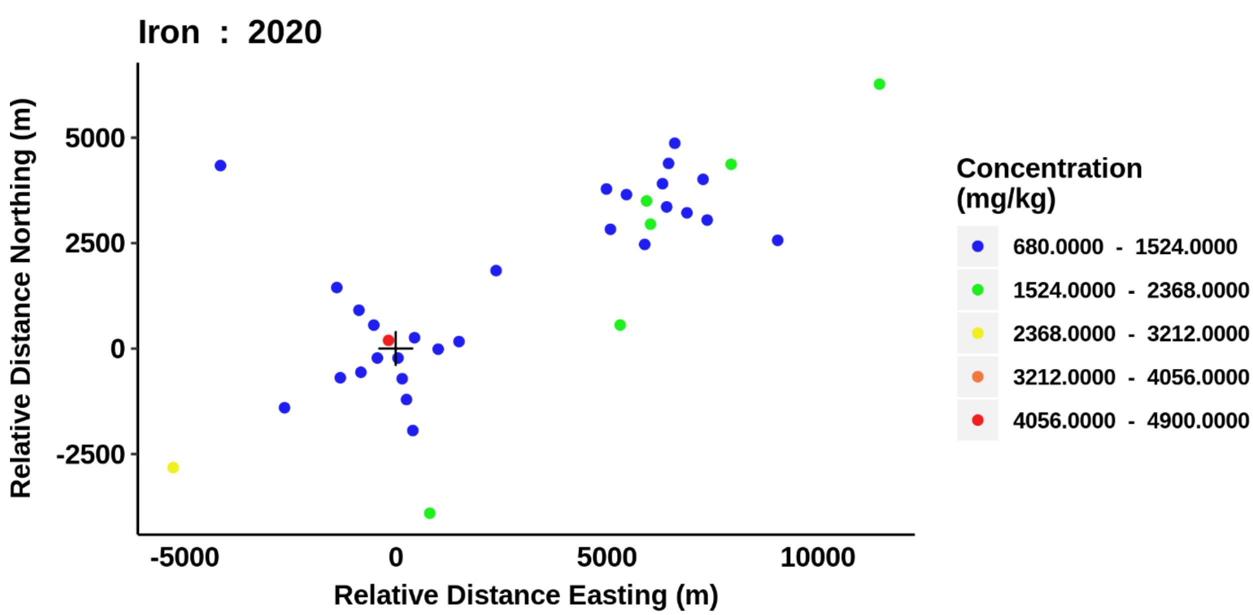


Figure 4-8 Spatial pattern of iron (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). All baseline samples above detection limit with an average concentration of 1123 mg/kg.

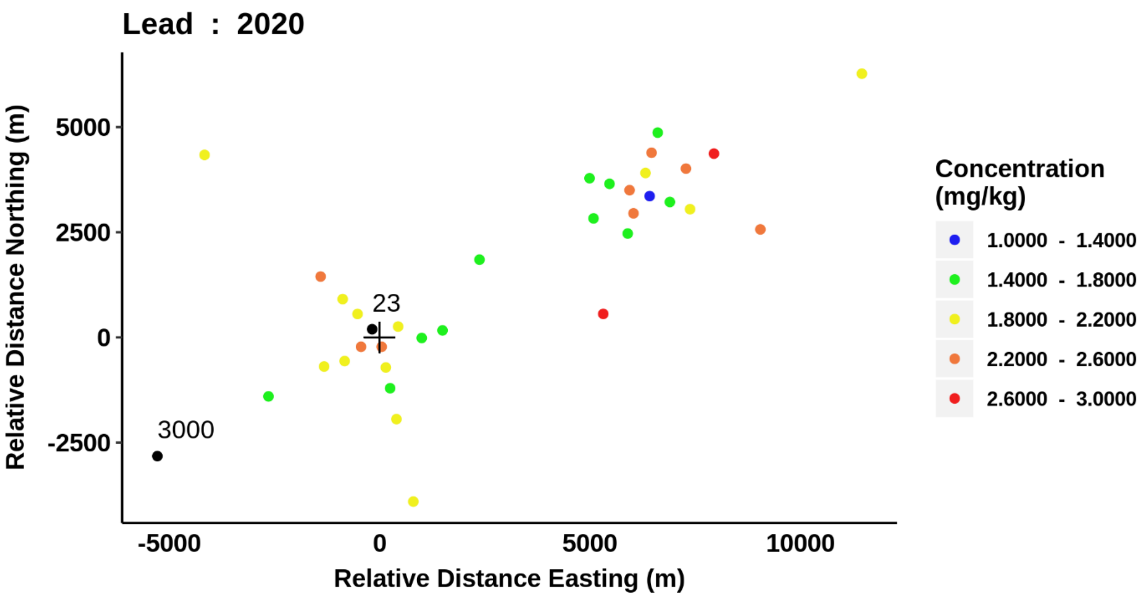


Figure 4-9 Spatial pattern of lead (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Largest outlier is represented by black dot with the concentration noted next to it. Average baseline concentration was 1.8 mg/kg.

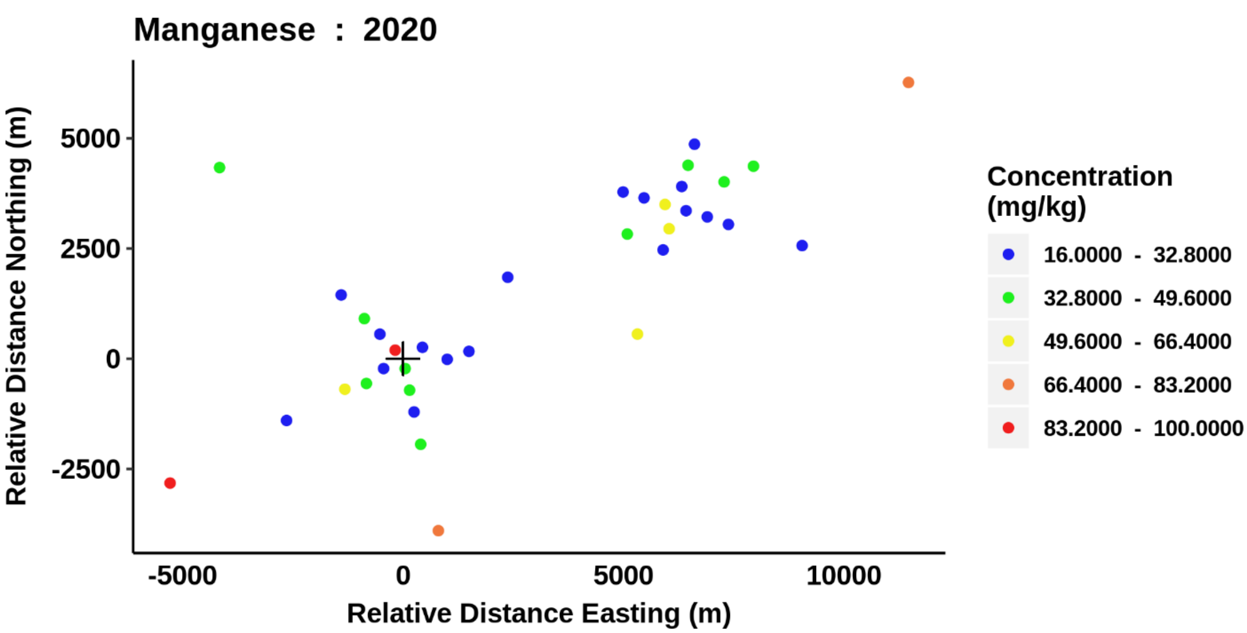


Figure 4-10 Spatial pattern of manganese (mg/kg) from 2020 EEM samples within the survey area around from the platform (cross). All 2014 baseline samples were above the detection limit with an average concentration of 30 mg/kg.

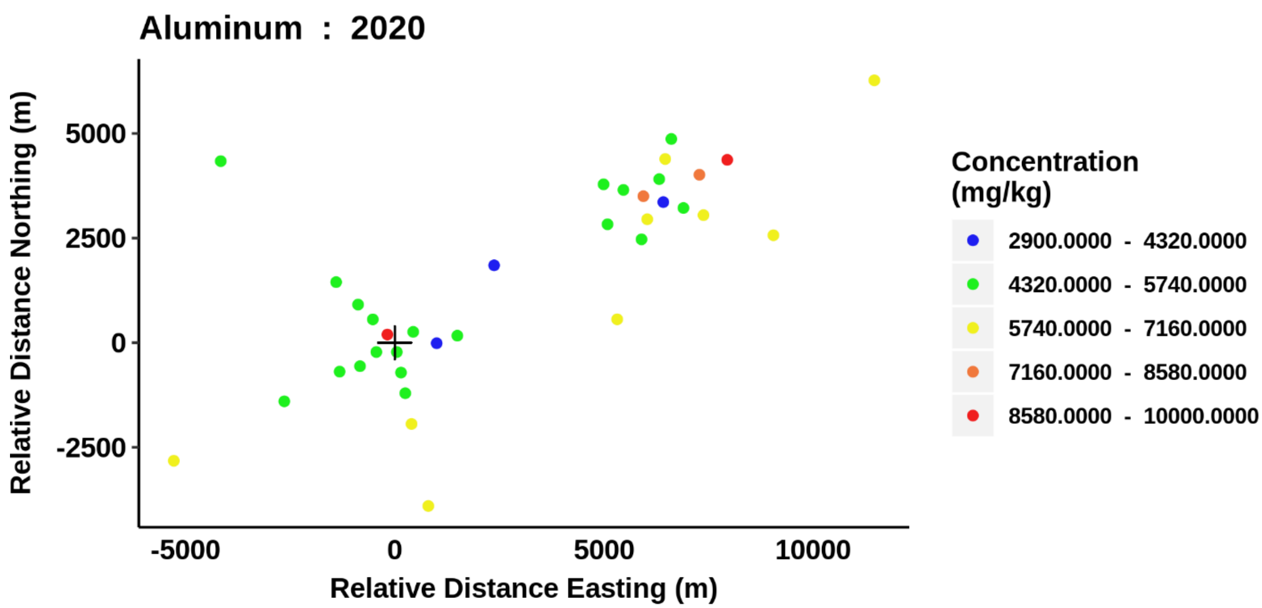


Figure 4-11 Spatial pattern of aluminum (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). The average baseline concentration was 5232 mg/kg.

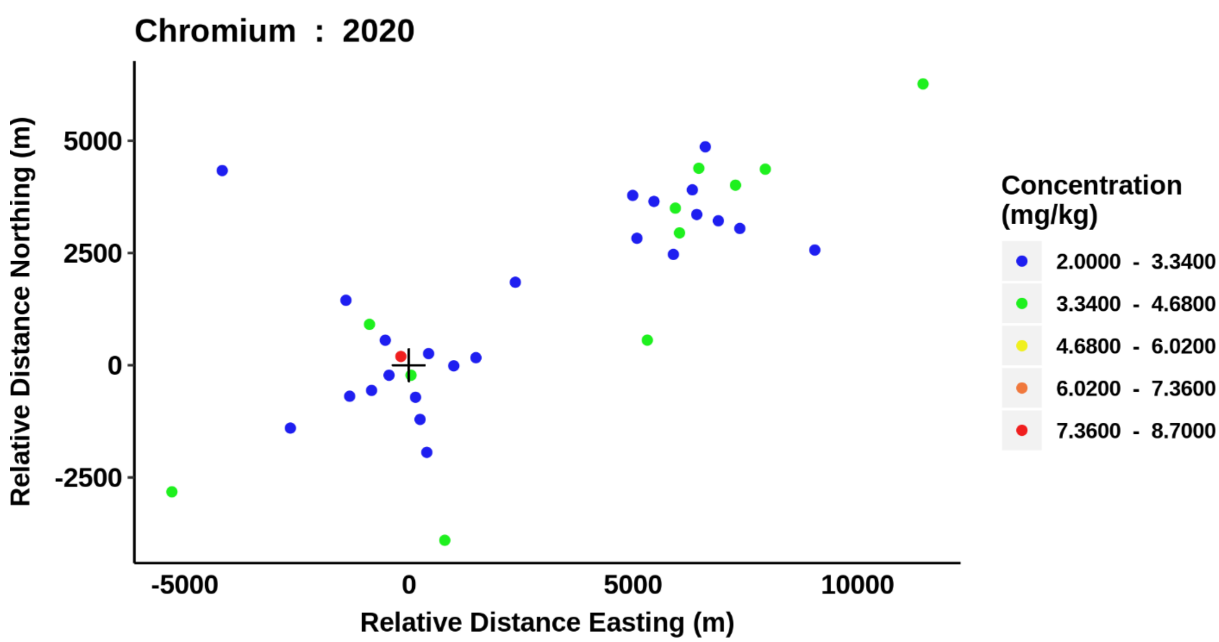


Figure 4-12 Spatial pattern of chromium (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 3.0 mg/kg.

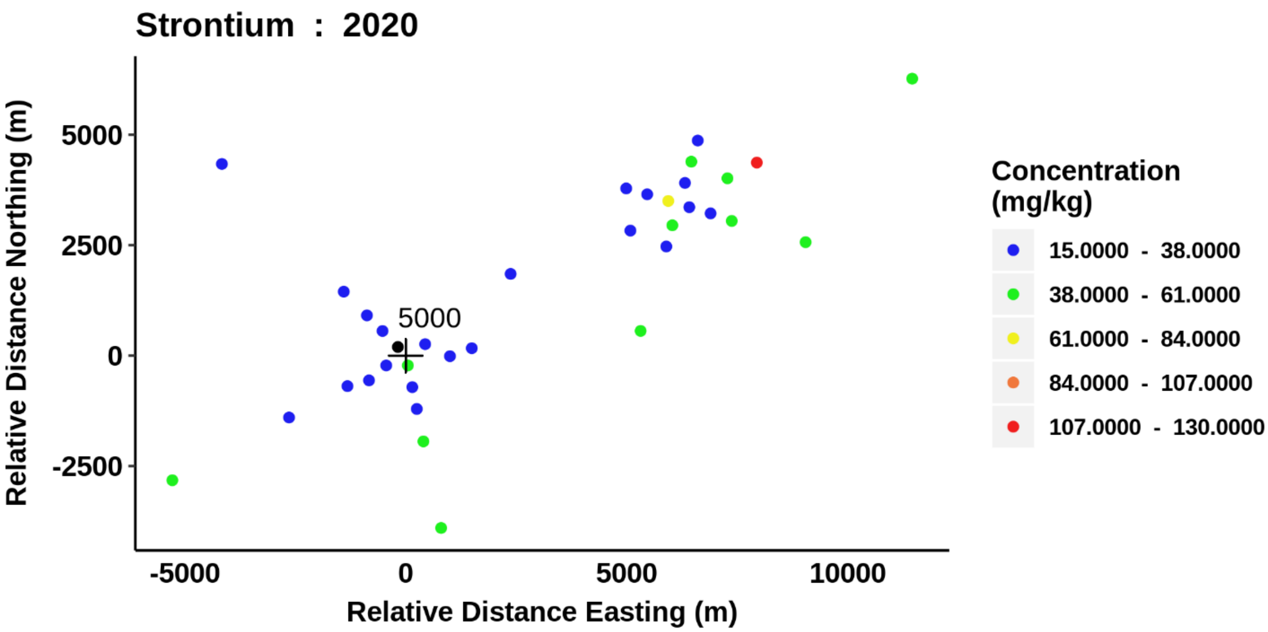


Figure 4-13 Spatial pattern of strontium (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Largest concentration outlier represented by a black dot with the concentration next to it. Average baseline concentration was 49.0 mg/kg.

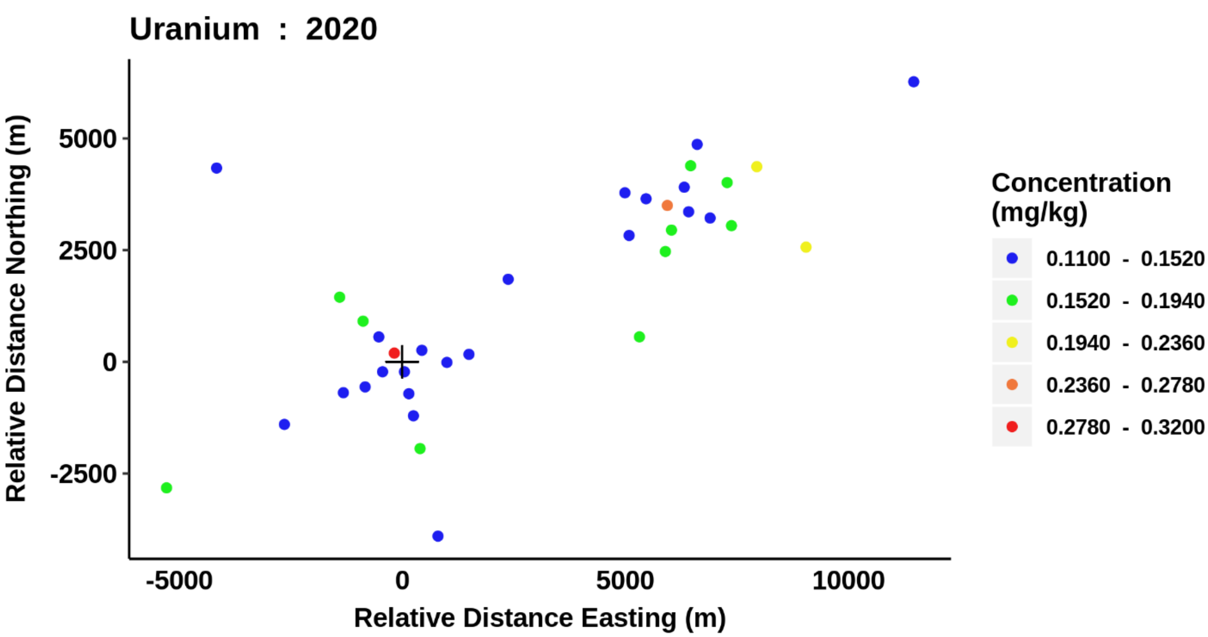


Figure 4-14 Spatial pattern of uranium (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 0.17 mg/kg.

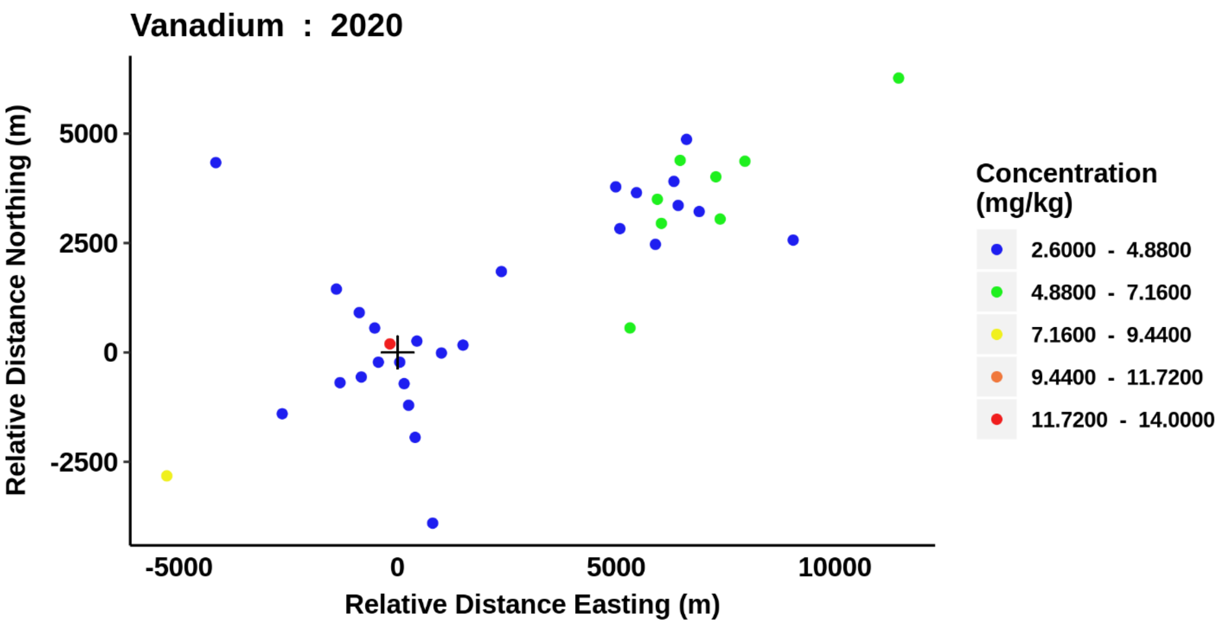


Figure 4-15 Spatial pattern of vanadium (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average concentration of 2014 baselines samples was 4.3 mg/kg.

Hydrocarbons

Both fuel and lube range hydrocarbons were below the 75 percent criteria but were screened-in for further analysis as they are expected discharges from the platform. A total of 50 percent of fuel range hydrocarbon samples and less than 45 percent of lube range hydrocarbon samples were above RDL (0.25 mg/kg). Hydrocarbon concentrations ranged between 0.25 to 432 mg/kg for fuel range (C_{10}-C_{21} hydrocarbons) and 0.25 to 14 mg/kg for lube range (C_{21}-C_{32} hydrocarbons). Elevated concentrations of these hydrocarbons occurred within 750 m of the Platform. The highest concentrations of both hydrocarbon ranges occurred at 8-250. This was similarly observed in previous EEM surveys (2018 and 2019).

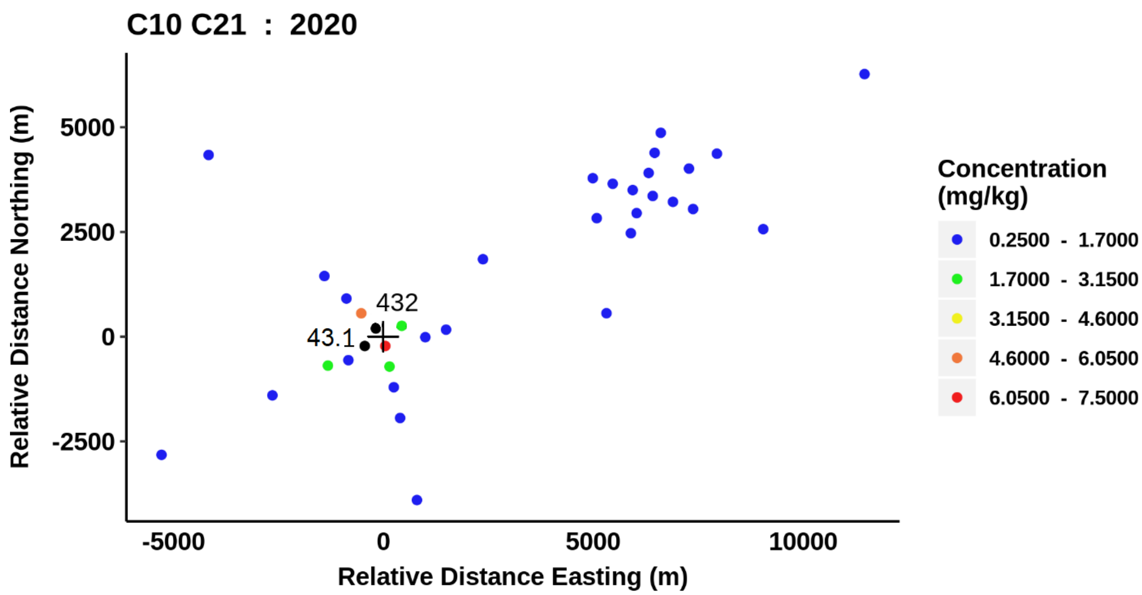


Figure 4-16 Spatial pattern of >C_{10}-C_{21} (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Largest outlier represented by black dot with the concentration next to it. When detected (61% of samples) average 2014 concentration was 0.48 mg/kg.

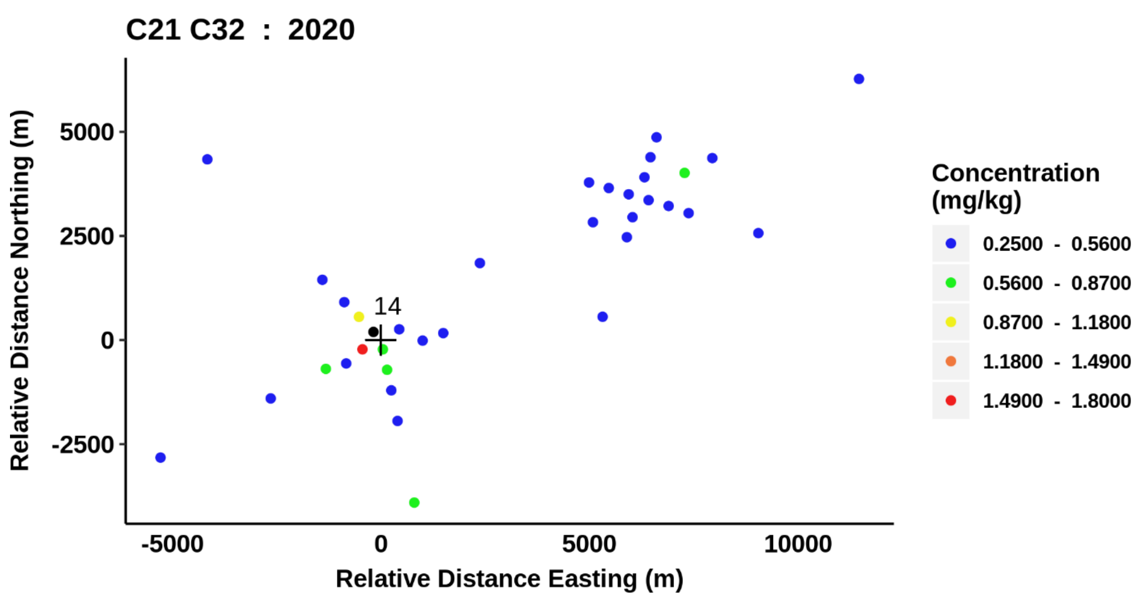


Figure 4-17 Spatial pattern of >C_{21}-C_{32} (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Largest concentration outlier is represented by a black dot with the concentration noted next to it. When above the detection limit (70% of samples) the average concentration of 2014 baselines samples was 0.44 mg/kg.

Other Analytes

Spatial distributions for the last five screened-in analytes are presented in Figure 4-18 to Figure 4-22. Moisture concentrations ranged between 15 to 19 percent with the highest concentration of moisture occurring at station D-250 (19 percent) (Figure 4-18). Redox potential ranged between 58 to 297 mV (Figure 4-19). No negative values were recorded in 2020 sampling. The highest concentration of sulphide was reported at station 4-250 (Figure 4-20). Concentrations of sulphide appeared to be relatively high and decreased with increasing distance from the Hebron Platform along radial 8 (8-250: 15.5 µg/g, 8-750: 15.3 µg/g, 8-1250: 5.8 µg/g). The highest concentration of sulphur was reported at station 8-250 (Figure 4-21). Ammonia levels ranged between 1.2 to 18 mg/kg with the highest concentration observed at station C-1000 (Figure 4-22). The highest concentrations of ammonia in the previous EEM years have also occurred within the northeast cluster.

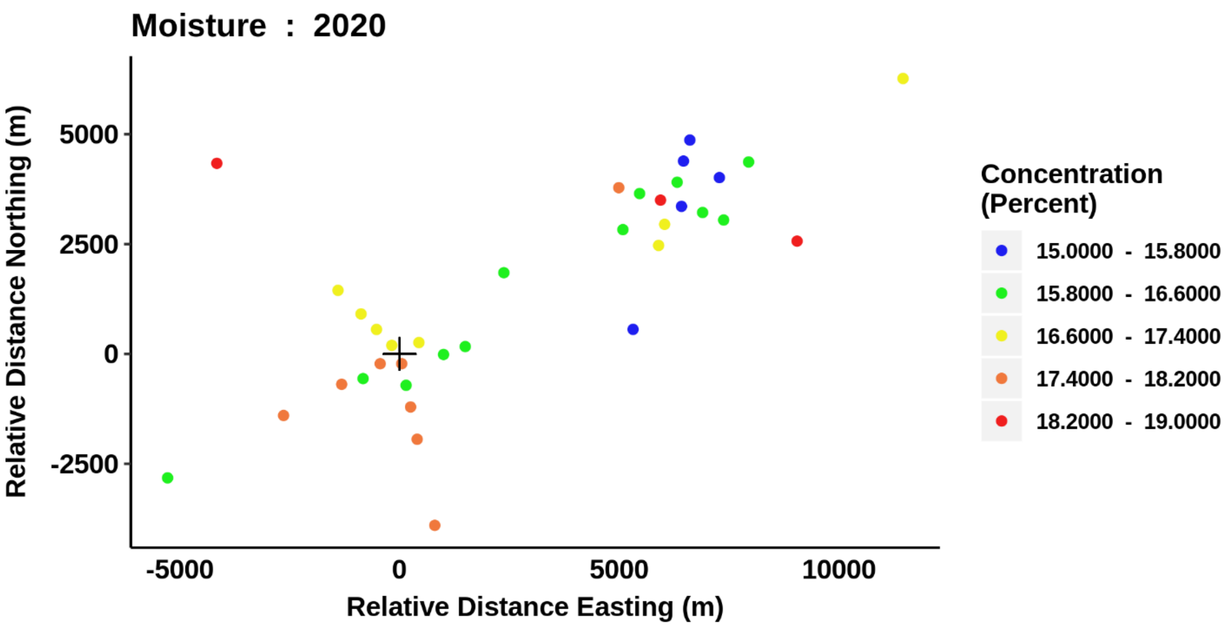


Figure 4-18 Spatial pattern of moisture (precent) from 2020 EEM samples within the survey area around the platform (cross). When above the detection limit (98% of samples) the average moisture content of 2014 baselines samples was 15%.

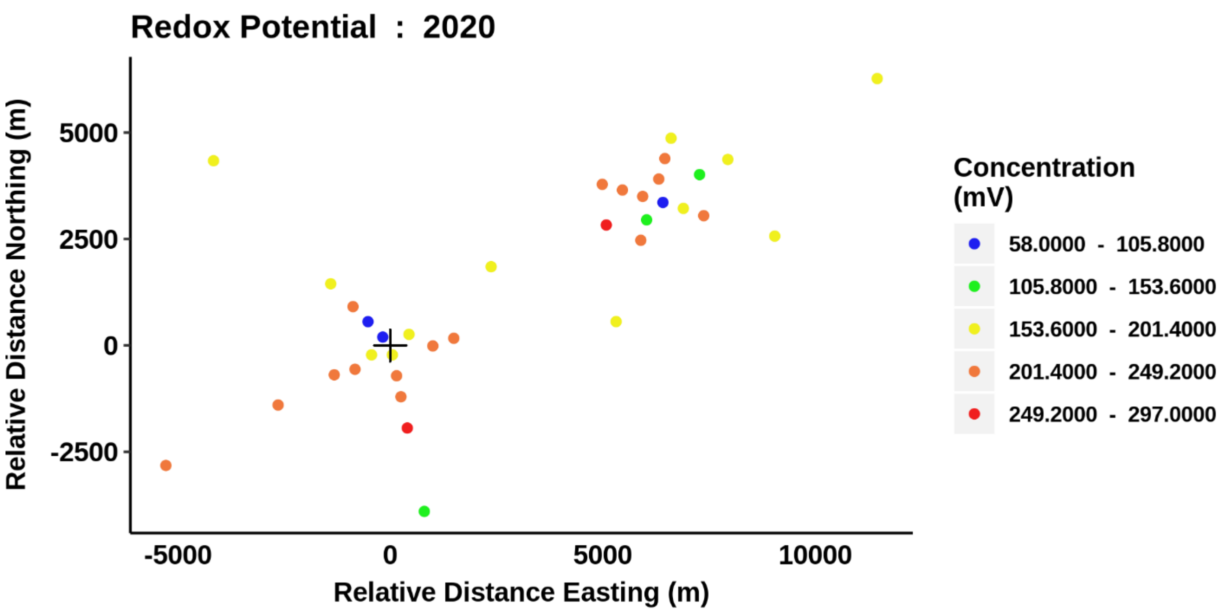


Figure 4-19 Spatial pattern of redox potential (mV) from 2020 EEM samples within the survey area around the platform (cross). Values not reported during baseline program

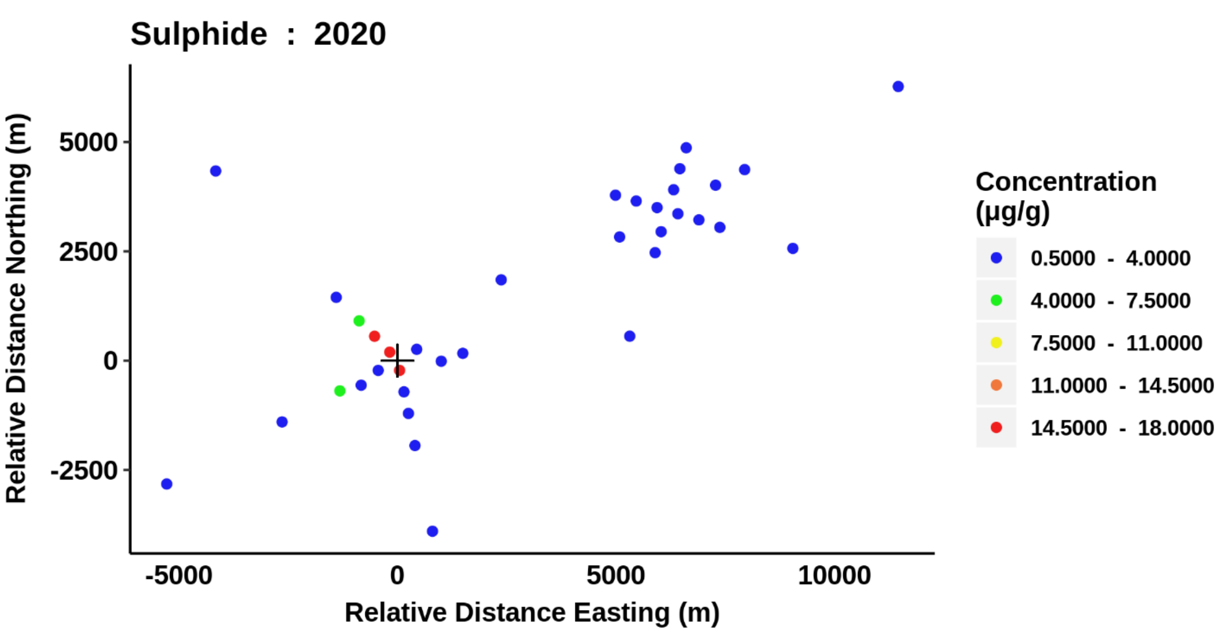


Figure 4-20 Spatial pattern of sulphide (µg/g) from 2020 EEM samples within the survey area around the platform (cross). Values not reported during 2014 baseline program.

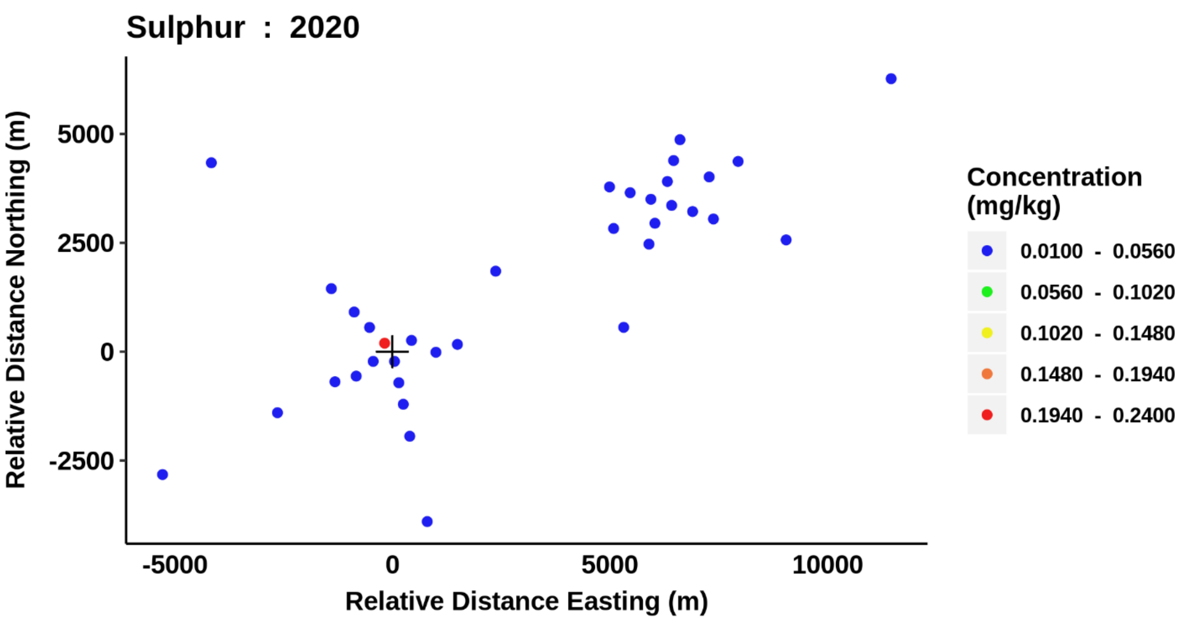


Figure 4-21 Spatial pattern of sulphur (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). When above the detection limit (15% of samples) the average concentration of 2014 baseline samples was 0.034 mg/kg.

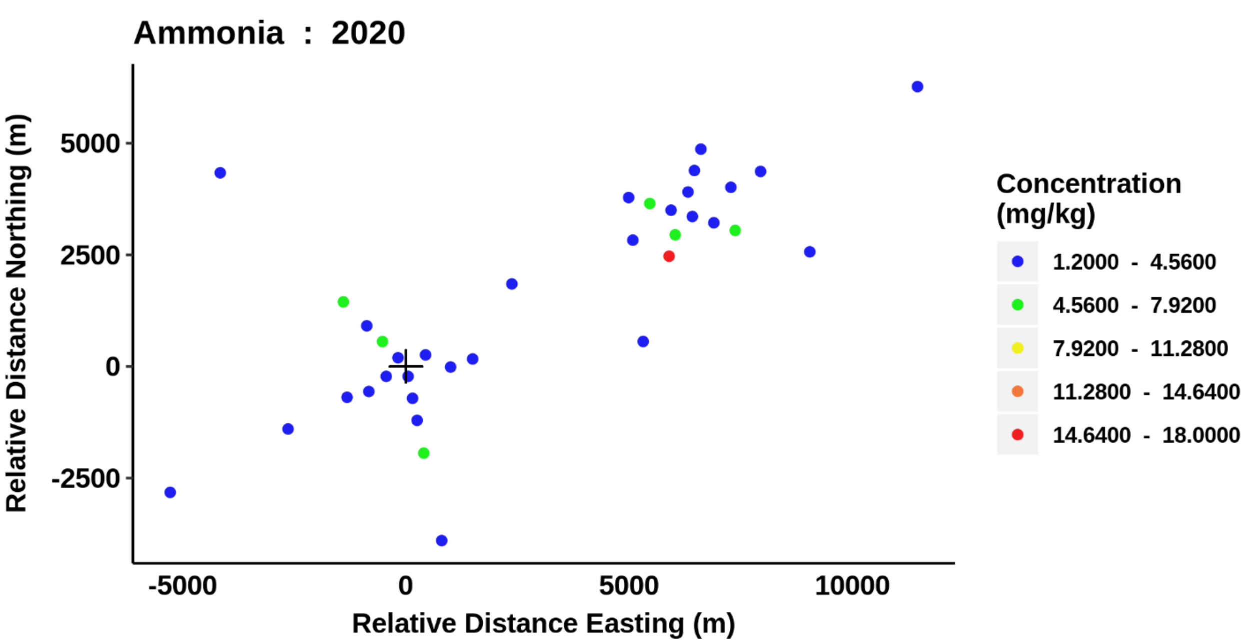


Figure 4-22 Spatial pattern of ammonia (mg/kg) from 2020 EEM samples within the survey area around the platform (cross). Values not reported during 2014 baseline program.

Results-Statistical

Spearman Rank Correlations

Table 4.5 and Table 4.6 present spearman rank correlations calculated for screened-in analyte concentrations to distance from the Hebron Platform (platform), distance from the Terra Nova FPSO and correlations to each other. Scatterplots for screened-in analytes by distance from the Hebron Platform and Terra Nova FPSO are presented Figure 4-23 and Figure 7-24 respectively.

From spearman rank correlations, six analytes were correlated to distance from the platform ($\rho S<0.05$) and five analytes with distance from the Terra Nova FPSO. Differences in particle sizes of gravel and sand (percent concentrations) were statistically significant with distance from the platform and Terra Nova FPSO (Table 4.5). For both drilling sources, gravel was positively correlated with distance (i.e., increased concentration of gravel with increased distance) and sand was negatively correlated with distance (i.e., decreased concentration of sand with increased distance from source). Concentrations of gravel in sediment samples was higher at stations more than 6,000 m from the Hebron Platform (Figure 4-23). Barium, C_{10}-C_{21} hydrocarbons, C_{21}-C_{32} hydrocarbons, and sulphur were negatively correlated with distance from the platform (Table 4.5, Figure 4-23). All other screened-in analytes concentrations were not statistically significant with distance.

There were several significant Spearman rank correlations coefficients found between analytes (Table 4.6). Concentrations of TOC, fuel and lube range hydrocarbons, barium, and metals were most strongly correlated with percent fines. Similarly, barium was significantly correlated to TOC, fuel and lube range hydrocarbons, sulphide, sulphur, and metals. As expected, particle sizes for gravel and sand were either not correlated or negatively correlated with the fuel and lube range hydrocarbons.

Table 4.5 Spearman rank correlations (ρS) of screened-in analytes by distance to drilling sources in 2020

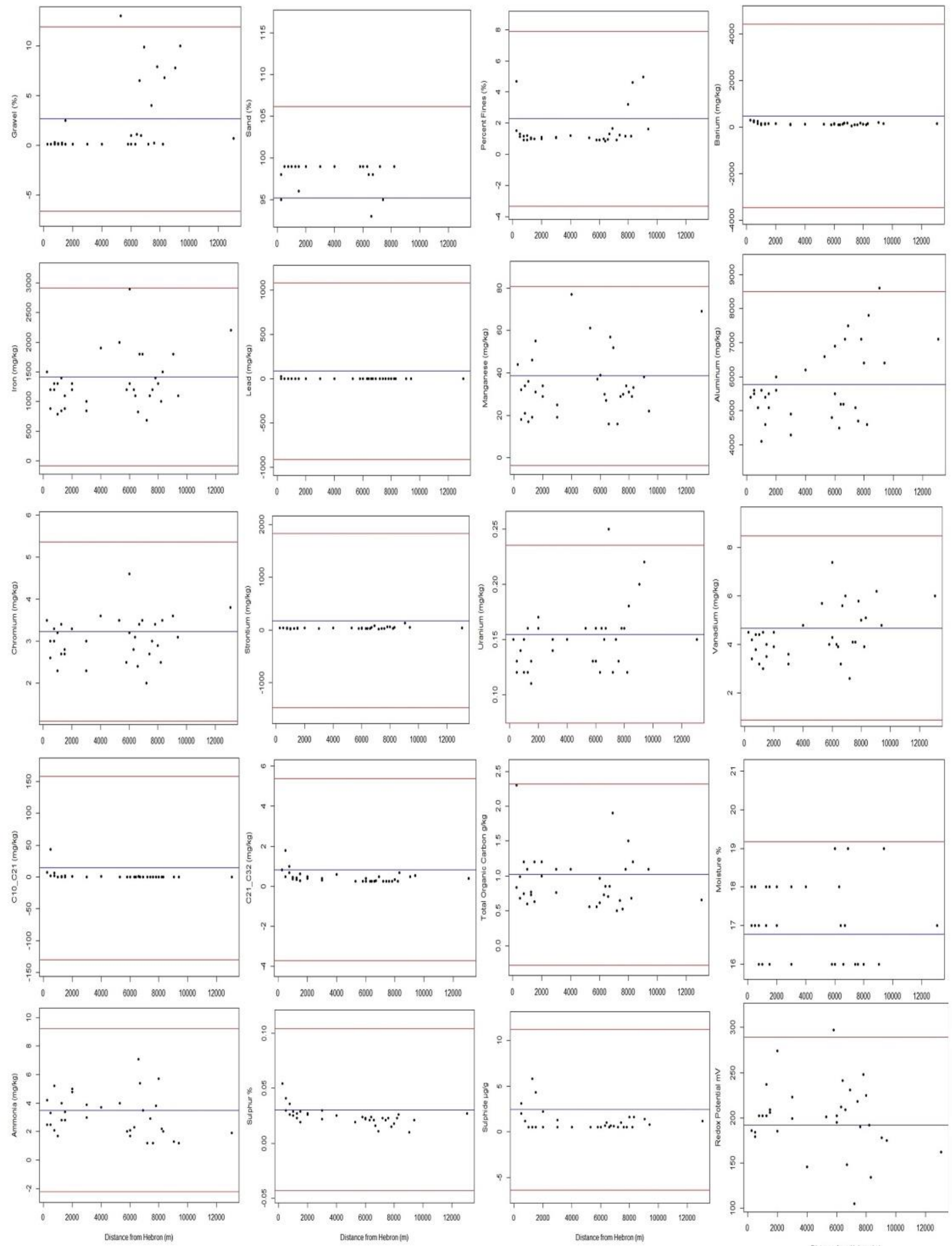
Analyte	Spearman Rank Correlation (ρS) with Distance from Activity	
	Hebron	Terra Nova
Gravel	**0.618*** **	0.446**
Sand	-0.585**	-0.512*
Percent Fines	0.295	0.257
Barium	-0.360*	-0.194
Iron	0.106	0.107
Lead	0.053	0.107
Manganese	-0.007	-0.043
Aluminum	0.226	0.208
Chromium	0.068	0.046
Strontium	0.126	0.126
Uranium	0.282	0.246
Vanadium	0.290	0.259
Total Organic Carbon	-0.028	-0.137
>C_{10}-C_{21} Hydrocarbons	**-0.746*** **	**-0.596*** **
>C_{21}-C_{32} Hydrocarbons	**-0.593*** **	-0.503**
Moisture	-0.284	-0.317
Redox Potential	0.020	-0.116
Sulphide	-0.288	-0.057
Sulphur	**-0.537*** **	-0.450**
Ammonia	-0.223	-0.255

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

Table 4.6 Spearman Rank Correlation Matrix (ρ) of screened-in analytes in 2020

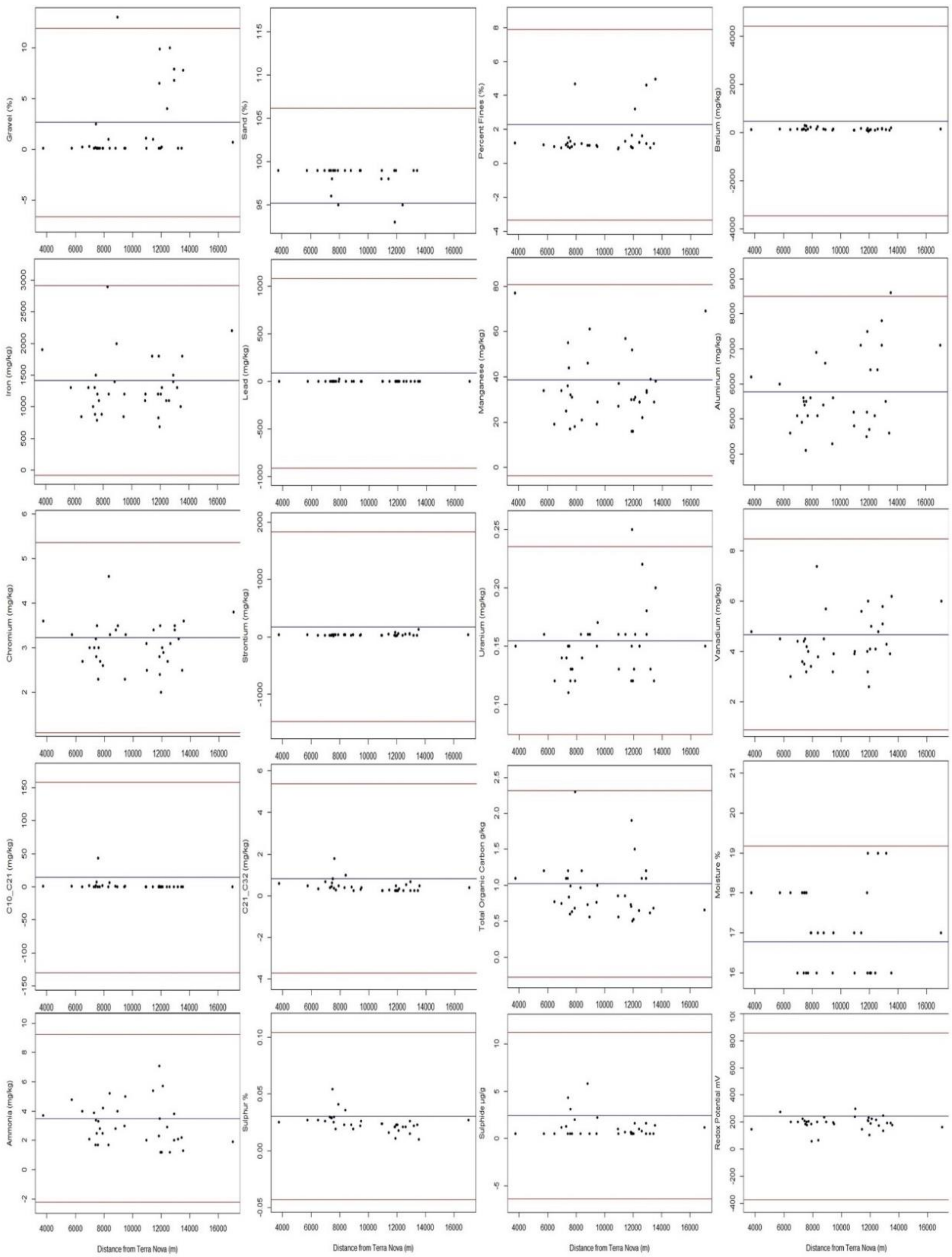
Analyte	Gravel	Sand	Percent Fines	Sulphide	Sulphur	Ammonia	TOC	Moisture	Barium	Iron	Lead	Manganese	Redox Potential	C_{10}-C_{21}	C_{21}-C_{32}	Aluminum	Chromium	Strontium	Uranium
Gravel																			
Sand	**-0.85*** **																		
Percent Fines	0.33	**-0.62*** **																	
Sulphide	-0.07	-0.1	0.27																
Sulphur	-0.43**	0.29	0.12	0.5**															
Ammonia	0.03	0.01	-0.16	0.21	-0.09														
TOC	0.23	-0.28	0.46**	0.46**	0.29	0.35*													
Moisture	-0.26	0.18	0.02	0.31	0.23	0.21	0.32												
Barium	0.02	-0.16	0.43**	**0.58*** **	0.38*	0.19	**0.59*** **	0.28											
Iron	0.22	-0.45**	**0.59*** **	0.16	0.01	0.02	0.37*	0.05	0.49**										
Lead	0.33*	**-0.55*** **	**0.63*** **	0.36*	0.1	0.09	**0.55*** **	0.15	**0.73*** **	**0.83*** **									
Manganese	0.13	-0.33*	0.42*	0.11	0.03	-0.02	0.27	0.15	0.37*	**0.87*** **	**0.68*** **								
Redox Potential	0.12	0.03	-0.37*	-0.26	-0.36*	0.23	-0.06	0.01	-0.32	-0.18	-0.31	-0.04							
C_{10}-C_{21}	-0.38*	0.32	-0.01	0.51**	**0.57*** **	0.3	0.35*	0.3	**0.62*** **	0.03	0.2	0.07	-0.21						
C_{21}-C_{32}	-0.19	0.09	0.28	**0.65*** **	**0.62*** **	0.05	**0.57*** **	0.45**	**0.74*** **	0.14	0.4*	0.13	-0.25	**0.73*** **					
Aluminum	0.48**	**-0.63*** **	**0.63*** **	0.26	0.02	0.15	**0.6*** **	0.1	**0.65*** **	**0.78*** **	**0.88*** **	**0.66*** **	-0.21	0.1	0.27				
Chromium	0.22	-0.45**	**0.6*** **	0.28	0.18	0.08	0.51**	0.2	**0.59*** **	**0.92*** **	**0.87*** **	**0.77*** **	-0.27	0.13	0.28	**0.81*** **			
Strontium	0.42*	**-0.58*** **	**0.64*** **	0.34*	0.03	0.23	**0.67*** **	0.16	**0.77*** **	**0.73*** **	**0.88*** **	**0.57*** **	-0.24	0.19	0.4*	**0.93*** **	**0.77*** **		
Uranium	0.46**	**-0.59*** **	0.49**	0.23	-0.15	0.24	**0.57*** **	0	0.45**	**0.64*** **	**0.72*** **	0.4*	-0.05	0	0.17	**0.76*** **	**0.7*** **	**0.74*** **	
Vanadium	0.41*	**-0.62*** **	**0.68*** **	0.13	-0.12	-0.07	0.42*	0.01	0.49**	**0.93*** **	**0.85*** **	**0.8*** **	-0.11	-0.1	0.13	**0.84*** **	**0.85*** **	**0.81*** **	**0.73*** **

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



Note: [1]Blue lines represent the mean analyte concentration; [2]Red lines indicate ±2 SD for each analyte.

Figure 4-23 Scatterplots of 2020 analyte concentrations versus distance (m) from the Hebron Platform



Note: [1]Blue lines represent the mean analyte concentration; [2]Red lines indicate ±2 SD for each analyte.

Figure 4-24 Scatter plots of 2020 analyte concentrations versus distance (m) from Terra Nova area

Threshold Regression Models

Distance relationships for concentrations primary variables (barium, C_{10}-C_{21}, and C_{21}-C_{32} hydrocarbons) were further investigated using threshold regression models (Figure 4-25 to Figure 4-27). Concentrations of these analytes decreased with increasing distance from the Hebron Platform (MinD). The threshold distance with the lowest unexplained variance occurred at 500 m from the Platform for all three constituents, indicating elevated concentrations occurred within 500 m from the Platform. This is consistent with observed concentrations at 8-250 and 4-250, which had relatively higher concentrations compared to other stations.

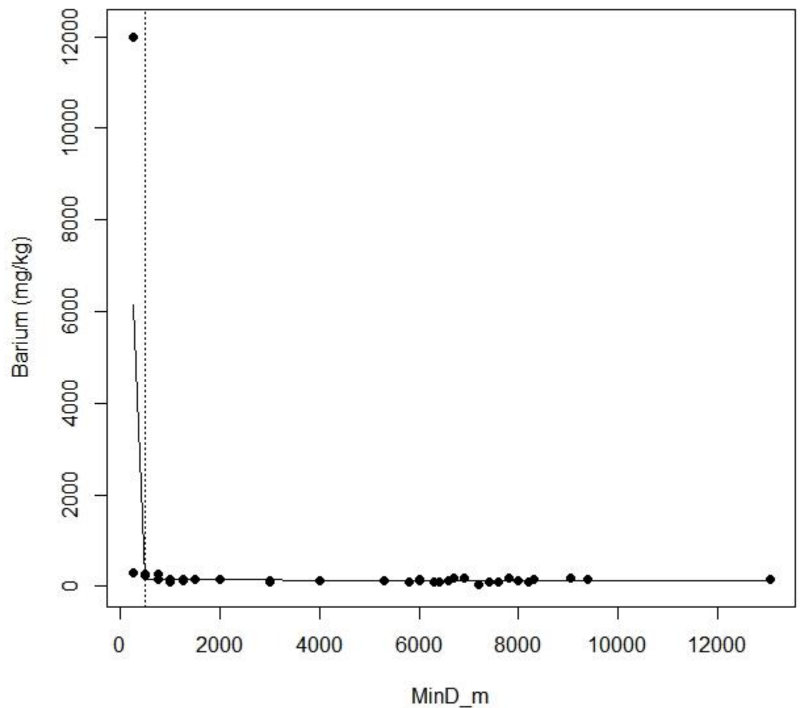


Figure 4-25 Distance gradient for concentration of barium (mg/kg) with distance from the Hebron Platform (MinD_m). The dotted line indicates a threshold of 500 m.

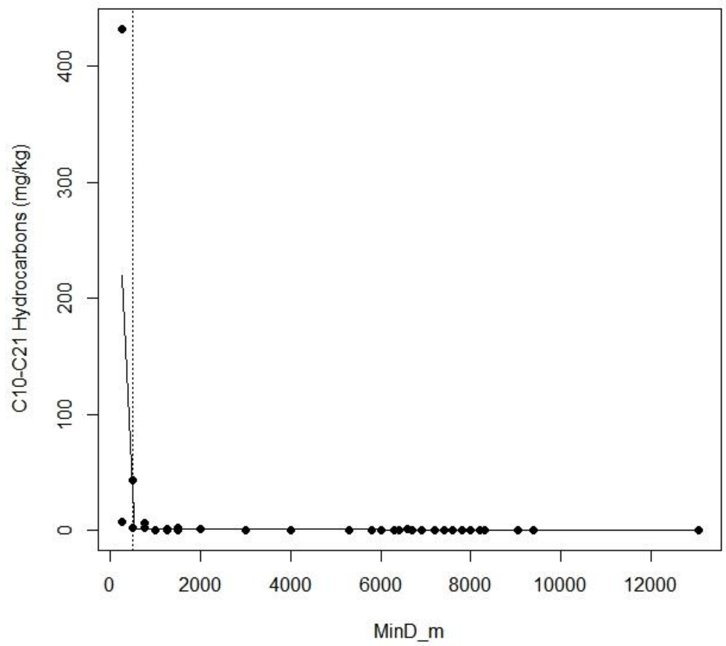


Figure 4-26 Distance gradient for concentration of C_{10}-C_{21} hydrocarbons (mg/kg) with distance form the Hebron Platform (MinD_m). The dotted line indicates a threshold of 500 m.

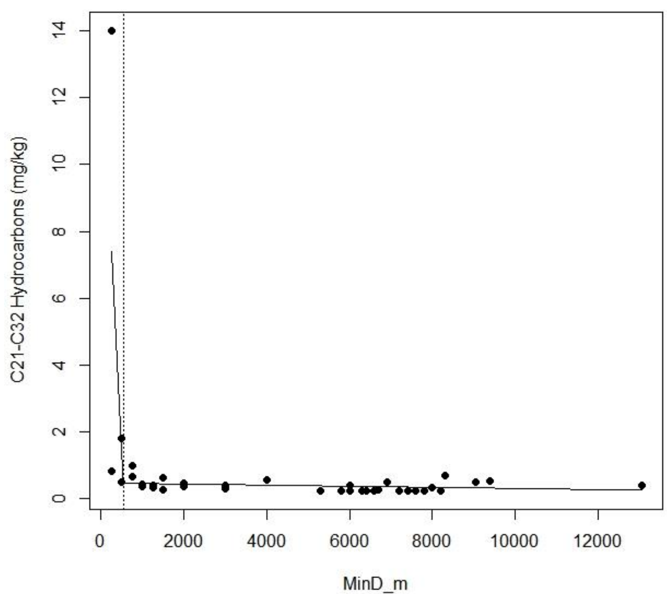


Figure 4-27 Distance gradient for concentration of C_{21}-C_{32} hydrocarbons (mg/kg) with distance form the Hebron Platform (MinD_m). The dotted line indicates a threshold of 500 m.

Multi-Year Comparisons

Multivariate statistical analyses for multi-year comparisons showed a statistically significant difference between the factor Year (2014, 2018, 2019, and 2020) relative to covariate factor Field (distance bin from the Hebron Platform) (Table 4.7). The interaction term Field x Year was not statistically significant. For all years, there was a statistically significant difference between the Far-field and the Near-and Mid-fields (p=0.001 and p=0.002 respectively). Near-field stations, and specifically station 8-250, had higher analyte concentrations in both 2018, 2019, and 2020 EEM surveys when compared to baseline levels.

Table 4.7 ANCOVA analysis results for screened-in analytes for all survey years (2014-2020).

Source	df	SS	MS	Pseudo-F	P(permutation)	permutations
Main Test						
Field	2	2086.2	1043.1	12.9	**0.001***	997
Year	3	1134.6	378.2	4.6774	0.004**	999
Field x Year	6	88.523	14.754	0.18247	0.999	999
Residuals	132	10673	80.857			
Total	143	14399				
Pairwise						
Fields				**t**	**P(permutation)**	**permutations**
Near, Mid				1.428	0.073	998
Far, Near				3.9482	**0.001***	999
Far, Mid				3.3277	0.002**	998
Notes: Statistically significant at p<0.05 (*), p<0.01 (**), p<0.001 (**BOLD**)						

4.3.2 Toxicity

Based on the two toxicity testing screening criteria, four stations were screened-in for toxicity testing, all of which were at or within 500 m from the platform (Table 4.8). Three of these EEM sediment samples were below the no-effect PetroTox threshold; station 8-250 reported levels above threshold. Amphipod survival of screened-in sediments ranged between 79 to 98 percent and all were deemed non-toxic based on Environment Canada guidelines. Site 8-250 had the lowest amphipod survival at 79 percent and was the only sample where a sulphur odor was detected.

As per recommendations from ECCC, pore water analysis was replaced with sediment ammonia, sulphide, and redox potential analyses. All sediment samples were deemed non-toxic compared to the control sediment (Table 4.9) with percent mortalities ranging from 1 to 21 percent, and it was therefore concluded that sediment concentrations of ammonia or sulphide did not impact the toxicity of the samples.

Table 4.8 Amphipod toxicity testing summary for sediment samples screened-in for the 2020 Hebron EEM.

Station ID	Amphipod Survival (percent)	Sample Standard Deviation	Significant Difference from Control	30% Reduction from Control	Interpretation
4-250	89	17.46	No	No	Non-toxic
8-250	79	10.37	No	No	Non-toxic
6-500	88	13.42	No	No	Non-toxic
FL-500	98	2.74	No	No	Non-toxic
Control Sediment*	99	2.24	NA	NA	NA

Notes:

NA= Not Applicable

*Control sediment consisted of sediment from which the amphipods were collected.

Table 4.9 Amphipod assay summary (2020), sediment physiochemical analysis, and PetroTox level.

Station ID	% Mortality	Toxicity	Dry Sediment Ammonia (µg/g NH_3-N)	Dry Sediment Sulphides (µg/g S)	Wet Sediment Redox Potential (Eh)	C_{10}-C_{21} hydrocarbons (mg/kg) (PetroTox)
4-250	11	Non-toxic	0.19	<0.1	398	7.5
8-250**	21	Non-toxic	0.25	<0.1	357	432.0
6-500	12	Non-toxic	0.24	<0.1	381	43.1
FL-500	2	Non-toxic	0.22	<0.1	394	2.13
Control Sediment*	1	NA	0.23	<0.1	376	NA

Notes:

NA= Not Applicable

* Control sediment consisted of sediment from which the amphipods were collected.

**Strong sulfur odor was noted in the sediment upon closure

4.3.3 Benthic Community Structure

In EEM survey year three (2020), 36 benthic samples were collected which comprised 7,511 individuals from 157 taxa. Community structure monitoring parameters are presented in Table 4.10.

The overall number of taxa per sample ranged between 15 and 72 with a mean of 34. Of the six monitoring parameters, the stations with the lowest values were mainly found in the Near-field while those with the highest were found in the Far-field. Four of the seven stations with the lowest number of taxa occurred in the Near-field. The lowest number of taxa was recorded at 8-750 and the highest at station D-250.

Total abundances for all stations were lower (with the exception of Station 6-3000) than those reported at baseline (Figure 4-28). As observed in the baseline survey (and subsequent EEM survey years), abundances reported in 2020 samples were higher in the Far-field and specifically the northeast cluster (Table 4.10, Figure 4-28). The station with the highest abundance was B-3000 (n=687). Total abundance at stations within 750 m from the platform (except for station 4-750) showed an increase from 2019 levels (Figure 4-28).

Total biomass ranged between 0.37 g and 175.06 g with the lowest recorded at 8-750 and the highest recorded at FL-3000.

Species richness is a calculation that considers the number of individuals and the number of taxa present in a sample. Three of the five stations with the lowest species richness occurred within the Near-field, with the lowest reported at station 8-250. The highest species richness was reported in the Far-field at station 2-2000.

Evenness evaluates how individuals are distributed among the species present. High values (closer to 1) indicate lower variation in abundances between taxa in a sample and a low value indicates greater variation. Evenness ranged between 0.50 to 0.88 with a mean of 0.77. The station with the most variation occurred at 8-250 (J'=0.5) and the station with the least variation occurred at station C-3000 (J'=0.88) and 2-2000 (J'=0.88).

The sixth monitoring parameter is the Shannon-Weiner species diversity index which evaluates species diversity within each station. As in the other parameters, three of the five lowest stations were reported in the Near-field. The station with the lowest species diversity was 8-250 (H'=1.42). The highest species diversity occurred in the Far-field at station 2-2000 (H'=3.71).

The six community monitoring parameters have been calculated every survey year including baseline (excluding total biomass). The means for three of the parameters have slightly increased from baseline levels; number of taxa, evenness and Shannon-Weiner diversity index. Mean total abundance (N) has decreased from baseline (baseline: N=541, Y1: N=225, Y2: N=2013, Y3: N=209). In the baseline survey, the stations with the lowest reported abundances occurred with Near- and Mid-field. In EEM survey years one (2018) and two (2019), the lowest reported abundances mainly occurred at stations within the Near-field. Mean species richness (d) reported in 2020 (d=6.24) was lower than mean levels reported in baseline (d=11) but similar to those reported in previous EEM years (Y1: d=5.85, Y2: d=6.38).

Table 4.10 Community monitoring parameters for the 2020 EEM program. Light blue indicates five lowest values, orange indicates five 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	21	89	2.56	4.46	0.81	2.47
8-250	250	7940	17	123	2.38	3.33	0.50	1.42
FL-500	500	7900	25	132	55.78	4.92	0.76	2.46
6-500	500	7600	21	175	69.45	3.87	0.52	1.57
8-750	750	8380	24	142	64.04	4.64	0.74	2.35
4-750	750	6980	15	64	0.37	3.37	0.70	1.91
6-1000	1000	7410	28	97	34.95	5.90	0.81	2.69
FL-1000	1000	7580	24	86	14.88	5.34	0.81	2.62
8-1250	1250	8810	24	200	33.53	4.34	0.75	2.39
4-1250	1250	6490	24	103	32.41	4.96	0.80	2.54
6-1500	1500	7440	29	168	19.94	5.47	0.81	2.74
FL-1500	1500	7720	23	113	55.55	4.65	0.82	2.58
4-2000	2000	5730	30	200	53.19	5.47	0.81	2.74
8-2000	2000	9480	26	119	52.60	5.23	0.85	2.76
6-3000	3000	7300	29	247	0.66	5.08	0.82	2.77
FL-3000	3000	9440	20	97	175.06	4.15	0.80	2.38
4-4000	4000	3730	21	114	75.97	4.22	0.82	2.50
C-3000	5300	8950	62	269	34.68	10.90	0.88	3.64
FL-1250	5800	10970	28	146	66.17	5.42	0.64	2.13
6-6000	6000	8320	29	115	34.78	5.90	0.84	2.81
8-6000	6000	13190	22	89	39.22	4.68	0.85	2.62
D-1250	6300	11850	25	129	49.05	4.94	0.72	2.33
C-1000	6400	10930	31	133	76.38	6.14	0.83	2.86
D-750	6600	11870	55	403	22.61	9.00	0.83	3.32
C-500	6700	11430	48	267	3.91	8.41	0.82	3.17
D-250	6900	11900	72	536	45.77	11.30	0.75	3.22
B-250	7200	11950	29	95	70.27	6.15	0.80	2.69
A-500	7400	12420	46	348	42.18	7.69	0.73	2.80
B-750	7600	12040	20	67	70.89	4.52	0.81	2.44
A-1000	7800	12920	55	428	4.10	9.08	0.87	3.50
B-1250	8000	12120	60	395	9.56	9.87	0.69	2.83
A-1500	8200	13420	23	106	51.83	4.72	0.77	2.43
2-1250	8300	12910	58	492	2.63	9.20	0.85	3.47
2-2000	9050	13530	68	277	19.50	11.74	0.88	3.71

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)
B-3000	9400	12600	52	687	42.43	7.81	0.59	2.33
2-6000	13050	17010	45	260	24.96	7.91	0.75	2.85
Mean			34	209	40.40	6.24	0.77	2.67

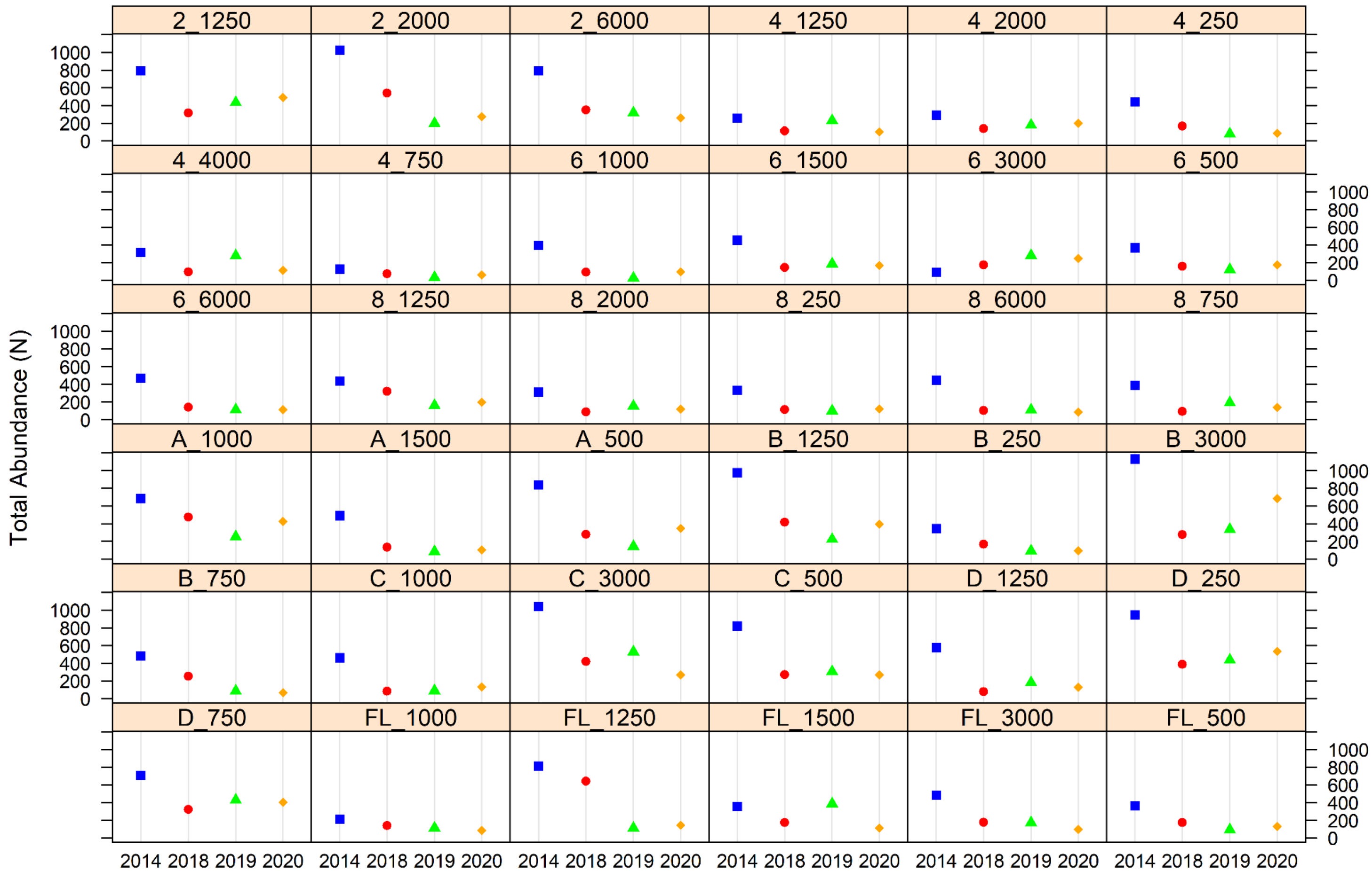


Figure 4-28 Total abundance (N) per station from 2014-2020.

Overall, the class Polychaeta accounted for 42 percent of all taxa observed followed by Clitellata at 24 percent, and the arthropods Amphipoda and Maxillopoda at 8 percent each. Within Polychaeta, the Spionid *Prionospio steenstrupi* was the most abundant species observed (n=533) particularly in the northeast cluster at stations A-500 (n=105), 2-1250 (n=54), B-1250 (n=46), and D-750 (n=42). The class Clitellata was comprised of two taxa, Clitellata (indeterminate) and Naididae (indeterminate). These taxa were observed at every station with the highest combined abundances occurring at stations more than 3,000 m from the platform (FL-1250 (n=92), 2-6000 (n=80), 8-1250 (n=66), 6-3000 (n=61)). Amphipods were found throughout the survey area; however, the highest abundances were in the northeast cluster (2-1250 (n=64), D-250 (n=60), A-1000 (n=51), and B-3000 (n=43)). The Maxillopoda species *Balanus crenatus* (barnacle) was mainly observed at stations within the northeast cluster and at two stations near the platform, 6-500 (n=105) and 8-250 (n=83). Highest abundances were observed at stations B-3000 (n=353), D-250 (n=147), and B-1250 (n=146).

Several taxa are used as indicator species for the presence or absence of pollution, particularly polychaetes (Diaz and Reish 2009). Tolerant taxa include the Capitellidae and Spionidae families (Pocklington and Wells 1992) and intolerant species include *Exogone* spp., *Harmothoe* spp., and *Polycirrus* spp. (Hiscock et al. 2004). Capitellidae were observed in low abundances throughout the survey area but mainly in the northeast cluster. Spionidae species were relatively more abundant but mainly observed in the northeast cluster with the highest abundances observed at stations A-500 (n=118) and 2-1250 (n=100). *Exogone hebes*, *Harmothoe imbricata*, and *Polycirrus eximius* were all observed at least once within the survey area in 2020. *E. hebes* (synonymous with *Parexogone hebes*) is a polychaete in the Syllidae family. It was the most widely distributed and abundant of the three species, being observed at least once at all stations. The highest abundances were also observed in the northeast cluster. *Harmothoe imbricata* (in the Polynoidae family) was observed at seven stations in low abundance (n<11). *Polycirrus eximius* (in the Terebellidae family) was only observed at five stations, all within the northeast cluster.

In addition to annelids, the top contributing taxa to overall abundance included arthropods, molluscs, and echinoderms. The 2020 percent contribution to total abundance for annelids and molluscs were similar to those observed in previous survey years (Table 4.11). Arthropod precent contribution has increased from 13.70 percent in the baseline survey to 30.75 percent in the year three (2020) survey. Echinoderm contributions have decreased from 6.26 percent observed in baseline and 1.93 percent in year three.

Table 4.11 Percent contribution to total abundance 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
2020	Year 3	59.54	30.75	4.25	1.93

Statistically significant differences were detected between benthic invertebrate species abundance per station with respect to distance from the Hebron Platform in 2020 (Table 4.12). All distance bins were statistically different from each other ($p<0.05$). The non-metric dimensional scaling (nMDS) plot shows separation between stations within 6,000 m of the Platform and those in the northeast cluster at a 40 percent similarity level (Figure 4-29). From the nMDS, stations are mainly grouped within their distance bin. Station 8-250 had the highest concentrations of several analytes and is only grouped with station 6-500 at the 60 percent similarity level.

The presence and abundance of invertebrate taxa are commonly used as environmental indicators. Differences in species abundance per distance bins was examined using SIMPER analysis. Stations within 1,000 m from the platform (Near-field) were 46.59 percent similar. Four species contributed over 50 percent to the similarity, and all were species of annelids. The top four species were Naididae (indeterminate) (23.15 percent), *Tharyx* sp. (15.55 percent), Clitellata (indeterminate) (8.10 percent), and *Exogone hebes* (7.07 percent). These species were also top contributors to Near-field similarity in previous EEM years and baseline. Stations 1,000 m to 2,000 m from the platform (Mid-field) had an average similarity of 58.01 percent. Six species contributed to 52.94 percent of the similarity. The top two contributors were also Naididae (indeterminate) (16.30 percent) and *Tharyx* sp. (8.85 percent). The other four species include the arthropod *Leptognathia caeca* (8.03 percent), and the annelids *Scoloplos armiger* (7.26 percent), *Aricidea catherinae* (6.42 percent), and *Prionospio steenstrupi* (6.08 percent). Near- and Mid-field stations were 53.07 percent dissimilar due in part to the presence of *Balanus crenatus* and *Aricidea catherinae*. Stations more than 2,000 m from the platform had an average similarity of 39.71 percent. Nine species contributed to 52.02 percent of the overall similarity. The top seven contributing species to Far-field station similarity were also present in the Near- and Mid-field main contributing species. The other two species were the arthropods *Priscillina armata* (3.55 percent), and *Eudorellopsis deformis* (2.82 percent).

Table 4.12 Results of One-way PERMANOVA testing main and pair-wise effects on Field on Bray-Curtis similarities of benthic invertebrate species assemblage

Source	df	MS	Pseudo-F	P(perm.)	Unique Perm.
Main testing					
Field	2	5101.8	3.0757	**0.001**	997
Residuals	33	1658.8			
Total	35				
Pair-wise testing					
Field	**Denom. Df**		**t**	**P(perm.)**	**Unique Perm.**
Near, Mid	12		1.575	**0.012**	858
Mid, Far	26		1.557	**0.038**	999
Far, Near	28		1.968	**0.001**	999

Notes: Perm= permutation, **Bold** values indicate statistically significance (***P*<0.05**)

Near: <1,000 m; Mid: 1,000 m to 2,000 m; Far: >2,000 m from the Hebron Platform

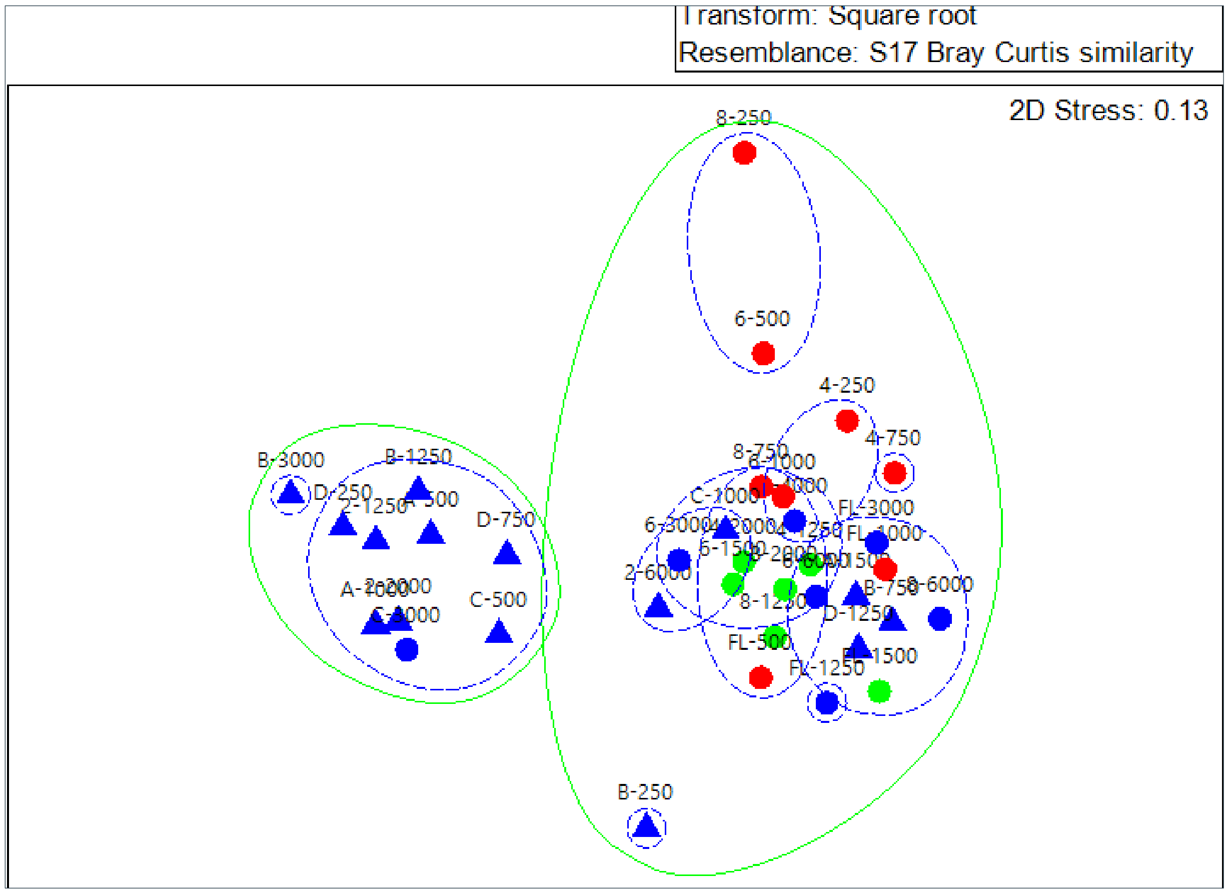


Figure 4-29 nMDS plot of benthic invertebrate family abundance per station. Colors indicate distance from Platform (red: ≤1,000 m, green: 1,000 to 2,000 m, blue: >2,000 m), symbols indicate proximity to Platform (circles indicate stations within 6,000 m, and triangles greater than 6,000 m). Cluster analysis is represented by lines: 40% similarity (green solid line) and 60% similarity (blue dotted line).

Multivariate analysis demonstrated family assemblages differed between distance bins (Table 4.12), these bins were examined separately in addition to the whole field analysis. The relationship between the invertebrate family assemblage and screened-in analytes was examined using a step-wise DISTLM analysis. In 2020 (Year Three), two predictor variables explained 52 percent of the observed variation in the Near-field, gravel and C_{21}-C_{32} hydrocarbons (Table 4.) with C_{21}-C_{32} hydrocarbons explaining 37.3 percent of the variability in family assemblage. Station 8-250 was closely associated with concentrations of C_{21}-C_{32} hydrocarbons compared to other Near-field stations (Figure 4-, A). In the Mid-field, four variables explained 90 percent of the variation, C_{21}-C_{32} hydrocarbons, TOC, manganese, and strontium. C_{21}-C_{32} hydrocarbon concentrations explained 35.1 percent of family assemblage variation. Stations in the Mid-field were loosely grouped (at 60 percent similarity) and mainly associated with concentrations of TOC and C_{21}-C_{32} hydrocarbons (Figure 4-, B). Three variables (gravel, chromium, and aluminum) explained 46.4 percent of the family assemblage in the Far-field. Gravel concentrations explained 30.4 percent of the variation observed in the Far-field. Stations within the northeast cluster were closely associated with concentrations of gravel while, stations within 6,000 m of the platform were more closely associated with chromium concentrations (Figure 4-, C). When all survey stations were examined, three variables explained 37 percent of the variation. Gravel contributed 25 percent of the explained variance followed by C_{10}-C_{21} hydrocarbons (7 percent), and uranium (<4 percent). Station 8-250 was closely associated with the concentration of C_{10}-C_{21} hydrocarbons, while stations in the northeast cluster were associated with gravel concentrations (Figure 4-, D).

Table 4.13 Results of DISTLM multivariate regression of predictor analytes on family assemblages

Analyte	AIC	SS (trace)	Pseudo-F	*P*	Variance Explained (%)	Cumulative R^2	Residual df
Near-field							
>C_{21}-C_{32} Hydrocarbons	55.861	3111.4	3.570	**0.001**	0.373	0.373	6
Gravel	55.725	1225.5	1.530	0.14	0.147	0.520	5
Mid-field							
>C_{21}-C_{32} Hydrocarbons	40.045	1321.3	2.1671	0.081	0.351	0.351	4
TOC	39.695	790.41	1.439	0.192	0.21022	0.562	3
Manganese	38.519	677.37	1.3953	0.311	0.18015	0.74	2
Strontium	34.854	593.28	1.571	0.351	0.158	0.900	1
Far-Field							
Gravel	155.77	9501	8.715	**0.001**	0.304	0.303	20
Chromium	155.22	1699.7	1.726	0.075	0.005	0.434	18
Aluminum	154.14	2314.1	2.552	**0.009**	0.074	0.508	17
Whole							
Gravel	255.14	12953	11.425	**0.001**	0.252	0.252	34
>C_{10}-C_{21} Hydrocarbons	253.13	4062.2	3.8873	**0.001**	0.079	0.330	33
Uranium	252.93	2046	2.0183	**0.017**	0.040	0.370	32

Notes:
Bold values indicate statistical significance of $P<0.05$. * indicates a statistical significance of $P<0.001$

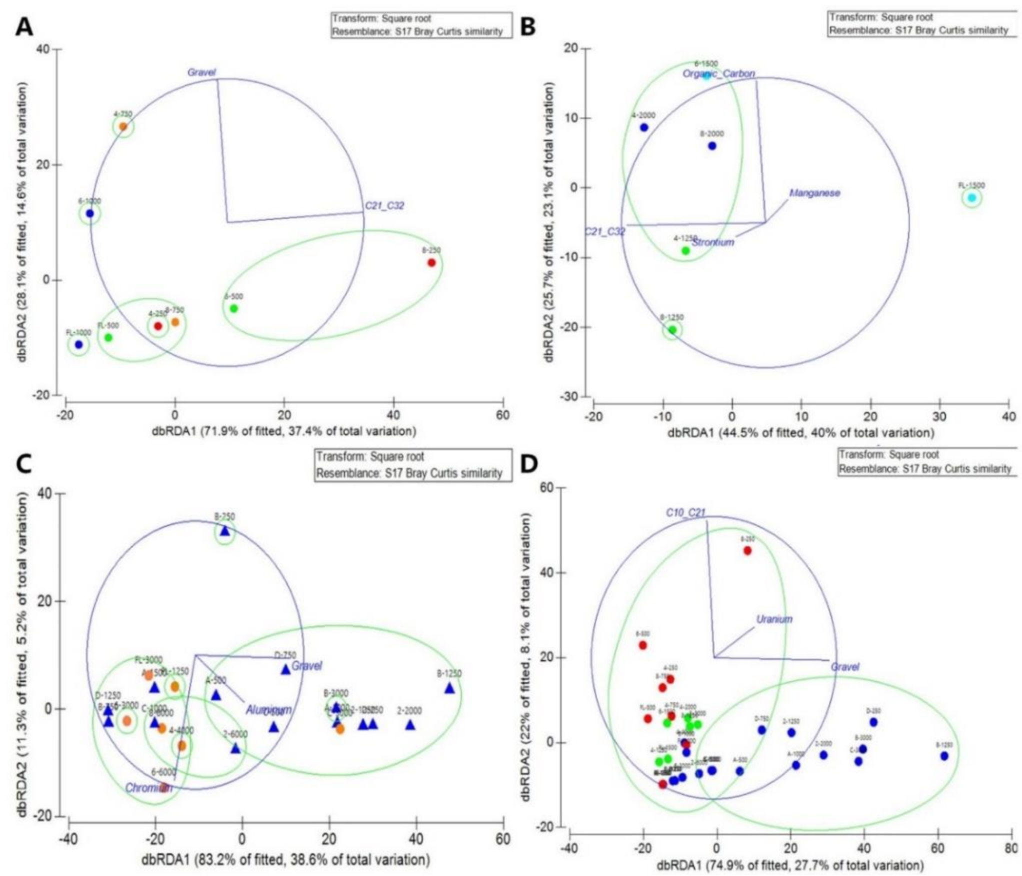


Figure 4-30 dbRDA plots of Y3 EEM community structure and screened-in analytes best fit DistLM models: Near-field (A), Mid-field (B), Far-field (C), and Total (D; all fields). Symbol colors indicate distance from platform, triangles indicate stations >6,000 m from the platform. Green solid line indicates 60% similarity.

4.4 Summary of Results

4.4.1 Physical and Chemical Characteristics

A total of 20 analytes were screened-in for further analysis in 2020. There was a statistically significant difference between EEM years and fields. Several analytes were negatively correlated to distance from the Hebron Platform including barium, fuel and lube range hydrocarbons, and sulphur. The distance based on the Threshold Regression Model for concentrations of barium, C_{10}-C_{21} hydrocarbons, and C_{21}-C_{32} hydrocarbons occurred at 500 m from the Hebron Platform. This was an expected result as outlined in the CSR. All other screened-in analytes concentrations were not statistically significant with distance. Station 8-250 sediment had the highest reported concentrations of ten analytes including barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons, sulphur, and several metals. This is similar to previous EEM survey years (2018 and 2019). Also, as in previous EEM surveys, the highest concentrations of gravel, precent fines, TOC, ammonia, and moisture occurred at stations more than 6,000 m from the Hebron Platform.

4.4.2 Toxicity

No Hebron EEM sediment samples >500 m from the platform were at or above PetroTox thresholds thus, only samples ≤500 m from the platform were screened-in for toxicity testing. Of the four samples evaluated, all were deemed non-toxic. These results are consistent with toxicity results observed in previous EEM years and baseline.

4.4.3 Benthic Community Structure

The six community monitoring parameters have been assessed every survey year including baseline (excluding total biomass). In 2020, of the six monitoring parameters, the stations with the lowest values were mainly found in the Near-field while those with the highest were found in the Far-field. This trend was also observed in previous EEM years. However, in the baseline survey while the highest values were mainly in the Far-field, the lowest values for the number of taxa, abundance, and species richness were distributed throughout all distances from the Platform. There was little overall change in community parameters compared among the three EEM years (2018-2020). The means for three of the parameters slightly increased in 2020 from baseline levels; number of taxa, evenness and Shannon-Weiner diversity index. This tends to indicate that Hebron EEM benthic communities were more diverse, and taxa are more evenly distributed than in baseline. The mean total abundance (N), however, has decreased in subsequent EEM surveys from baseline levels (baseline: N=541, Y1: N=225, Y2: N=2013, Y3: N=209). Overall, the class Polychaeta accounted for 42 percent of all taxa observed followed by Clitellata at 24 percent, and the arthropods Amphipoda and Maxillopoda at 8 percent each. Within Polychaeta, the Spionid *Prionospio steenstrupi* was the most abundant species observed (n=533) particularly in the northeast cluster. Capitellidae were observed in low abundances throughout the survey area but mainly in the in the northeast cluster. Spionidae species were relatively more abundant but mainly observed in the northeast cluster with the highest abundances observed at stations A-500 (n=118) and 2-1250 (n=100). Transition and intolerant species (e.g., *Tharyx* sp. and *Exogone hebes*) were observed throughout the survey area with the highest abundances observed more than 1,000 m from the Platform. The benthic communities at stations within 1,000 m from the Platform were statistically different from those at greater distances by the presence of Clitellata taxa, *Tharyx* sp., and *Exogone hebes*. At stations more than 1,000 m from the Platform, arthropods and other species of annelids contributed more to the community structure.

In 2020, Near-field stations had some of the lowest diversity index values, and from SIMPER analysis these stations were 46.59 percent similar. The top four species (all annelids) contributed over 50 percent to the group similarity. The top four species were Naididae (indeterminate) (23.15 percent), *Tharyx* sp. (15.55 percent), Clitellata (indeterminate) (8.10 percent), and *Exogone hebes* (7.07 percent). These species were also top contributors to Near-field similarity in previous EEM years and baseline. Species which are present in low-diversity communities must endure the conditions which may cause the reduction in diversity. The station with the lowest diversity value was Station 8-250 (H'= 1.42). The benthic community was mainly comprised of 17 taxa with the highest abundances from the families Balanidae (N=83), Phyllodocidae (N=12), and Naididae (N=8). The barnacle *Balanus crenatus* was the most abundant species (N=83) observed at this station. This species was not recorded at station 8-250 in the baseline survey but was recorded at relatively high abundances in the northeast cluster. The polychaete family Phyllodocidae is considered tolerant to enrichment effects (Paine et al., 2014).

Family assemblages were compared to screened-in analytes at each station. In 2020 (Year Three), two predictor variables explained 52 percent of the observed variation in the Near-field, gravel and C_{21}-C_{32} hydrocarbons. Station 8-250 had the highest concentrations of several analytes (including C_{21}-C_{32} hydrocarbons). In the Mid-field, four variables explained 90 percent of the variation, C_{21}-C_{32} hydrocarbons, TOC, manganese, and strontium. C_{21}-C_{32} hydrocarbon concentrations explained 35.1 percent of family assemblage variation. Stations in the Mid-field were loosely grouped (at 60 percent similarity) and mainly associated with concentrations of TOC and C_{21}-C_{32} hydrocarbons.

5.0 WATER QUALITY COMPONENT

5.1 Methods

5.1.1 Field Collection

Water quality sampling was conducted on September 29, 2020 to characterize the produced water plume being discharged during operations. This year was the second for produced water sampling at the Hebron Project (first year of monitoring was 2019). Similar to other sampling components (e.g., sediment), water samples were collected within the Near-field at fixed stations along radials that were located from 50 - 500 m from the produced water outfall which is located at the north-northeast side of the platform (Figure 5-1). However, rather than a Near-field distance of 1,000 m, it was restricted to 500 m. Reference water samples were collected at two reference stations (1-16000 and 7-16000). Prior to sampling, station E-50 was relocated to ensure a 50 m buffer from the lifeboat station on the platform (Figure 5-1, Table 5.1).

Weather conditions during water sampling were generally good with winds ranging from 17-20 kts and wave height approximately 1.4-1.9 m. Marine weather forecasts indicated direction of primary surface swells were north northwest.

Water was collected using 10 L Niskin bottles (Figure 5-2) at three depths per sample station; 1) top - approximately 5 m below the surface, 2) middle – below the mixed seawater/produced water layer and within the produced water plume at 35 m, and 3) bottom - 10 m above the sea floor. The middle Niskin depth was located within the produced water zone which was determined with a SeaBird Conductivity, Temperature, Depth (CTD) profiler (Figure 5-2) by comparing the water column characteristics at the nearest sampling station to the produced water outfall (N-50) to a further station (N-100). Data was collected on pH, temperature, conductivity, salinity, and dissolved oxygen through the water column. CTD profiles were uploaded to a field laptop, plotted, and viewed for changes to temperature, conductivity, dissolved oxygen, and salinity that indicate presence of the plume.

Upon retrieval of the Niskin bottles, water was decanted into appropriate laboratory provided sample containers and stored at 4^{0}C. Field duplicates were collected at N-100 (bottom), E-100 (surface), W-50 (bottom) and W-500 (surface) stations. Water sampling raw data and QA/QC procedures are presented in Volume II of this report.

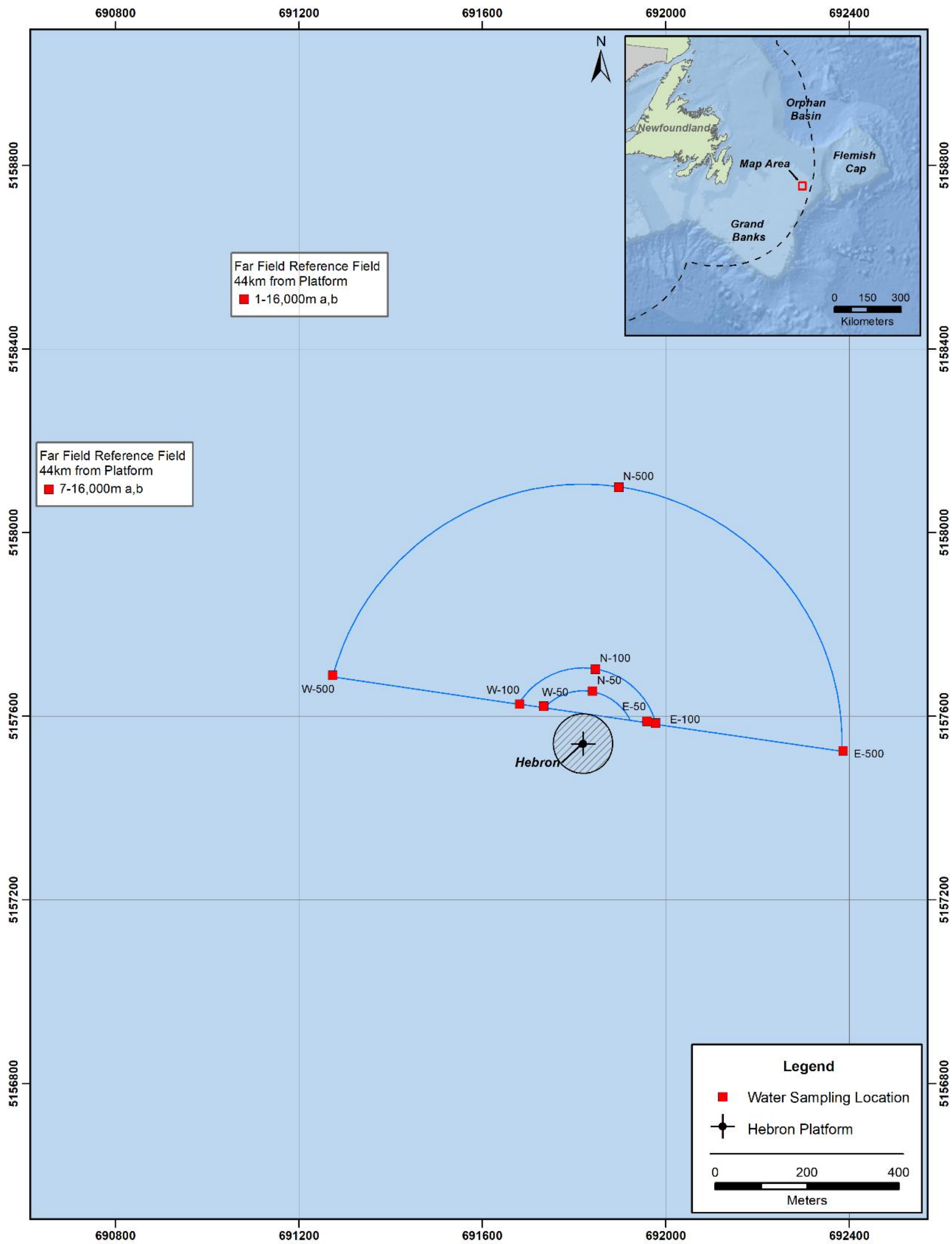


Figure 5-1 Water column sampling stations and CTD profile stations, September 29, 2020.

Table 5.1 Coordinates (proposed and actual) for the 2020 Hibernia water sampling program.

Station ID	Proposed Easting	Proposed Northing	Station Order	Actual Easting	Actual Northing
N-50	691837.00	5157654.51	1	691840.47	5157654.75
N-100	691844.62	5157704.00	2	691846.65	5157702.70
N-500	691895.52	5158099.99	8	691897.46	5158098.97
E-50[1]	691958.70	5157585.33	4	691958.97	5157588.58
E-100	691978.35	5157582.72	3	691977.84	5157584.70
E-500	692384.33	5157523.80	9	692386.22	5157524.47
W-50	691734.12	5157619.78	5	691733.89	5157621.61
W-100	691680.75	5157626.29	6	691681.90	5157626.55
W-500	691273.86	5157685.72	7	691274.16	5157689.12
1-16000	668966.00	5195809.00	11	668967.12	5195808.48
7-16000	653424.00	5179363.00	10	653422.42	5179363.92

Notes:

[1] Station E-50 was moved prior to departure to maintain 50 m separation from a lifeboat station.

All coordinates presented in UTMs, Zone 22, NAD83

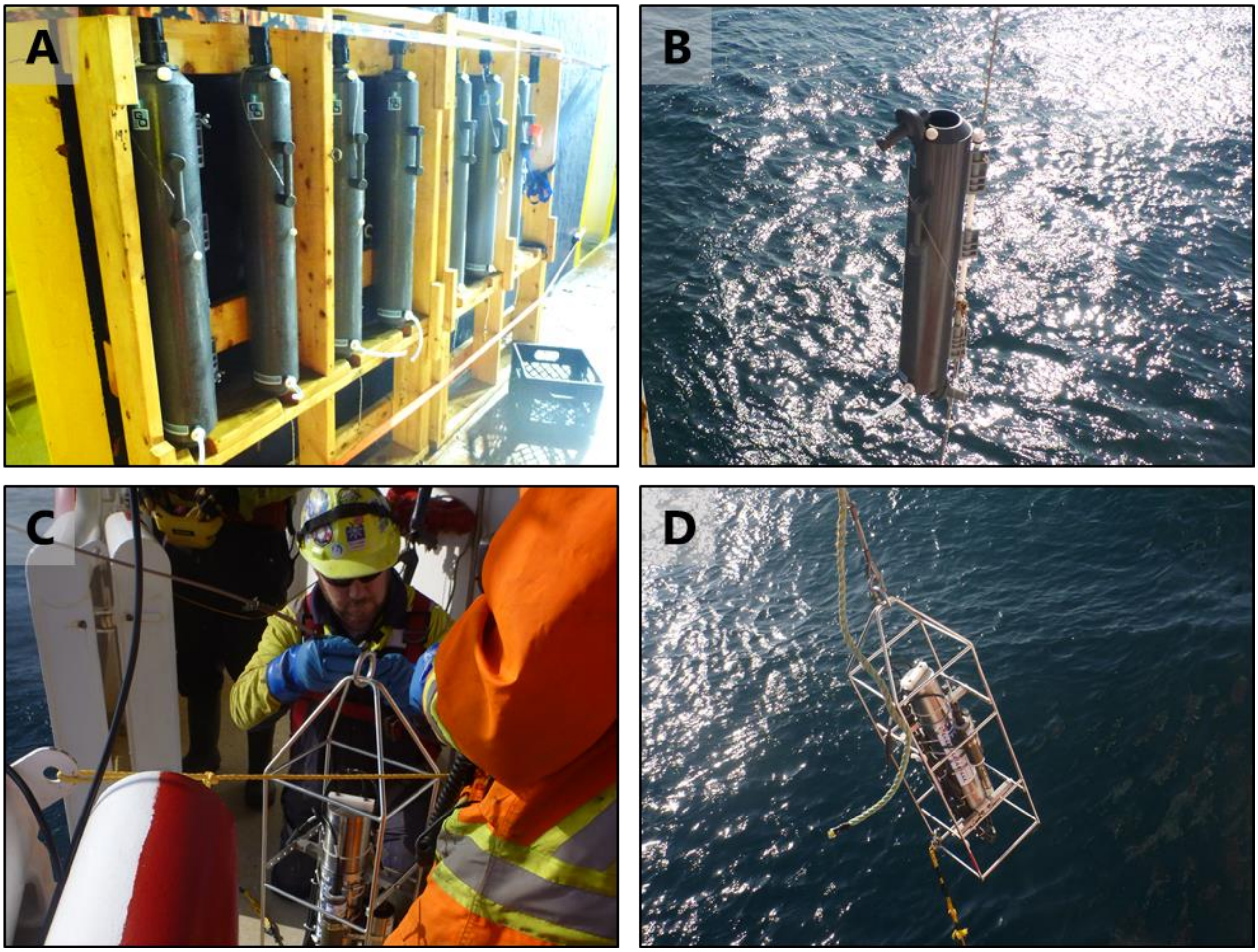


Figure 5-2 Niskin bottles in their rack (A), Niskin bottle being deployed (B), CTD being prepared for deployment (C), and CTD deployed from the *Avalon Sea* (D).

5.1.2 Laboratory Analysis

All marine samples were analyzed for chemical constituents including BTEX, hydrocarbons, TPH, and trace metals. Metals and hydrocarbons were screened for reporting and analysis if 50 percent or more of all samples within the Hebron Platform Site exceeded their RDL.

Onboard Produced Water Sampling

Chemical characteristics of the onboard produced water, prior to discharge, was used to identify analytes associated with potential enrichment or depletion in the marine receiving environment. Produced water is sampled annually prior to discharge as part of normal operations for the Hebron Project (EMCP 2018). Produced water samples were collected onboard the Platform by a laboratory technician on September 29, 2020. Samples were stored in coolers with ice packs and shipped back to shore via helicopter. Produced water was analyzed for chemistry (metals, inorganics, hydrocarbons, BTEX, radionuclides, alkylated phenols, PAHs, and alkyl-PAHs) and toxicity (sea urchin fertilization and Microtox).

Table 5.2 Water chemistry parameters and associated detection limits across monitoring years.

Parameter	Unit	Detection Limit		
		2014	2019	2020
Metals				
Aluminum	µg/L	10	10	10
Antimony	µg/L	0.50	0.50	0.50
Arsenic	µg/L	0.50	0.50	0.50
Barium	µg/L	1.0	1.0	1.0
Beryllium	µg/L	1.0	1.0	1.0
Bismuth	µg/L	1.0	1.0	1.0
Boron	µg/L	50	50	50
Cadmium	µg/L	0.050	0.050	0.050
Calcium*	mg/L	1000	1.0	1.0
Chromium	µg/L	0.50	0.50	0.5
Cobalt	µg/L	0.10	0.10	0.10
Copper	µg/L	0.50	0.50	0.50
Iron	µg/L	2.0	2.0	2.0
Lead	µg/L	0.10	0.10	0.10
Lithium	µg/L	20	20	20
Magnesium	mg/L	1.0	1.0	1.0
Manganese	µg/L	0.50	0.50	0.50
Mercury	µg/L	0.013	0.013	0.013
Molybdenum	µg/L	1.0	1.0	1.0
Nickel	µg/L	0.20	0.20	0.20
Phosphorus	µg/L	50	n/a	n/a
Potassium	mg/L	1.0	1.0	1.0
Selenium	µg/L	0.50	0.50	0.50
Silicon*	µg/L	100	1000	1000
Silver	µg/L	0.050	0.050	0.05
Sodium*	mg/L	1.0	5.0	2.0
Strontium	µg/L	10	10	10
Sulphur	mg/L	20	20	20
Thallium	µg/L	0.10	0.10	0.10
Tin	µg/L	1.0	1.0	1.0

Parameter	Unit	Detection Limit		
		2014	2019	2020
Titanium	µg/L	10	10	10
Uranium	µg/L	0.050	0.050	0.05
Vanadium	µg/L	10	10	10
Zinc	µg/L	1.0	1.0	1.0
Petroleum Hydrocarbons				
Benzene	mg/L	0.0010	0.0010	0.0010
Toluene	mg/L	0.0010	0.0010	0.0010
Ethylbenzene	mg/L	0.0010	0.0010	0.0010
Total Xylenes	mg/L	0.0020	0.0020	0.0020
C_6 - C_{10} (less BTEX)	mg/L	0.010	0.10	0.090
>C_{10}-C_{16} Hydrocarbons	mg/L	0.050	0.050	0.050
>C_{16}-C_{21} Hydrocarbons	mg/L	0.050	0.050	0.050
>C_{21}-<C_{32} Hydrocarbons	mg/L	0.10	0.10	0.090
Modified TPH (Tier1)	mg/L	0.10	0.10	0.090
Total Oil & Grease	mg/L	n/a	0.50	0.50
Polycyclic aromatic Hydrocarbons [a]				
1-Chloronaphthalene	µg/L	0.050	n/a	n/a
1-Methylnaphthalene	µg/L	0.050	n/a	n/a
2-Chloronaphthalene	µg/L	0.050	n/a	n/a
2-Methylnaphthalene	µg/L	0.050	n/a	n/a
Acenaphthene	µg/L	0.010	n/a	n/a
Acenaphthylene	µg/L	0.010	n/a	n/a
Anthracene	µg/L	0.010	n/a	n/a
Benzo(a)anthracene	µg/L	0.010	n/a	n/a
Benzo(a)pyrene	µg/L	0.010	n/a	n/a
Benzo(b)fluoranthene	µg/L	0.010	n/a	n/a
Benzo(e)pyrene	µg/L	0.010	n/a	n/a
Benzo(g,h,i)perylene	µg/L	0.010	n/a	n/a
Benzo(j)fluoranthene	µg/L	0.010	n/a	n/a
Benzo(k)fluoranthene	µg/L	0.010	n/a	n/a
Chrysene	µg/L	0.010	n/a	n/a
Dibenz(a,h)anthracene	µg/L	0.010	n/a	n/a
Fluoranthene	µg/L	0.010	n/a	n/a
Fluorene	µg/L	0.010	n/a	n/a
Indeno(1,2,3-cd)pyrene	µg/L	0.010	n/a	n/a

Parameter	Unit	Detection Limit		
		2014	2019	2020
Naphthalene	µg/L	0.20	n/a	n/a
Perylene	µg/L	0.010	n/a	n/a
Phenanthrene	µg/L	0.010	n/a	n/a
Pyrene	µg/L	0.010	n/a	n/a
Other Parameters [a]				
Hardness	mg/L	0.50	0.50	0.50
Chlorophyll a	µg/L	0.50	n/a	n/a
Phaeophytin A	µg/L	0.50	n/a	n/a
Nitrogen (Ammonia Nitrogen)	mg/L	0.050	n/a	n/a
Phosphorus	mg/L	0.020	n/a	n/a
Total Inorganic Carbon	mg/L	0.50	n/a	n/a
Total Organic Carbon	mg/L	5.0	n/a	n/a
Total Suspended Solids	mg/L	1.0	n/a	n/a

Notes:

[a] Analysis for polyaromatic hydrocarbons and particular other parameters were discontinued in development of the EEM design plan (EMCP 2017a).

* RDL varied across years.

5.1.3 Seawater Analyses

The physical and chemical characteristics of water samples included quantitative assessment of frequently detected parameters (analytes detected above RDL in >50 percent of samples at the Hebron Platform). Boxplots were generated for all frequently detected parameters. Infrequently detected parameters (analytes above RDL that were detected in 20-49 percent of samples) were also noted. Where available, detected analytes were also compared against Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life (CCME 2014).

Analysis of variance (ANOVA) were used to compare between sites (Hebron Platform, Reference) for all analytes included in analyses as outlined above with both Site and Depth included as factors. When no significant Site x Depth interaction was detected, the ANOVA was repeated excluding the Site x Depth interaction term from the model. ANOVAs were also used to compare sites across monitoring years. Where ANOVAs were used, assumptions (heterogeneity, normality, and independence) were checked to ensure a normal error structure was appropriate for analysis (Quinn and Keough 2002a). Log transformations were also applied to meet these assumptions where required.

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 2017a). However, half RDL was used for statistical analysis as a conservative value (EMCP 2017a).

To further focus analyses, concentrations of analytes from pre-discharged produced water were compared against water sampling results from reference stations. Analytes that were ten times or higher the levels observed for reference stations were considered potential produced water analytes that may result in local enrichment.

5.2 Results

5.2.1 Water Column Profiles

Water column profiles were collected at a reference station (Reference Station 1) and at station N-50 for determination of the mid-water depth range for sampling within an area that is perceived to be affected by the produced water discharge (Figure 5-3, Figure 5-4). That is, detectable differences between the water profile characteristics of the two stations are assumed to be caused by plume's influence.

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 62 m, i.e., the thermocline), followed lastly by a steady temperature below the thermocline (>60 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 became supersaturated in the mixed layer (i.e., >100 percent). 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 5-4). However, the surface layer at N-50 was deeper compared to the reference station which may be indicative of the influence of platform discharges. This is illustrated in Figure 5-5 where the temperature profile for both the reference station (faint line) and N-50 (bold line) are graphed. The depth ranges identified based on the profiles included surface (<16 m), middle (16-62 m, and bottom (63-85 m), with the middle water sample depth set at 35 m.

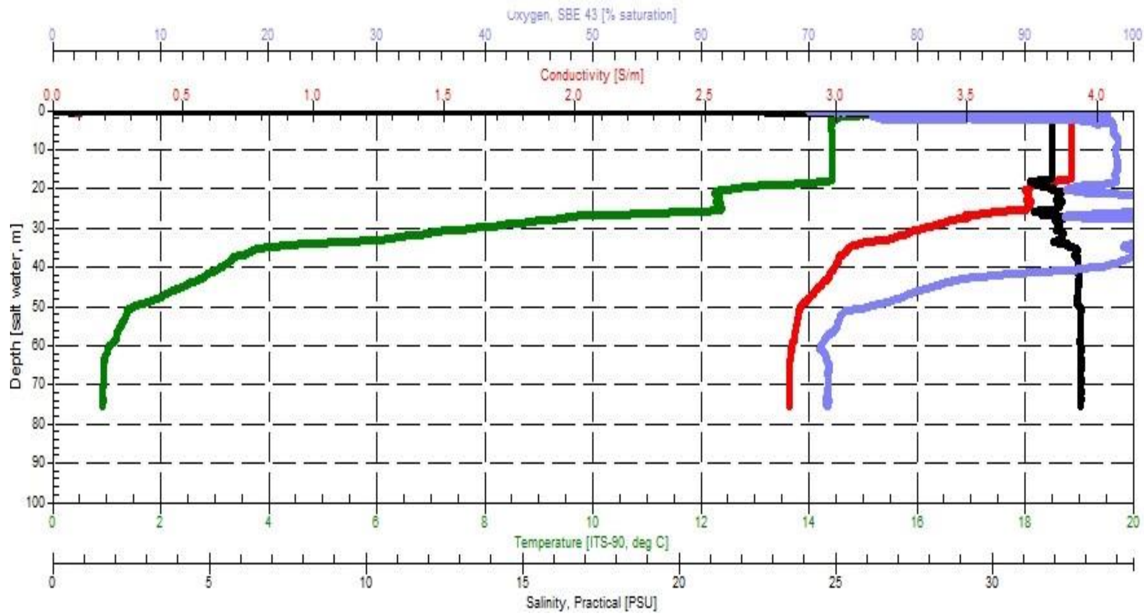


Figure 5-3 CTD Profile at Reference Station 1.

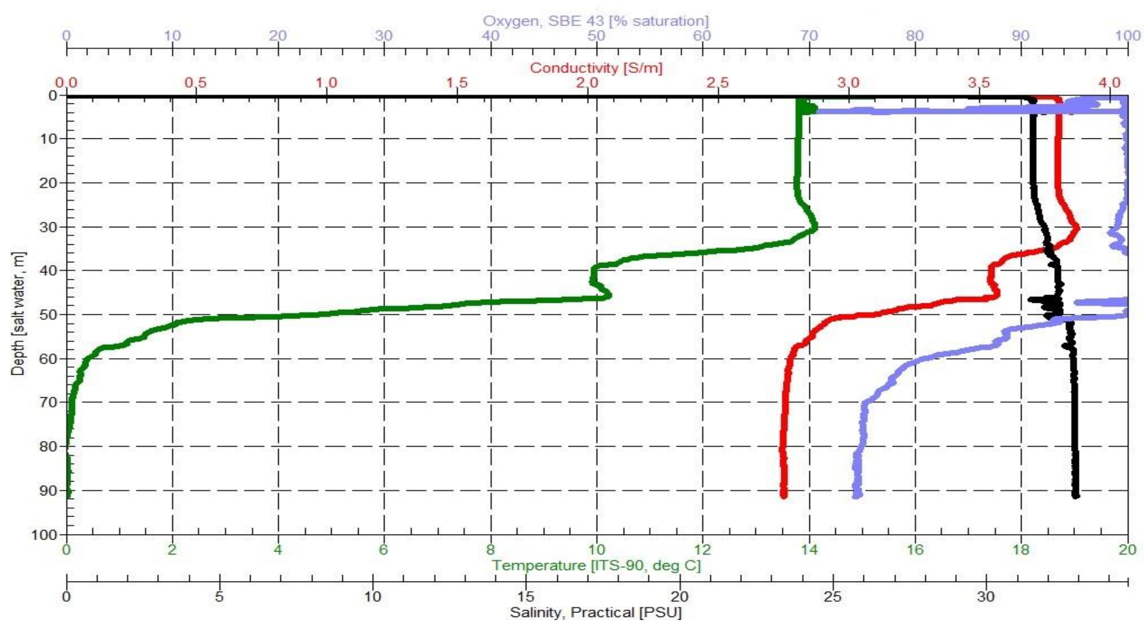


Figure 5-4 CTD Profile at Station N-50.

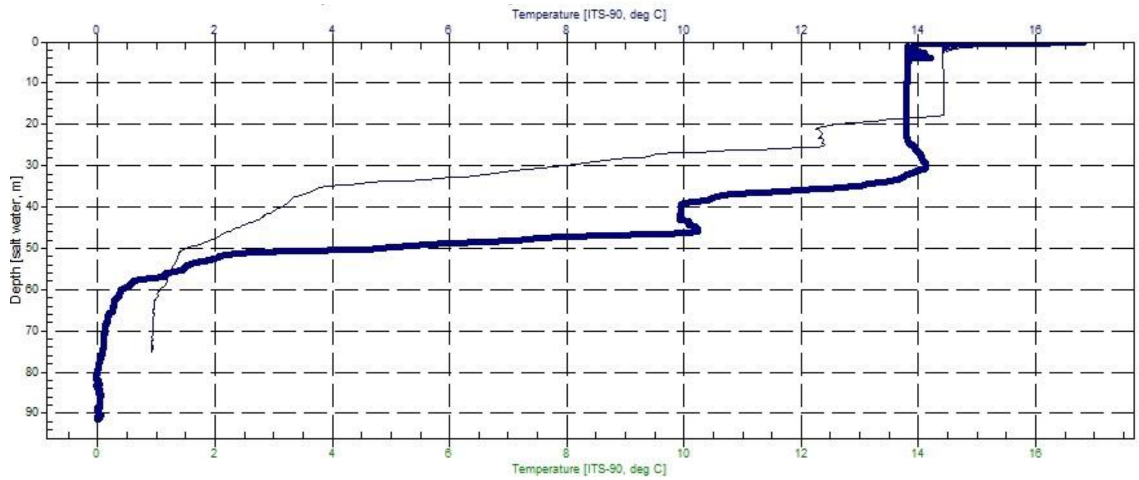


Figure 5-5 Temperature Profiles for the Reference station (faint line) and station N-50 (bold line)

5.2.2 Chemical and Physical Characteristics

Fifteen water sample parameters (14 metals and total hardness [$CaCO_3$]) were frequently detected within 50-500 m of the Hebron Platform produced water outlet (Table 5.3, Table 5.4). Seven of these were also detected in pre-discharge produced water at concentrations greater than ten times the Reference Site concentrations: barium, calcium, lithium, magnesium, potassium, sodium, and strontium. These analytes may potentially change in water sample concentrations near the platform due to produced water release. Boxplots by Site and sampling depth are presented in Figure 5-6. It is noted that petroleum hydrocarbons (e.g., C_6 to $<C_{32}$, BTEX, TPH) were not detected in any water samples.

Laboratory detection limits for some analytes were confounded within the onboard produced water due to the sample matrix. As a result, RDLs in produced water were much higher for many constituents such as arsenic, molybdenum, nickel, sulphur and zinc when compared to water sample RDLs. Direct comparisons among onboard produced water and marine water samples were not completed.

Within Year Comparison

Based on the ANOVA results, there were no significant interaction terms among Site and Depth analyte concentrations and therefore no detectable project effects. Analyte concentrations among the three sample depths followed the same general pattern of higher concentrations in near-bottom samples and lower concentrations in the top (near-surface) samples. ANOVA tests were re-run with the interaction term removed. Boron concentrations were significantly higher at the Platform Site relative to the Reference Site and was the only significantly different analyte among Sites (Table 5.5). It should be noted that the relatively low number of Reference water samples caused an unbalanced design and therefore likely reduced the statistical power to detect differences.

CCME Guidelines

Of the detected analytes during the water sampling program, only Arsenic had an associated CCME guideline (Table 5.2). Detected Arsenic levels were well below CCME marine water guidelines (CCME 2014).

Table 5.3 Summary of Platform Site chemical data from frequently detected analytes from the 2020 EEM water sampling and corresponding values from onboard produced water prior to discharge.

Parameter	CCME	RDL	Units	Hebron							Overboard Produced Water	
				N	%>RDL	Mean	St.Dev.	Median	Minimum	Maximum	RDL	Value
Metals												
Arsenic	12.5	0.50	µg/L	27	100	1.74	0.15	1.73	1.42	2.04	10	<10
Barium	n/a	1.0	µg/L	27	100	6.8	1.1	6.3	5.5	8.9	10	16,000
Boron	n/a	50	µg/L	27	100	4,410	163	4,410	4,160	4,750	500	29,000
Calcium	n/a	1.0	mg/L	27	100	369	13	370	344	391	1000	1,300,000
Lithium	n/a	20	µg/L	27	100	168	6	167	157	179	20	4800
Magnesium	n/a	1.0	mg/L	27	100	1,196	41.1	1,200	1,110	1,260	1000	410,000
Molybdenum	n/a	1.0	µg/L	27	100	9.8	0.3	9.8	9.3	10.4	20	<20
Nickel	n/a	0.20	µg/L	21	78	1.6	6.0	0.4	<0.20	31.8	20	<20
Potassium	n/a	1.0	mg/L	27	100	365	11	365	346	384	1000	270,000
Sodium	n/a	5.0	mg/L	27	100	9,328	210	9,280	8,960	9,680	10000	17,000,000
Strontium	n/a	10	µg/L	27	100	7,521	240.1	7,500	7,150	7,940	200	300,000
Sulphur	n/a	20	mg/L	27	100	862	28	865	811	901	50000	<50,000
Uranium	n/a	0.05	µg/L	27	100	2.92	0.10	2.89	2.66	3.15	1.0	<1.0
Zinc	n/a	1.0	µg/L	18	67	3.1	5.5	1.3	<1.0	25.1	500	<500
Calculated Parameters												
Total Hardness ($CaCO_3$)	n/a	0.5	mg/L	27	100	5,845.2	197.6	5,890.0	5,440.0	6,150.0	1.0	5,000

Table 5.4 Corresponding Reference Site chemical data for frequently detected analytes from the 2020 EEM water sampling.

Parameter	CCME	RDL	Units	Reference Stations						
				N	%>RDL	Mean	St.Dev.	Median	Minimum	Maximum
Metals										
Arsenic	12.5	0.50	µg/L	6	100	1.68	0.09	1.65	1.57	1.81
Barium	n/a	1.0	µg/L	6	100	6.6	0.8	6.4	5.8	7.8
Boron	n/a	50	µg/L	6	100	4,268	114	4,270	4,070	4,380
Calcium	n/a	1.0	mg/L	6	100	366	7	367	353	374
Lithium	n/a	20	µg/L	6	100	168	5	170	159	174
Magnesium	n/a	1.0	mg/L	6	100	1,170	28	1,175	1,120	1,200
Molybdenum	n/a	1.0	µg/L	6	100	9.7	0.2	9.7	9.5	10.0
Nickel	n/a	0.20	µg/L	6	100	0.9	0.6	0.7	0.5	2.1
Potassium	n/a	1.0	mg/L	6	100	360	10	364	342	370
Sodium	n/a	5.0	mg/L	6	100	9,390	219	9,450	9,060	9,600
Strontium	n/a	10	µg/L	6	100	7,548	195	7,610	7,220	7,750
Sulphur	n/a	20	mg/L	6	100	848	29	855	798	874
Uranium	n/a	0.05	µg/L	6	100	2.94	0.07	2.95	2.85	3.05
Zinc	n/a	1.0	µg/L	1	17	1.8	3.1	0.5	0.5	8.0
Calculated Parameters										
Total Hardness ($CaCO_3$)	n/a	0.5	mg/L	6	100	5,736.7	131.3	5,765.0	5,500.0	5,880.0

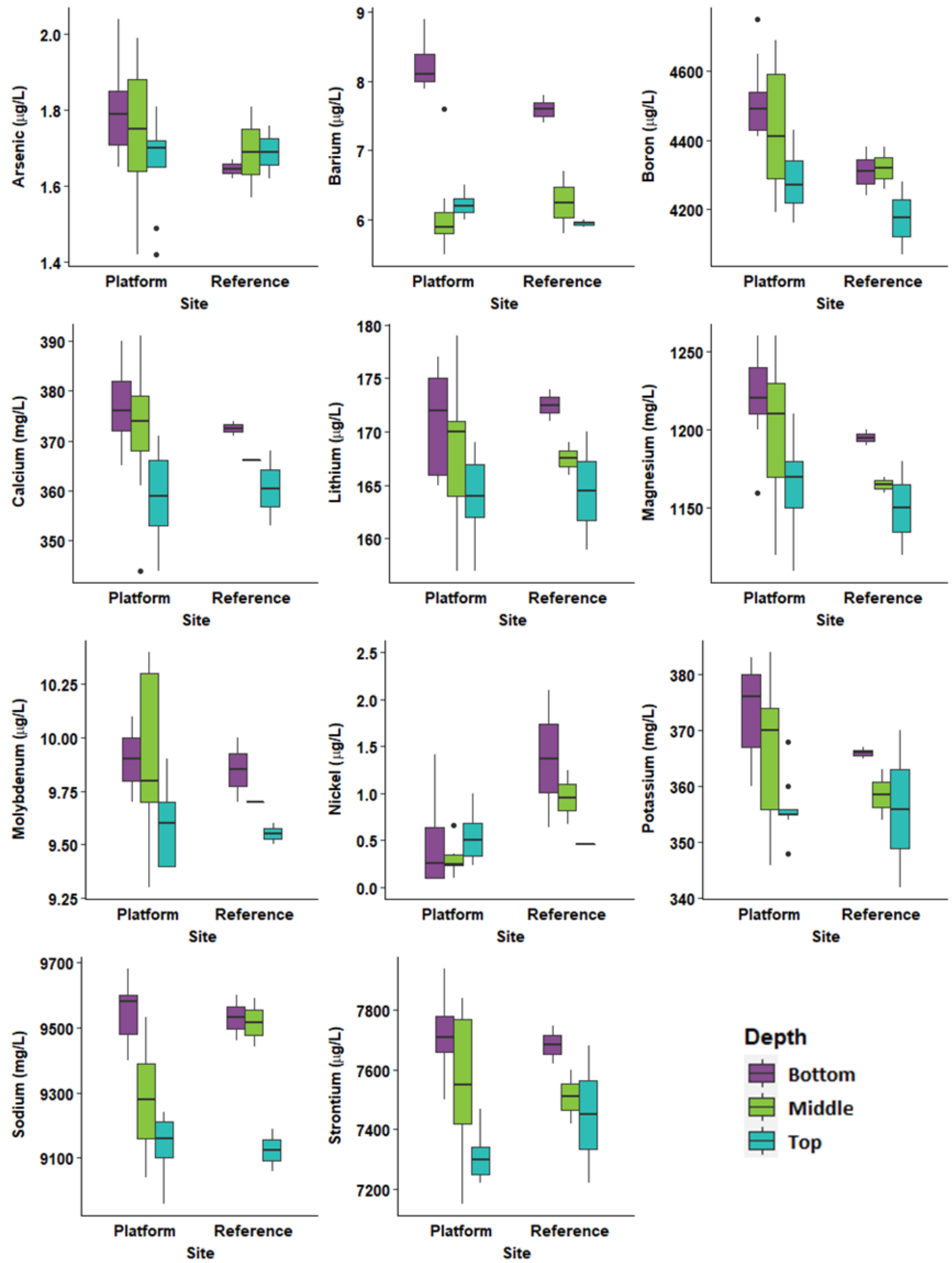


Figure 5-6 Boxplots of frequently detected chemical parameters by site (Hebron Platform, Reference) and sampling depth (bottom, middle, surface).

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. Outlier for nickel (31.8 µg/L) is not displayed.

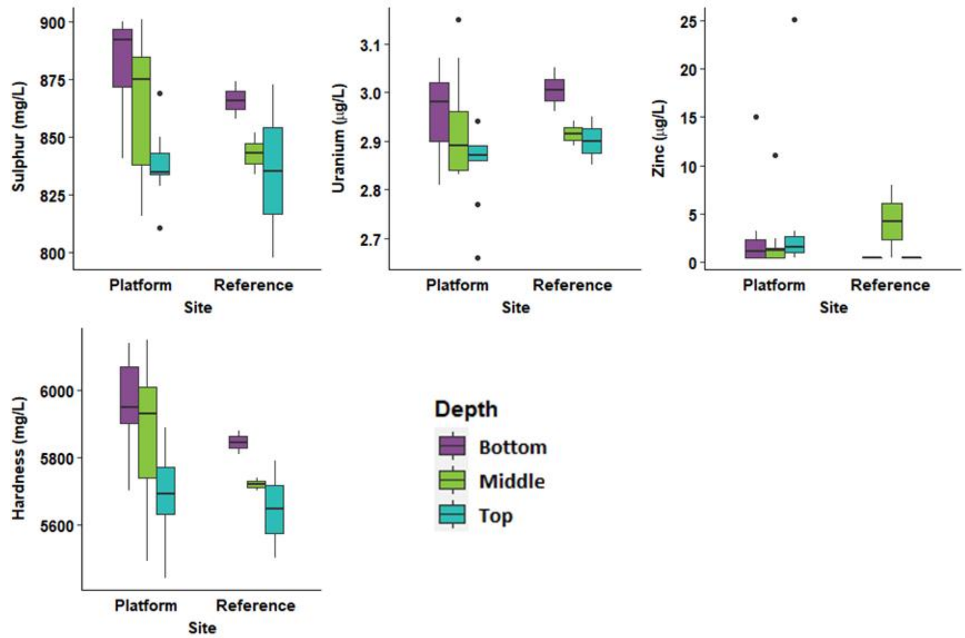


Figure 5-6 Boxplots of frequently detected chemical parameters by site (Hebron Platform, Reference) and sampling depth (Bottom, Middle, Top) (Continued).

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. Outlier for nickel (31.8 µg/L) is not displayed.

Table 5.5 Results of ANOVA (p-values) for frequently detected constituents across sites (Hebron Platform, Reference) and sampling depth (Top, Middle, Bottom).

Analyte	Site (Platform, Reference)	Sampling Depth (Top, Middle, Bottom)
Arsenic	0.354	0.192
Barium[1]	0.314	**<0.001*** **
Boron	**0.020***	**0.001****
Calcium	0.510	0.001
Lithium	0.828	**0.011***
Magnesium	0.097	**0.003****
Molybdenum	0.330	**0.006****
Nickel[1]	0.130	0.184
Potassium	0.237	**0.002****
Sodium	0.274	**<0.001*** **
Strontium	0.739	**<0.001*** **
Sulphur	0.216	**0.002****
Uranium	0.563	**0.025***
Zinc[1]	0.226	0.837
Calculated Parameters		
Total Hardness ($CaCO_3$)	0.133	**0.001****

Notes:
[1] Data was log transformed
Significance: '***': p<0.001, '**': p<0.01, '*': p<0.05, '.': p<0.10*
There were no significant interactions among Site x Depth
Grey shaded rows indicate constituents that may potentially change in water sample concentrations near the platform due to produced water release.

Table 5.6 Results of ANOVA (p-values) for frequently detected constituents across Monitoring Year (2014, 2019, 2020) and Sampling Site (Hebron Platform, Reference Site).

Analyte	p-Value		
	Year	Site	Year x Site[3]
Metals			
Arsenic	**<0.001*****	0.2622	0.904
Barium[1,2]	0.316	0.941	0.707
Boron	**<0.001*****	**<0.001*****	**<0.001*****
Calcium[1]	**0.040***	0.185	**0.060 .**
Lithium	**<0.001*****	**<0.001*****	**<0.001*****
Magnesium	**<0.001*****	**0.085 .**	0.852
Molybdenum	**<0.001*****	0.803	0.382
Nickel[1,2]	**0.058 .**	0.331	0.773
Potassium	**<0.001*****	0.353	**0.020***
Sodium	0.581	**0.023***	**0.002****
Strontium	0.786	0.262	0.288
Sulphur	**<0.001*****	0.522	**0.076 .**
Uranium	**<0.001*****	**<0.001*****	**<0.001*****
Zinc[1,2]	**<0.001*****	0.308	**0.072 .**
Calculated Parameters			
Total Hardness ($CaCO_3$)	**<0.001*****	0.329	0.714

Notes:

[1] Data was log-transformed

[2] Log-transformed data did not meet normality assumptions

[3] Comparisons only for 2014 and 2020 monitoring years.

Significance: '***': p<0.001, '**': p<0.01, '*': p<0.05, '.': p<0.10

5.3 Summary of Results

For the 2020 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 column samples. Fifteen water sample parameters (14 metals and total hardness [$CaCO_3$]) were frequently detected (detected in >50 percent of all samples) within 50-500 m of the Hebron Platform produced water outlet. Chemical parameters detected in pre-discharged produced water with potential for local enrichment included barium, calcium, lithium, magnesium, potassium, sodium, and strontium.

Among Hebron Platform and Reference Site water samples, there was no interaction between Site and Water Depth indicating no project-induced changes. Boron was the only constituent with a significant difference between Sites. Concentrations between the three water sample depths followed a general trend of higher concentrations in near-bottom (bottom) samples and lower concentrations in near-surface (top) samples.

There were no clear patterns for differences in analyte levels for both within year and across year analyses among sampling sites. This indicates that the potential effects on the environment may be highly localized and variable.

6.0 COMMERICAL FISH COMPONENT

6.1 Methods

6.1.1 Field Collection

The 2020 commercial fish and fish health sampling program was conducted aboard the Ocean Choice International (OCI) Fishing Vessel (FV) *Aqviq* using a Goldentop 31 trawl towed within a 2 km radius of the Hebron Platform and associated Reference Area. The Reference Area is located 80 km NW from the Hebron Platform (Figure 6-1). All sampling was conducted according to the requirements of the Experimental License issued by Fisheries and Oceans Canada (NL-5945-20) (see Volume II). All fish processing and sampling was performed by WSP personnel. The crew of the *Aqviq* operated the trawl and aided in fish sorting of the trawl contents. WSP team worked in a complimentary fashion with the ship's watch system. The fishing crew worked 6-hour shifts; the WSP crews worked 12-hour shifts. Each 12-hour shift was directed by the WSP team leader. Tows were 15 minutes in duration and start and finish coordinates were recorded on bridge sheets. American Plaice (*Hippoglossoides platessoides*) were immediately removed from the cod-end and placed in a large fish tub with flow-through sea water.

For each trawl, all species were identified, counted, and recorded. American Plaice greater than 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 necessary, livers and top fillets were sampled from additional fish to ensure sample volumes were sufficient for analyses. Sample handling and storage was completed as quickly as possible to maintain sample integrity; prepared samples were stored in appropriate facilities on-board the vessel. Furthermore, the deck of the vessel was cleaned with degreaser after each tow to mitigate against contamination between trawls/sites and ship sources.

Comparisons were made between the 2018, 2019, and 2020 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 2021). Additionally, an update to the Hebron Design Plan changed the number of composite samples and minimum number of fish in each composite (Table 6-1).

Table 6-1 Sampling design differences between the 2015 Fish Characterization and Hebron EEM methodologies.

Parameters	2015 Fish Characterization Study (baseline) / HSE EEM	2018 and 2019 Hebron EEM	2020 Hebron EEM
Minimum Fish Length	>250 mm	>300 mm	>300 mm
Fillet Body Burden Sampling	10 single fish fillets	5 fillet composites (each 10 fish minimum)	10 fillet composites (each 5 fish minimum)
Liver Body Burden Sampling	10 liver composites (each 7 fish minimum as per (HMDC 2017)	5 liver composites (each 10 fish minimum)	10 liver composites (each 5 fish minimum)
Archive Sample	Heart, spleen, gonads	None	None
Gross pathology	Not completed	Completed	Completed

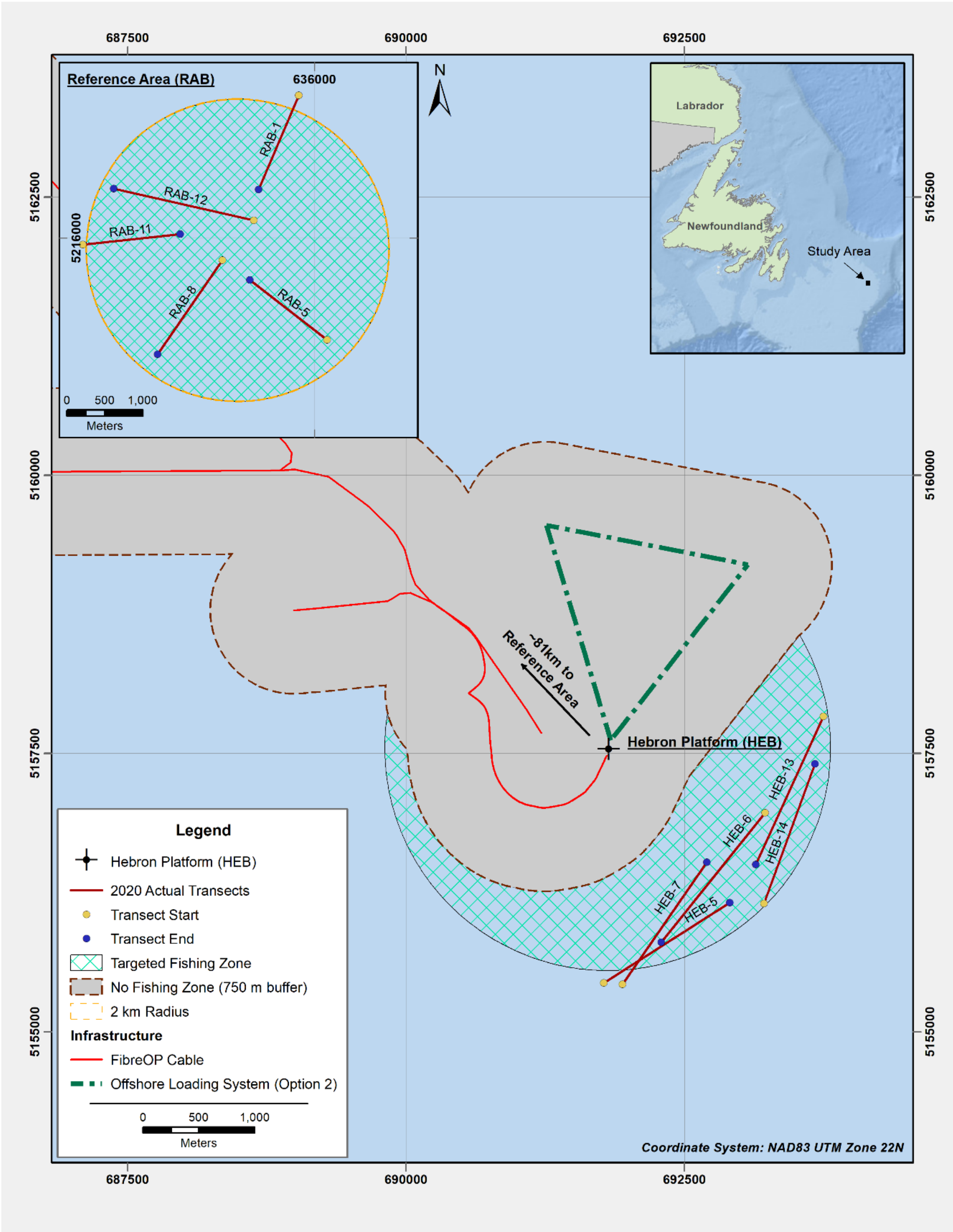


Figure 6-1 Hebron 2020 EEM commercial fish sampling program trawl locations.

6.1.2 Field Sampling

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

1. Live fish had blood drawn for haematology analyses. Two blood smears on microscope slides were prepared, dried and fixed in methanol.
2. Morphometrics (total length, 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% 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.

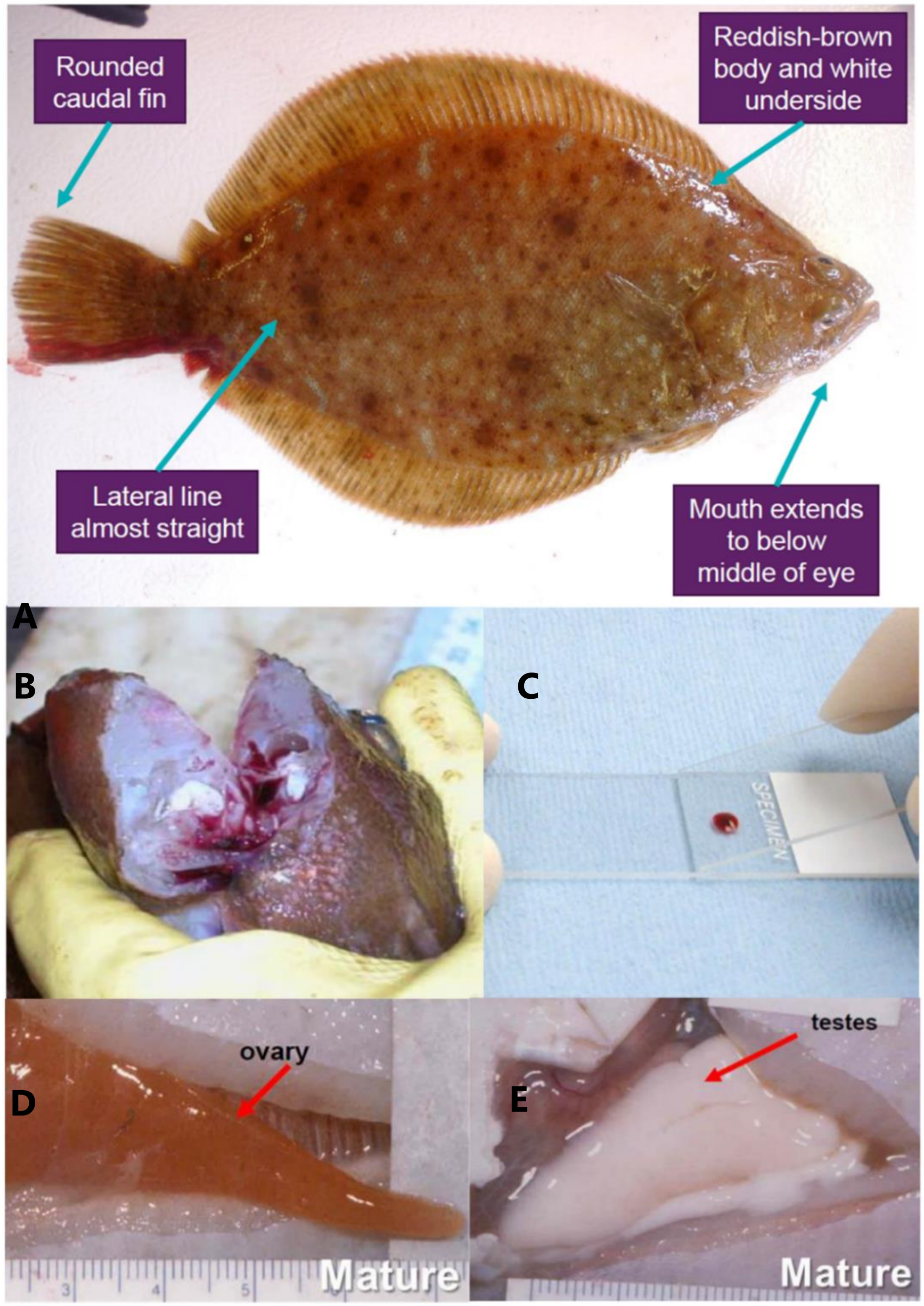


Figure 6-2 Examples of field sampling measures taken aboard the FRV *Nuliajuk*: American Plaice with identifying characteristics (A), otoliths being extracted (B), creating a blood smear (C), mature female ovary (D), and mature male testes (E). (Daigle et al. 2006, Sejwal 2014).

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 2017a). Tissue and liver samples were composites of at least five individual fish per sample, and composites were used to ensure sufficient portions for tests. Analytes listed in the design plan and additional tested analytes are listed in Table 6-2. Laboratory results for metals, hydrocarbons and PAHs were screened in for reporting and further analysis if 50 percent or more of tested samples exceeded their RDL at one or more sites. One-way ANOVAs were used to compare between the Hebron Platform and Reference Area in 2020, and two-way ANOVAs were used to compare across years and sites. Where ANOVAs were used, assumptions (heterogeneity, normality, and independence) were checked to ensure a normal error structure was appropriate for analysis (Quinn and Keough 2002). Two methods were used to process those parameters that were screened in which included some sample values which were below detection limits (RDL):

- For descriptive statistics, the value of the RDL was used for calculation so as not to present mean values below the detection limit as per the design plan (EMCP 2017a).
- For statistical analysis, Half RDL was used as a conservative value (EMCP 2017a).

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

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

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 were performed using two qualitative assays; the triangle test and the Hedonic Scaling test (EMCP 2017a).

The triangle test was used to qualitatively assess American Plaice fillet samples for any disparities in sensory perception between samples collected from the Hebron Platform versus the Reference Area (EMCP 2017a). As described in Chapter 3, a panel of 24 people were each provided three unidentified fish tissue samples (homogenized and cooked to 35°C) and were asked to discriminate one from the other two. The test was ranked according to the number of panelists who were correctly able to discriminate the outlier sample.

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

Before samples were sent for taste test analysis, care was taken to ensure no potential health risks were present in fillets. Health Canada's List of Contaminants and other Adulterating Substances in Foods (Health Canada 2020) lists the maximum allowable limit of certain metals and PAHs in fish protein for human consumption. Results from the chemical analysis of American Plaice fillets were screened against these values prior to taint testing.

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 described in Section 5.3 of the Design Plan (EMCP 2017a). 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 induced changes. Monitoring these characteristics over time near the Hebron Platform and at the Reference Area allows for monitoring and detection of 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 sites 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 indices are used: all values, a modified value excluding skin and fins (as these may be a result of trawl damage), and another value excluding skin, fins, and parasites (as they may simply be a result of different life history of fishes and not project-induced changes). 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 2018-2020 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 2017a). Results from the Reference Area in 2015 were not available. Comparisons between sites in 2020 were conducted using one-way ANOVAs, and across years and sites (with only the Hebron Platform in 2015) using 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 2017a). Basal EROD activity and response to exposure of a contaminant can vary between genders and sexual maturity may have the greatest influence on this response in certain species of fish (Kirby et al. 1999, Mathieu et al. 2011). One-way ANOVAs were used to compare between sites in 2020, and two-way ANOVAs to compare across years and sites.

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, microscopical histological examinations of tissue samples were 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 2017a). The histological parameters examined included the presence of different lesions defined according to standard methods (Khan and Kiceniuk 1984, Khan 1990, 1995, Khan et al. 1994). Gill and liver samples were processed for histopathology comparisons by the CDRF using haematoxylin and eosin, which stains nuclei purple-blue and cytoplasm red-pink, respectively. Gill samples were assessed by the CDRF and liver samples were assessed by Dr. Rasul Khan. Fisher's t-test was used to compare each liver histology in 2020, while one-way ANOVAs were used to compare gill histologies. Cross-year comparisons were completed using multivariate analysis of variance (MANOVA) incorporating each histopathology factor that was detected in fish, with two-way ANOVAs used to compare each factor in the MANOVA to verify which are driving any significant differences found.

6.2 Results

6.2.1 Field Collection

There were five trawls conducted at the Hebron Platform and five conducted at the Reference Area in 2020 (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 taxa at the Hebron Platform was American Plaice (n=1,444), followed by Snow Crab (n=282) and Stalked Tunicates (n=39) (Table 6-3). At the Hebron Reference Area, Yellowtail Flounder were the most common species overall (n=345), followed by American Plaice (n=257) and Snow Crab (n=28) (Table 6-3). The number of American Plaice retained for processing from each tow is given in Table 6-4, and the start and end coordinates for each tow is given in Table 6-5.

Length-frequency distributions were created using 84 American Plaice collected from each survey location in 2020 (Figure 6-5). Of these, only three fish from both areas (Hebron Platform and Reference Area) were male. Male fish ranged from 306 mm to 386 mm, with an average of 361 mm at the Hebron Platform and 337 at the Reference Area. Female American Plaice retained from both sites were comparable in size and were much larger than the males on average (Figure 6-5). The greater proportion of larger female fish were collected at the Hebron Platform, though the largest fish collected was a female at the Reference Area (Figure 6-5).

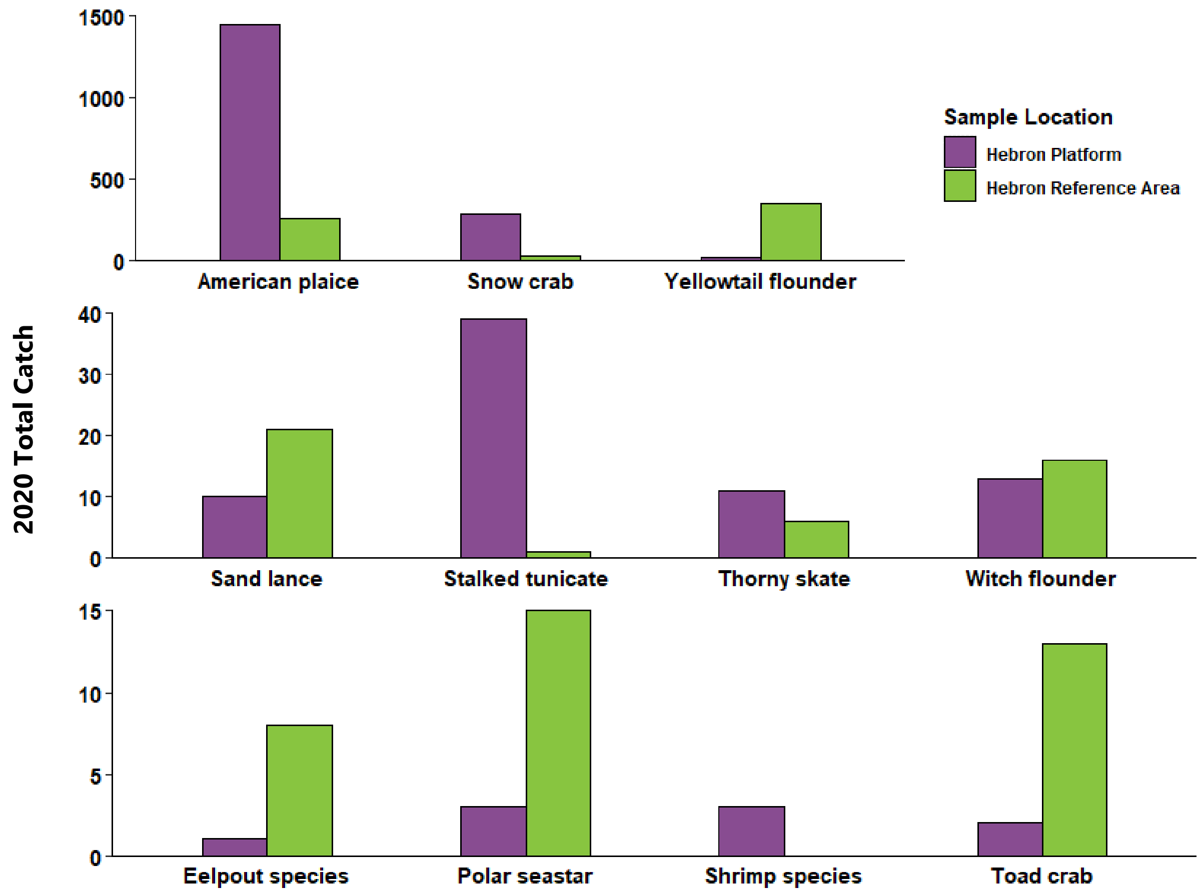


Figure 6-3 Catch at Hebron Platform and Reference Area during the 2020 EEM. Animals with two or fewer individuals were not presented, see Table 6-3 for all fauna species captured.

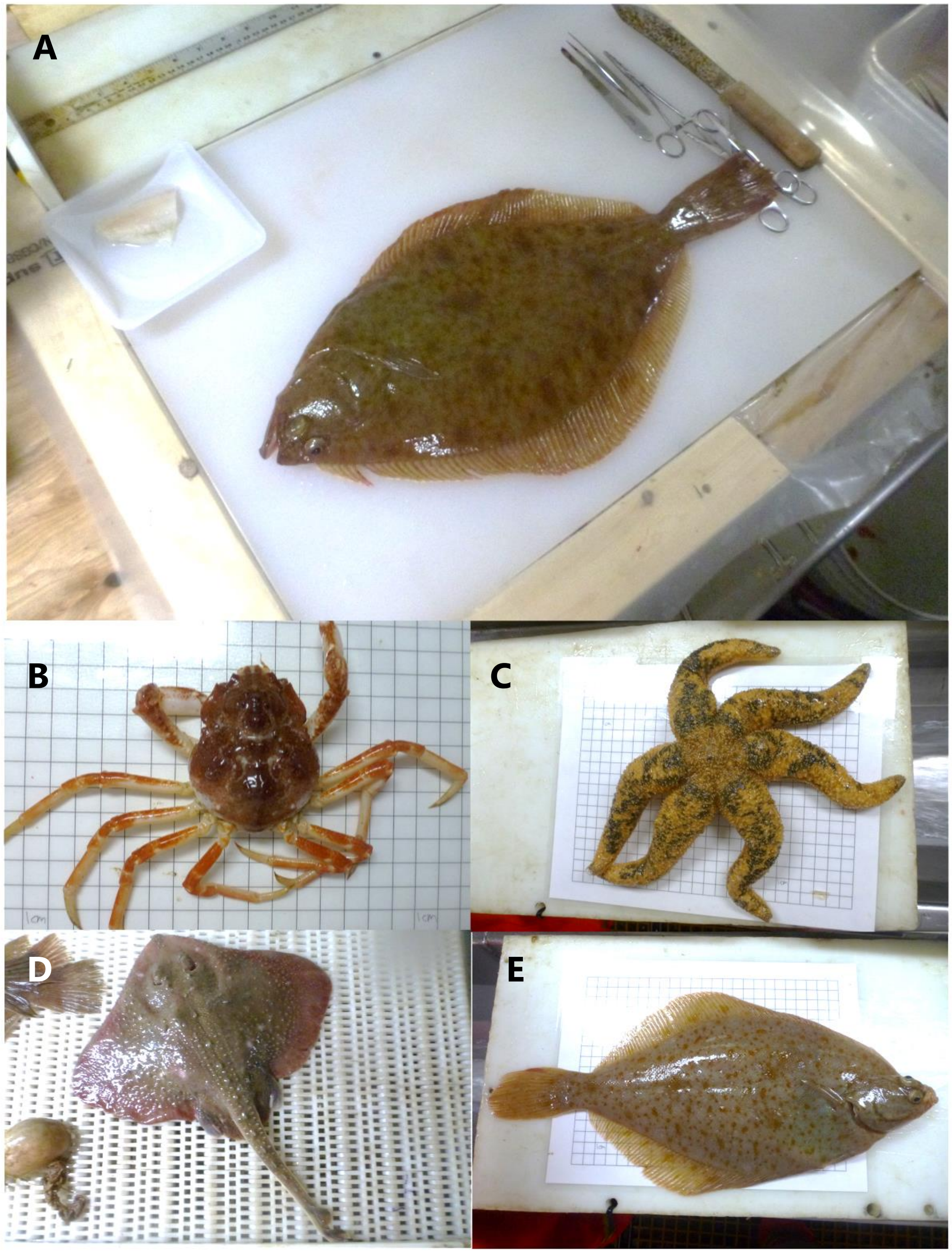


Figure 6-4 Representative catch species from the Hebron 2020 EEM program: American Plaice (A), Toad Crab (B), Polar Star (C), Thorny Skate (D), and Yellowtail Flounder (E). See Table 7.1 for scientific names.

Table 6-3 Total catch per species and catch per unit effort (number per trawl) around the Hebron Platform and Reference Area in 2020.

Faunal Group	Species Name	Scientific Name	Hebron Platform		Reference Area	
			Total Catch	CPUE (n=5)	Total Catch	CPUE (n=5)
Fish	American Plaice	*Hippoglossoides platessoides*	1444	288.8	257	51.4
Fish	Atlantic cod	*Gadus morhua*	2	0.4	0	0
Fish	Eelpout (NS)	Zoarcidae (F)	1	0.2	8	1.6
Fish	Sand Lance	*Ammodytes dubius*	10	2	21	4.2
Fish	Thorny Skate	*Amblyraja radiata*	11	2.2	6	1.2
Fish	Witch Flounder	*Glyptocephalus cynoglossus*	13	2.6	16	3.2
Fish	Yellowtail Flounder	*Pleuronectes ferruginea*	16	3.2	345	69
Ascidian	Stalked Tunicate	*Boltenia ovifera*	39	7.8	1	0.2
Ascidian	Tunicate (NS)	Tunicata (SP)	2	0.4	0	0
Cnidarian	Jellyfish (NS)	Medusozoa (SP)	1	0.2	0	0
Crustacean	Shrimp (NS)	Decapoda (O)	3	0.6	0	0
Crustacean	Toad Crab	*Hyas* sp.	2	0.4	13	2.6
Crustacean	Snow Crab	*Chionoecetes opilio*	282	56.4	28	5.6
Echinoderm	Green Sea Urchin	*Strongylocentrotus droebachiensis*	1	0.2	1	0.2
Echinoderm	Polar Sea Star	*Leptasterias polaris*	3	0.6	15	3
Echinoderm	Spiny Sunstar	*Crossaster papposus*	0	0	2	0.4

Note:
Taxonomic Groups: SP – Subphylum, O – Order, F - Family

Table 6-4 Tows completed, American Plaice retained for sampling and summary of samples taken for analysis in 2020.

Sampling area	Tow number	American Plaice Retained	Liver samples collected	Fillet samples collected	Sensory analyses samples collected (g)
Hebron Platform	HEB-05	14	14	14	1626.3
	HEB-06	14	14	14	942.2
	HEB-07	14	14	14	745.4
	HEB-13	14	14	14	1267.7
	HEB-14	14	14	14	1563.0
	Total	**70**	**70**	**70**	6144.4
Reference Area	RAA-01	14	14	14	1323.1
	RAA-05	14	14	14	752.6
	RAA-08	14	14	14	1389.2
	RAA-11	14	14	14	1225.0
	RAA-12	14	14	14	890.4
	Total	**70**	**70**	**70**	5580.1

Table 6-5 Start and end coordinates for each trawl for the Hebron Platform Commercial Fish Sampling Program, 2020.

Trawl ID	Depth (m)	Station Type	Start		End	
			Easting	Northing	Easting	Northing
HEB-05	92	Hebron Platform	691776.38	5155437.52	692904.92	5156159.27
HEB-06	92	Hebron Platform	693224.56	5156966.59	692291.88	5155804.23
HEB-07	92	Hebron Platform	693746.83	5157834.17	693139.61	5156502.29
HEB-13	92	Hebron Platform	693746.83	5157834.17	693139.61	5156502.29
HEB-14	91	Hebron Platform	693212.25	5156150.54	693670.97	5157407.23
RAB-01	81	Hebron Reference Area	635790.86	5217886.06	635259.91	5216643.52
RAB-05	72	Hebron Reference Area	636164.87	5214653.66	635144.12	5215447.53
RAB-08	78	Hebron Reference Area	634782.50	5215708.00	633924.56	5214461.89
RAB-11	80	Hebron Reference Area	632937.49	5215912.85	634225.36	5216053.01
RAB-12	80	Hebron Reference Area	635195.82	5216234.39	633343.59	5216653.90

Notes:

All coordinates presented in UTMs, Zone 22, NAD83

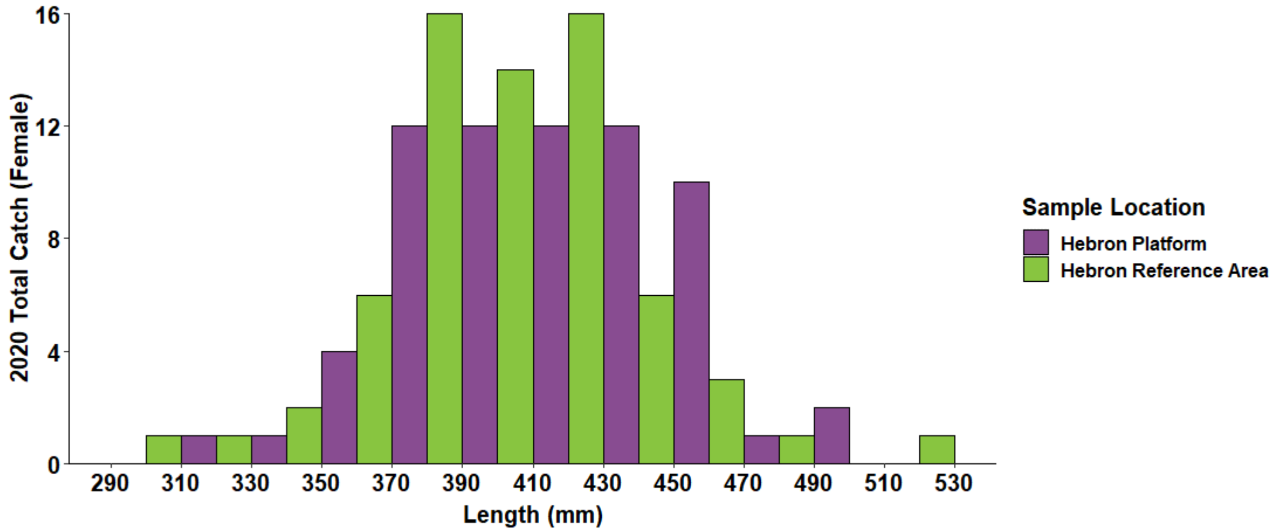


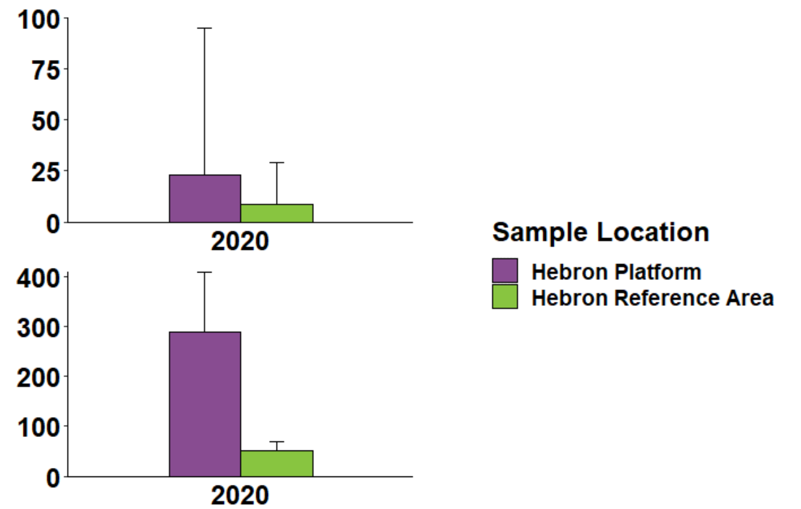
Figure 6-5 Length-frequency of female American Plaice collected from the Hebron Platform and Reference Area in 2020.

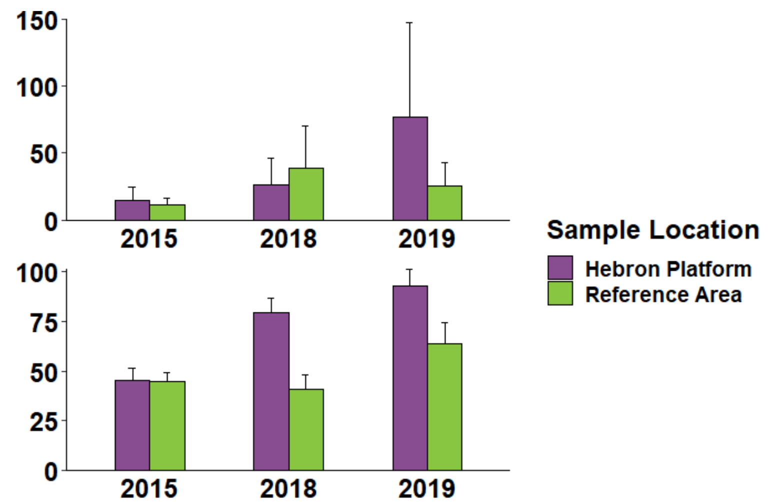
Across-year Comparison

Fish in previous monitoring years for the Hebron EEM were collection aboard the FRV *Nuliajuk* with a Campelen 1200 type trawl, while the 2020 EEM survey was aboard the OCI vessel *Aqviq* with a Goldentop 31 trawl (Table 6-6). As both trawls have different dimensions and differ in cod-end mesh size, catch per unit effort (CPUE) between these two time periods is no longer directly comparable, though generalizations can be made. CPUE in 2020 was lower overall than in previous years, and this is likely due to the lower catch of capelin and sand lance compared to previous years (with a typical catch in the thousands at both sites). In 2015, CPUE between the Hebron Platform and the Reference Area were similar for all species including American Plaice. Beginning in 2018 the CPUE for American Plaice, and in most years all species, was higher at the Hebron Platform compared to the Reference Area. This trend continued in 2020, with CPUE for American Plaice 4.6x higher at the Hebron Platform, and CPUE for all species 1.6x higher at the Hebron Platform (Table 6-6).

Table 6-6 Catch per unit effort (CPUE) across all Hebron EEM sampling years for all species and for American Plaice specifically.

<table>
<tr><th>Trawl Details</th><th>Average Catch per Unit Effort (+SD)</th></tr>
<tr><td>Monitoring Years: 2020
Vessel: OCI Aqviq
Gear Type: Goldentop 31 trawl, with 145 mm cod-end
Tow Details: 15-minute trawls at a speed of 3 knots

Top: all species
Bottom: American Plaice only</td><td>
</td></tr>
<tr><td>Monitoring Years: 2015-2019
Vessel: FRV Nuliajuk
Gear Type: Campelen 1200 trawl, with 44 mm cod-end
Tow Details: 15-minute trawls at a speed of 3 knots

Top: all species
Bottom: American Plaice only</td><td>
</td></tr>
</table>

6.2.2 Chemical Profiles of American Plaice Tissue

Ten 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 (greater than 50 percent above 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 ten samples (Table 6-7). No other metals were above their RDLs. No hydrocarbons were detected within the >C_{10}-C_{32} range in any sample, and no PAHs were detected among any sampled fillets (Table 6-7). One-way ANOVAs found no significant difference between the Hebron Platform and Reference Area for arsenic ($p=0.387$) but found significant differences between areas for mercury ($p=0.007$) and zinc ($p=0.007$) (Table 6-7); both these analytes are higher in the reference area samples.

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 ten samples (Table 6-8). One sample from the Hebron Platform (0.13 mg/kg) and one from the Reference Area (0.17 mg/kg) contained silver above RDL, and one sample from the Hebron Platform (0.54 mg/kg) and one sample from the Reference Area (0.66 mg/kg) contained vanadium above RDL. Hydrocarbons from the >C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32} ranges were detected in all ten samples from both areas (Table 6-8). No PAHs exceeded their RDL in any sample (Table 6-8). One-way ANOVAs found no significant difference between the Hebron Platform and Reference Area for iron or mercury (Table 6-8). Arsenic, cadmium, copper, manganese, selenium, and zinc were found to differ between the two sites and in all cases were higher at the Reference Area compared to the Hebron Platform (Table 6-8). Hydrocarbons in the C_{16}-C_{21} range did not significantly differ between sites, while C_{10}-C_{16} and C_{21}-C_{32} hydrocarbon did significantly differ between sites and were higher at the Reference Area (Table 6-8).

Table 6-7 Summary statistics of 2020 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=10)								**Reference Area Fillet composites (n=10)**						
Metals								**Metals**						
Arsenic	0.50	10	3.98	0.37	4.0	3.4	4.6	10	3.73	0.76	3.65	2.7	4.9	0.387
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	10	0.097	0.017	0.095	0.078	0.120	10	0.072	0.017	0.069	0.052	0.100	**0.007**
Selenium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Zinc	1.5	10	4.31	0.18	4.3	4.1	4.7	10	4.03	0.21	4.05	3.8	4.4	**0.007**
Hydrocarbons								**Hydrocarbons**						
None detected, all samples <RDL (15 mg/kg)								None detected, all samples <RDL (15 mg/kg)						-
PAHs								**PAHs**						
None detected, all samples <RDL (0.050 mg/kg) [a]								None detected, all samples <RDL (0.050 mg/kg)[a]						-

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

Table 6-8 Summary statistics of 2020 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 Fillet (n=10)**						**Reference Area Fillet (n=10)**						
Arsenic	0.50	10	2.7	0.89	2.2	2.0	4.6	10	3.73	0.77	3.7	2.6	5.4	**0.017**
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	10	0.631	0.176	0.57	0.44	0.92	10	0.828	0.152	0.78	0.64	1.2	**0.020**
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	10	2.90	1.07	2.4	1.9	5.5	10	4.94	1.46	4.65	2.7	7.3	**0.003**
Iron	15	10	40.3	8.45	40.5	27	57	10	54.7	21.15	49	29	110	0.074
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	10	0.891	0.047	0.91	0.78	0.95	10	0.946	0.044	0.955	0.86	1.00	**0.019**
Mercury	0.01	10	0.046	0.005	0.045	0.036	0.058	10	0.055	0.022	0.048	0.037	0.100	0.252
Selenium	0.50	10	1.88	0.12	1.85	1.7	2.1	10	2.32	0.22	2.3	2.0	2.7	**<0.001**
Zinc	1.5	10	24.9	2.39	24	22	30	10	32.5	2.84	32.5	27	37	**<0.001**
Hydrocarbons								**Hydrocarbons**						
>C_{10}-C_{16}	15	10	24.4	6.37	24	17	41	10	45.9	11.46	46	28	65	**<0.001**
>C_{16}-C_{21}	15	10	123.9	18.68	120	99	170	10	117.6	34.73	120	58	170	0.638
>C_{21}-C_{32}	15	10	248	57.24	235	190	400	10	360	117.6	355	170	590	**0.019**
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

Fillet 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, and 2020 data consists of 10 composites from multiple individuals. However, comparisons of metal and hydrocarbon loading in these two sample types (i.e., various sized composites verses individual fish) was 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 further analysis though values are mentioned in the text below.

Metals in Hebron Platform and Reference Area Fillets

Consistent with past EEM years, arsenic, mercury, and zinc were detected in all American Plaice fillets from both the Hebron Platform and Reference Area in 2020 (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 2020. The concentration of arsenic, mercury, and zinc in fish tissue from all EEM years is presented in Figure 6-6.

Separate two-way ANOVA results for arsenic, mercury, and zinc are given in Table 6-9. No significant results for site, year, or site-year interaction were found for arsenic and mercury ($\alpha=0.05$). For zinc, site and the interaction between site 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 6-6C shows zinc concentrations were lowest in 2018 and higher in 2020, though both are within the range of 2015 values. The non-significant interaction terms indicate no project-induced change.

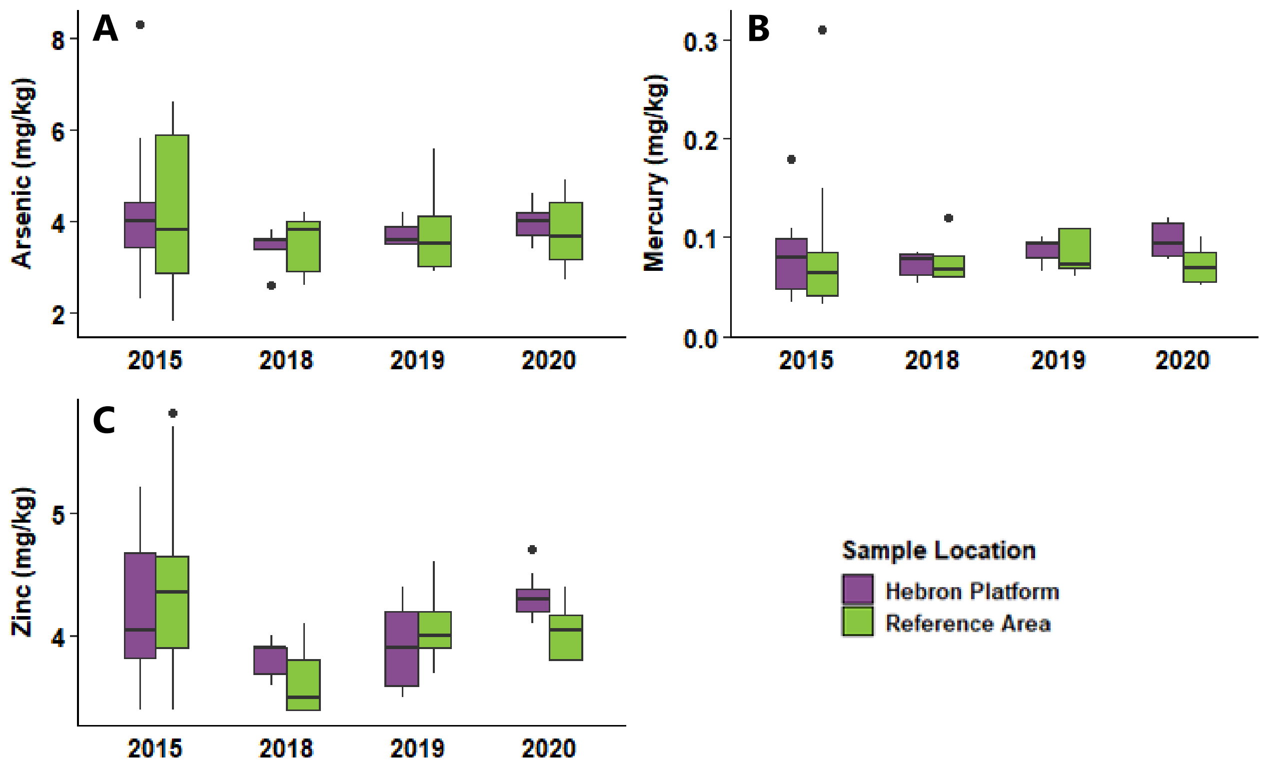


Figure 6-6 Boxplots of arsenic (A), mercury (B), and zinc (C) in American Plaice fillet tissue from the Hebron Platform and Reference Area from 2015 to 2020.

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 from 2015 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	0.048	0.048	0.036	0.851
Year	3	4.866	1.622	1.205	0.317
Site*Year	3	0.306	0.102	0.076	0.973
Residuals	52	70.002	1.346		
Mercury					
Site	1	0.0003	0.0003	0.189	0.666
Year	3	0.0010	0.0003	0.181	0.909
Site*Year	3	0.0031	0.0010	0.578	0.632
Residuals	52	0.0926	0.0018		
Zinc					
Site	1	0.011	0.011	0.050	0.824
Year	3	2.725	0.908	4.234	**0.009**
Site*Year	3	0.747	0.249	1.161	0.334
Residuals	52	11.155	0.215		

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

Metals in Hebron Platform and Reference Area Livers

Consistent with past EEM years, arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in all liver composites for the Hebron Platform and Reference Area in 2020 (Table 6-8). Cobalt, silver, and vanadium have been inconsistently observed in samples from previous years. No samples were above RDL for cobalt in 2020, but one sample from both the Hebron Platform and Reference Area were above their RDL for silver, and one in both areas 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 typically above RDL.

Comparisons across years (2015-2020) and across sites (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, sites, or site-year interaction was observed for mercury (Table 6-10). Arsenic, cadmium, iron, and selenium were significantly different between both sites and years (Table 6-10) with general decreasing trends from 2015 to 2020 and generally higher results at the Reference Area (Figure 6-7). Manganese had significant differences for both year and the interaction term, indicating a potential project-induced change (Table 6-10). Copper and zinc had significant results for site, year, and the interaction term indicating potential project-induced changes (Table 6-10).

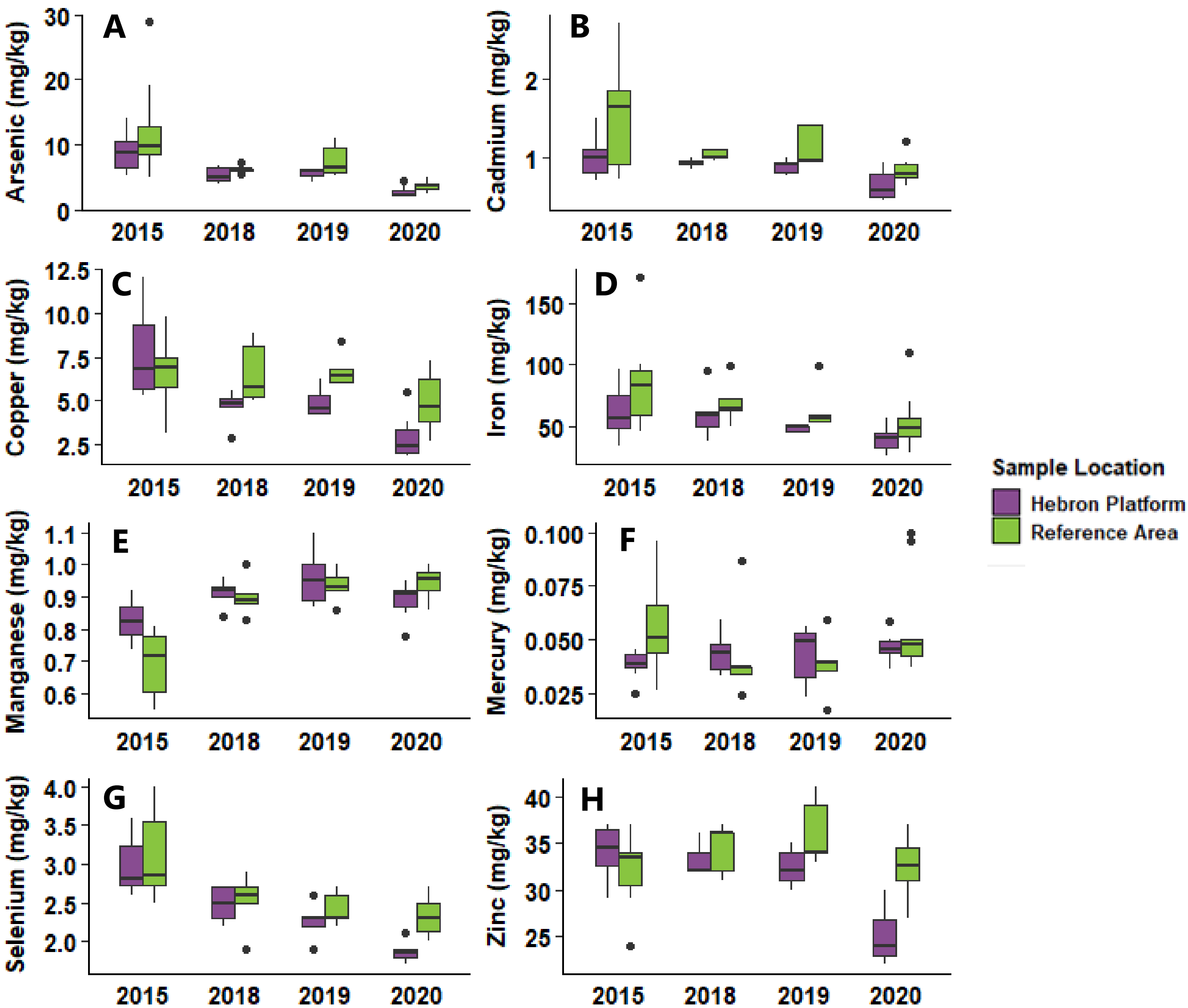


Figure 6-7 Boxplots of arsenic (A), cadmium (B), copper (C), iron (D), manganese (E), mercury (F), selenium (G), and zinc (C) in American Plaice liver composites from the Hebron Platform and Reference Area from 2015 to 2020.

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 from 2015 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	56.45	56.45	5.069	**0.029**
Year	3	534.13	<0.001	15.987	**<0.001**
Site*Year	3	14.87	4.958	0.445	0.722
Residuals	52	579.12	11.137		
Cadmium					
Site	1	1.282	1.282	13.311	**0.001**
Year	3	2.723	<0.001	9.423	**<0.001**
Site*Year	3	0.366	0.122	1.267	0.295
Residuals	52	5.008	0.096		
Copper					
Site	1	15.403	15.403	5.650	**0.021**
Year	3	107.673	35.891	13.165	**<0.001**
Site*Year	3	26.981	8.994	3.299	**0.027**
Residuals	52	141.766	2.726		
Iron					
Site	1	4352.000	4352.000	9.126	**0.004**
Year	3	6976.600	2325.500	4.877	**0.005**
Site*Year	3	488.000	162.700	0.341	0.796
Residuals	52	24797.500	476.900		
Manganese					
Site	1	0.015	0.015	3.676	0.061
Year	3	0.361	0.120	28.765	**<0.001**
Site*Year	3	0.090	0.030	7.207	**<0.001**
Residuals	52	0.217	0.004		
Mercury					
Site	1	0.0010	0.0010	3.5170	0.066
Year	3	0.0008	0.0003	0.9646	0.416
Site*Year	3	0.0011	0.0004	1.2536	0.299
Residuals	52	0.0149	0.0003		
Selenium					
Site	1	0.794	0.794	7.258	**0.009**
Year	3	9.368	3.123	28.564	**<0.001**
Site*Year	3	0.355	0.118	1.082	0.365

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Residuals	52	5.685	0.109		
Zinc					
Site	1	114.820	114.817	13.435	**0.001**
Year	3	331.880	110.628	12.945	**<0.001**
Site*Year	3	229.880	76.628	8.966	**<0.001**
Residuals	52	444.400	8.546		
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 2020 (Table 6-7). However, all liver composites from both sites contained hydrocarbons in the >C_{10}-C_{16}, >C_{16}-C_{21} and >C_{21}-C_{32} range (Table 6-8). Hydrocarbons in the >C_{16}-C_{21} range did not differ between the Hebron Platform and Reference Area in 2020, while >C_{10}-C_{16} and >C_{21}-C_{32} hydrocarbons were significantly higher at the Reference Area (Table 6-8). All liver composites at both sites also contained unidentified compounds in the fuel/lube range (see Maxxam Analytics report in Volume II).

In all previous EEM years, hydrocarbons in the >C_{16}-C_{21} and >C_{21}-C_{32} ranges were also detected in all liver samples above RDL and screened in for analysis (EMCP 2016b). However, >C_{10}-C_{16} hydrocarbons were first screened in for the 2019 EEM though some samples were still below RDL, and in 2020 all samples exceeded RDL. Comparisons across sites and years is presented in Table 6-11 and Figure 6-8. Hydrocarbons in the >C_{16}-C_{21} range significantly differed by year (Table 6-11) and have been steadily increasing in both areas since 2015 (Figure 6-8). Hydrocarbons in the >C_{21}-C_{32} range significantly differed by site and year (Table 6-11), with 2018 having the lower concentration and 2020 the highest, with values typically elevated at the Reference Area compared to the Hebron Platform (Figure 6-8). Hydrocarbons in the >C_{10}-C_{16} range significantly differed by site, year, and the interaction term and this indicates a potential project-induced change (Table 6-11).

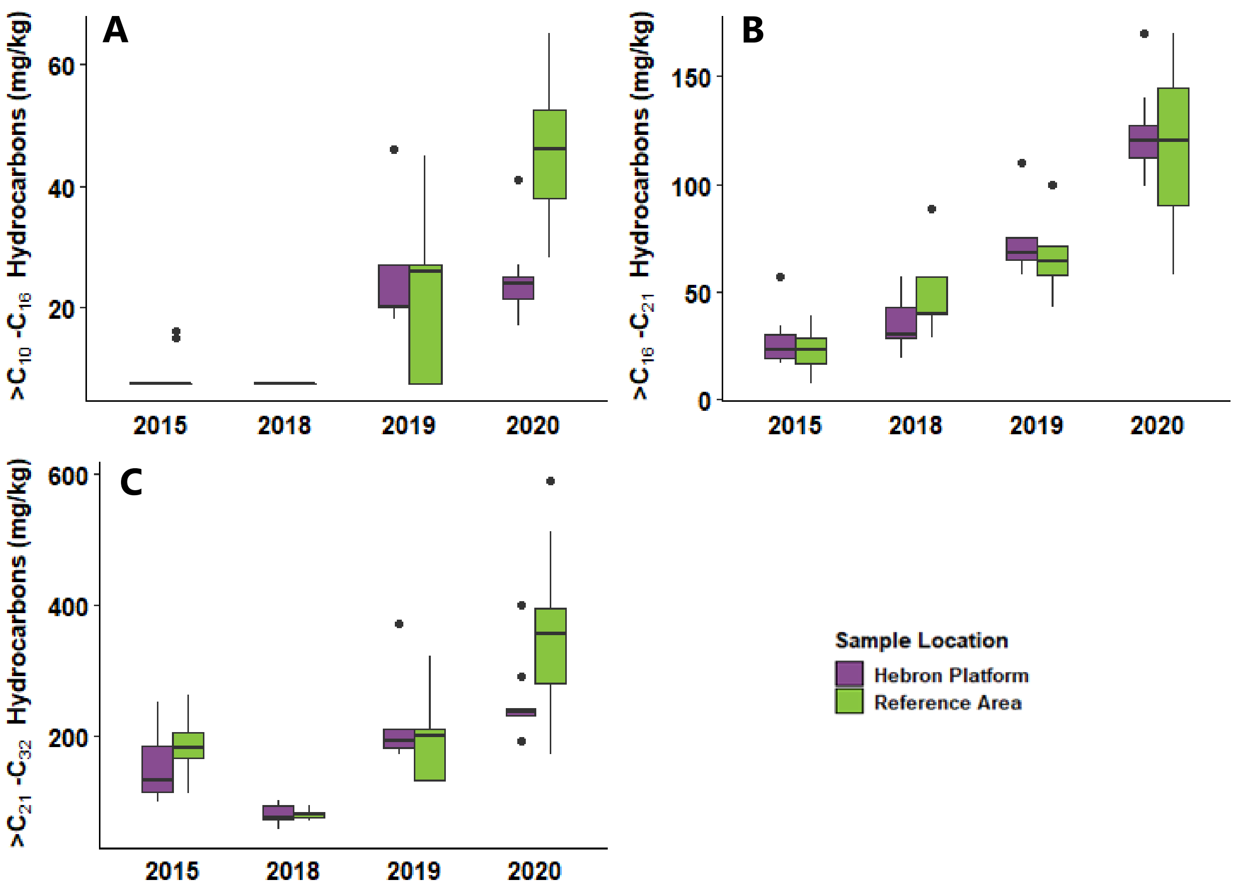


Figure 6-8 Boxplots of >C_{10}-C_{16} hydrocarbons (A), >C_{16}-C_{21} hydrocarbons (B), and >C_{21}-C_{32} hydrocarbons (C) in American Plaice liver composites from the Hebron Platform and Reference Area, 2015 to 2020.

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 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
>C_{10}-C_{16} Hydrocarbons					
Site	1	756.2	756.2	11.745	**0.001**
Year	3	9082.0	3027.3	47.024	**<0.001**
Site*Year	3	1600.3	533.4	8.286	**<0.001**
Residuals	52	3347.7	64.4		
>C_{16}-C_{21} Hydrocarbons					
Site	1	79	79	0.170	0.682
Year	3	99427	33142	71.005	**<0.001**
Site*Year	3	964	321	0.689	0.563
Residuals	52	24272	467		
>C_{21}-C_{32} Hydrocarbons					
Site	1	29260	29260	5.801	**0.020**
Year	3	387256	129085	25.590	**<0.001**
Site*Year	3	40662	13554	2.687	0.056
Residuals	52	262309	5044		
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 2020 (Table 6-7). In 2018 two compounds in liver composites (acenaphthylene and fluorene) were detected above their RDLs and screened in. Some detections for fluorene were observed in 2015, although co-matrix interference has often resulted in an elevated RDL for fluorene. No co-matrix interference was noted in 2019 or 2020.

Taste Panels

All fillets were deemed safe for human consumption based on Health Canada guidelines (Health Canada 2020; see 6.1.3.2). For the 2020 EEM program, 11 of 24 panelists were able to successfully discriminate the odd sample which indicates results are not significant (p=0.140). Comments from panelists for the triangle test are in Table 6-12. For the 2020 EEM, hedonic taste tests showed no significant differences between the Hebron Platform and the Reference Area (p=0.580; Table 6-13). Comments from panelists from the hedonic tests are in Table 6-14.

Overall, there were no significant differences between the Hebron Platform and Reference Area for the 2020 EEM taste panel results. These results are consistent with past EEM years, though no taste testing took place for the 2019 EEM.

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

Correctly guessed odd sample	Incorrectly guessed odd sample
More pleasant taste and odour	Thanks tastes good.
(Reference Area) taste more fresh than (Hebron Platform) and (Hebron Platform)	Not much difference.
(Hebron Platform) and (Hebron Platform) sweeter and saltier than (Reference Area).	(Hebron Platform) Slightly less sweet/favourable than other 2 samples.
Not a big difference but the other two samples seemed a little more bland.	No detectable difference.
No discernable difference.	Just a guess, all the same to me.
	Very similar to each other.
	(Hebron Platform) and (Reference Area) had less fish odour and bland taste.

Table 6-13 One-way ANOVA of hedonic taste test preference evaluation of American Plaice from the Hebron Platform and Reference Area in 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Between Groups	2	2.521	1.260	0.551	0.580
Within Groups	45	102.958	2.288		
Total	47	105.479			
Notes: Bolded p-value denotes a significant result (α=0.05)					

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

Preferred Reference Sample	Preferred Hebron Sample
More of a fishy taste on (Hebron Platform) sample.	(Reference Area) was very bland and (Hebron Platform) was sweeter.
(Reference Area) had a more seafood taste.	
(Reference Area) sweeter. Nice flavour for both.	Two samples taste similar. (Hebron Platform) flavour slightly better.
(Hebron Platform) slightly less desirable flavour.	
Not much difference between samples. (Reference Area) slightly better flavour.	Preferred (Hebron Platform). Not much difference. No bad after taste in either. Slight off flavour in (Reference Area) at first.
Sample (Hebron Platform) seems bland, fishy with processed taste to it. Sample (Reference Area) milder more pleasant taste.	

Preferred Reference Sample	Preferred Hebron Sample
(Hebron Platform) tastes slightly metallic/treated.	
(Hebron Platform) had an off flavour.	
(Reference Area) tastes good, soft. (Hebron Platform) strong fishy smell. Strong texture.	
(Hebron Platform) bland compared to (Reference Area).	
(Hebron Platform) tasted a little off compared to (Reference Area).	

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 6-15. During the 2020 EEM program, three males and 67 females were collected at the Hebron Platform, and three males and 67 females at the Reference Area. Fisher's exact test showed no difference in the ratio of male to female fish between sites (p=1.00). Due to the low numbers of male fish caught in 2020, no comparisons can be made between frequencies of maturity stages (Table 6-15). For female American Plaice, only code 530 (maturing in present year B) and code 560 (spent in present year) has significant differences between sites (Table 6-15), with code 530 having a higher incidence at the Reference Area and code 560 having a higher incidence at the Hebron Platform.

Table 6-15 Frequencies (%) of maturity stages of male (top) and female (bottom) American Plaice from the 2020 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	3	0	0	33	67	0	0	0
Reference Area	3	0	0	0	67	33	0	0

Female Maturity Stage (% of individuals)										
	n	**Immature (500)**	**Spent L (510)**	**Maturing A-P (520)**	**Maturing B-P (530)**	**Maturing C-P (540)**	**Partly Spent P (550)**	**Spent P (560)**	**Spent P Mat N (570)**	**Mat N (580)**
Hebron Platform	67	13	3	34	6	1	7	33	1	0
Reference Area	67	16	1	40	19	1	3	16	1	0
p-value		0.81	1.00	0.59	**0.04**	1.00	0.44	**0.04**	1.00	1.00

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

2020 Results

Some significant variations between sites existed for female American Plaice sampled, with none completed for male fish due to the small sample size (Table 6-16). Female fish significantly differed in all biological characteristics with the exception of age. Those that differed were higher (i.e., larger fish) at the Hebron Platform compared to the Reference Area. 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) adjusting the variable of interest on its covariate, compared between sites. Female fish still differed in gutted weight and liver weight but did not differ in gonad weight when covaried on gutted weight (Table 6-17).

Table 6-16 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 2020.

Parameter	Hebron Platform	Reference Area	p-value
Male			
No. of Fish	3	3	
Length (cm)	361 ± 17.8	337 ± 24.6	-
Total Body Weight (g)	440 ± 73.1	362 ± 92.7	-
Gutted Body Weight (g)	370 ± 62.8	307 ± 68.9	-
Liver Weight (g)	10.0 ± 2.31	5.9 ±0.92	-
Gonad Weight (g)	5.12 ± 1.66	5.25 ± 2.08	-
Age (years) [a]	7.67 ± 1.15	6.67 ± 0.58	-
Fulton's Condition Index [b]	0.78 ± 0.01	0.78 ± 0.02	-
Hepatosomatic Index [c]	2.71 ± 0.43	1.94 ± 0.17	-
Gonadosomatic Index [d]	1.35 ± 0.20	1.69 ± 0.55	-
Female			
No. of Fish	67	67	
Length (cm)	415 ± 36.6	401 ± 36.3	**0.024**
Total Body Weight (g)	717 ± 216	582 ± 180	**<0.001**
Gutted Body Weight (g) [e]	581 ± 166	491 ± 149	**<0.001**
Liver Weight (g)	17.4 ± 7.57	10.0 ± 4.08	**<0.001**
Gonad Weight (g)	22.0 ± 11.5	17.6 ± 11.2	**0.026**
Age (years) [f]	10.7 ± 1.70	10.1 ± 1.85	0.075
Fulton's Condition Index [b, e]	0.79 ± 0.10	0.74 ± 0.06	**<0.001**
Hepatosomatic Index [c, e]	2.94 ± 0.76	2.04 ± 0.47	**<0.001**
Gonadosomatic Index [d, e]	3.62 ± 1.10	3.43 ± 1.71	**0.035**

Notes:
All data are expressed as average values ± standard deviation
Bolded p-value denotes significant results (α=0.05)
[a] For male age calculations, n=3 for the Hebron Platform and n=3 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] One female fish at the Hebron Platform had no recorded gutted weight, and was excluded from gutted weight, FCI, HSI, and GSI
[f] For female age calculations, n=47 for the Hebron Platform and n=47 for the Reference Area

Table 6-17 Adjusted p-values from ANCOVA analysis of gutted, liver, and gonad weight for female American Plaice from the Hebron Platform and Reference Area in 2020.

Variable	Covariate	Adjusted p-value [a]
Female		
Gutted weight (g)	Length (mm)	**0.011**
Liver Weight (g)	Gutted weight (g)	**<0.001**
Gonad weight (g)	Gutted weight (g)	0.833

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 6-18). For male fish, significant results included male HSI differing between sites (higher at the Hebron Platform) and years (higher in 2020 compared to past years), and GSI differed between years, with higher values in 2019 compared to other EEM years (Table 6-18,Figure 6-9). However, due to the small sample size in 2020, there is little statistical confidence in these values. Female plaice significantly differed between sites and years for Fulton's condition index and had significant interaction terms for both HSI and GSI, indicating a potential project-induced change (Table 6-18, Figure 6-10).

Table 6-18 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 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
MALE					
Fulton's Condition Index					
Site	1	0.003	0.003	0.387	0.535
Year	3	0.043	0.014	2.094	0.104
Site*Year	3	0.008	0.003	0.389	0.761
Residuals	141	0.955	0.007		
Hepatosomatic Index					
Site	1	2.714	2.714	19.616	**<0.001**
Year	3	3.412	1.137	8.222	**<0.001**
Site*Year	3	0.676	0.225	1.629	0.185
Residuals	141	19.505	0.138		
Gonadosomatic Index					
Site	1	0.075	0.075	0.125	0.725
Year	3	8.228	2.742	4.536	**0.005**
Site*Year	3	0.202	0.067	0.112	0.953
Residuals	141	85.263	0.605		
FEMALE					
Fulton's Condition Index					
Site	1	0.098	0.098	8.090	**0.005**
Year	3	0.121	0.040	3.317	**0.020**
Site*Year	3	0.028	0.009	0.755	0.520
Residuals	399	4.843	0.012		
Hepatosomatic Index					
Site	1	12.372	12.372	39.188	**<0.001**
Year	3	38.375	12.792	40.518	**<0.001**
Site*Year	3	15.952	5.317	16.843	**<0.001**
Residuals	399	125.965	0.316		
Gonadosomatic Index					
Site	1	109.9	109.9	4.792	**0.029**
Year	3	454.0	151.3	6.599	**<0.001**
Site*Year	3	330.9	110.3	4.811	**0.003**
Residuals	399	9149.4	22.9		
Notes: Bolded p-value denotes a significant result (α=0.05)					

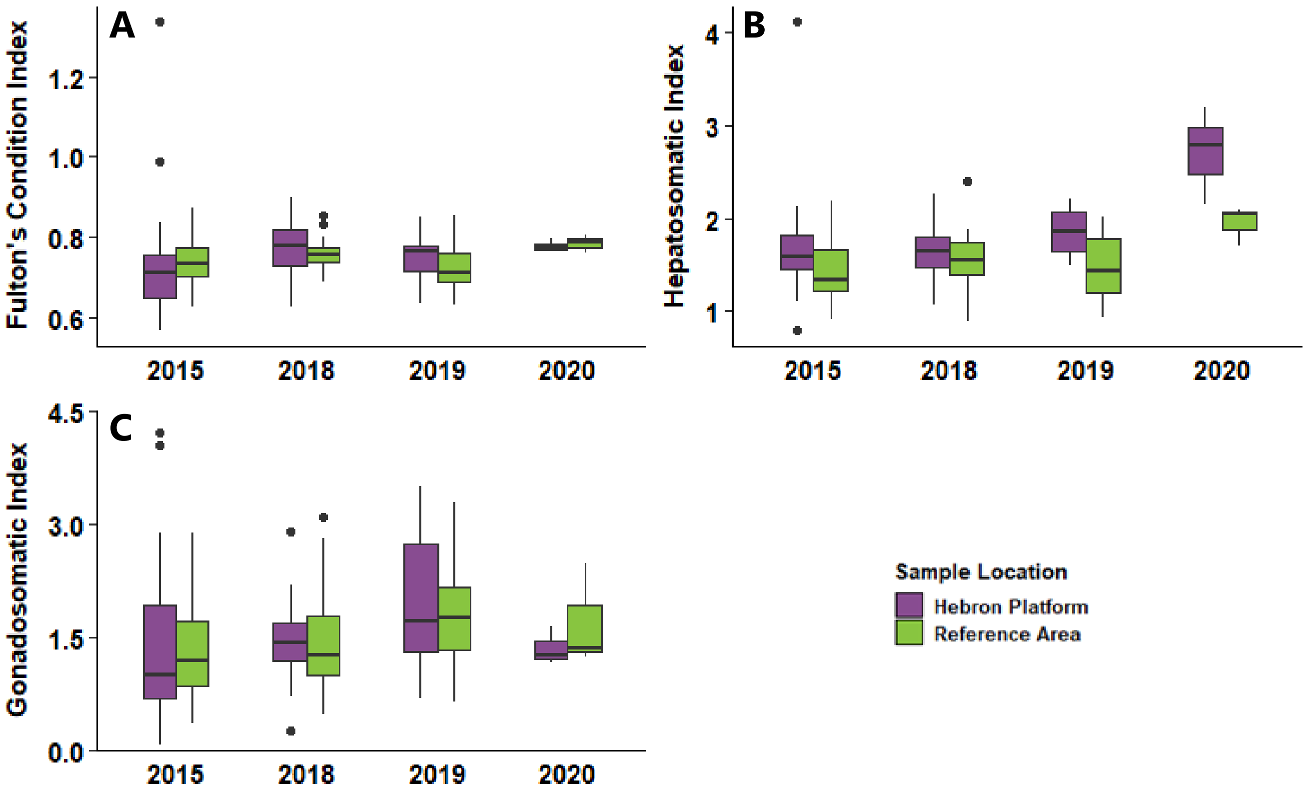


Figure 6-9 Boxplots of Fulton's condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for male American Plaice sampled from the Hebron Platform and Reference Area from 2015 to 2020.

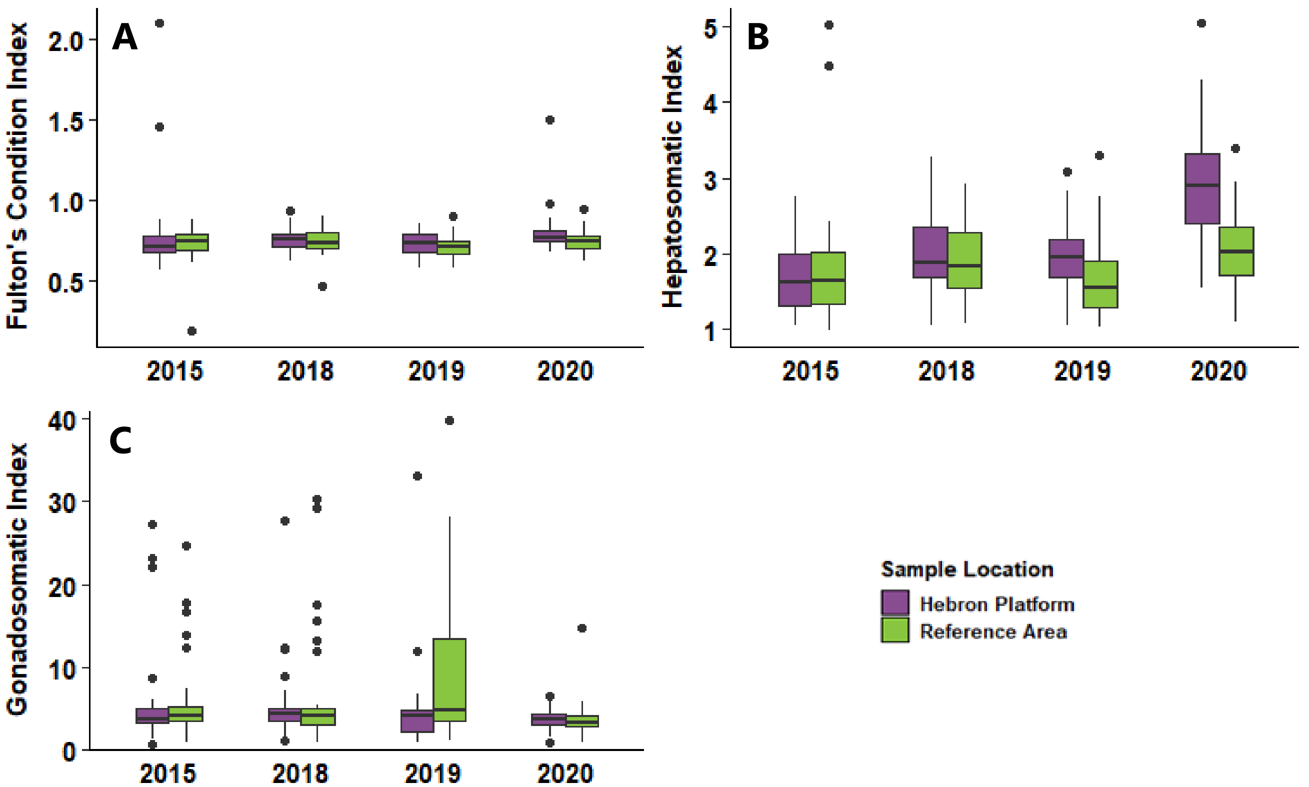


Figure 6-10 Boxplots of Fulton's condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for female American Plaice sampled from the Hebron Platform and Reference Area from 2015 to 2020.

Gross Pathology

<u>2020 Results</u>

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 6-11. Several minor conditions were noted including localized discolouration on the liver (such as bile accumulation in the anterior region of the liver; Figure 6-11A), inflammation of the hindgut (not shown here), and the presence of parasites in or on specimens (Figure 6-11A). These conditions and their prevalence at both sites are summarized in Table 6-19 for male and female plaice. Due to low catch numbers, no analysis is presented for male American Plaice. There were no significant differences among any of the parameters examined individually for females (Table 6-19). The totals of fish health conditions were compiled and analyzed (for female fish) as the health assessment index (HAI; Table 6-19). Female plaice differed for both HAI and its first modification, but after parasites were removed (HAI2) it was not significant (Table 6-19).

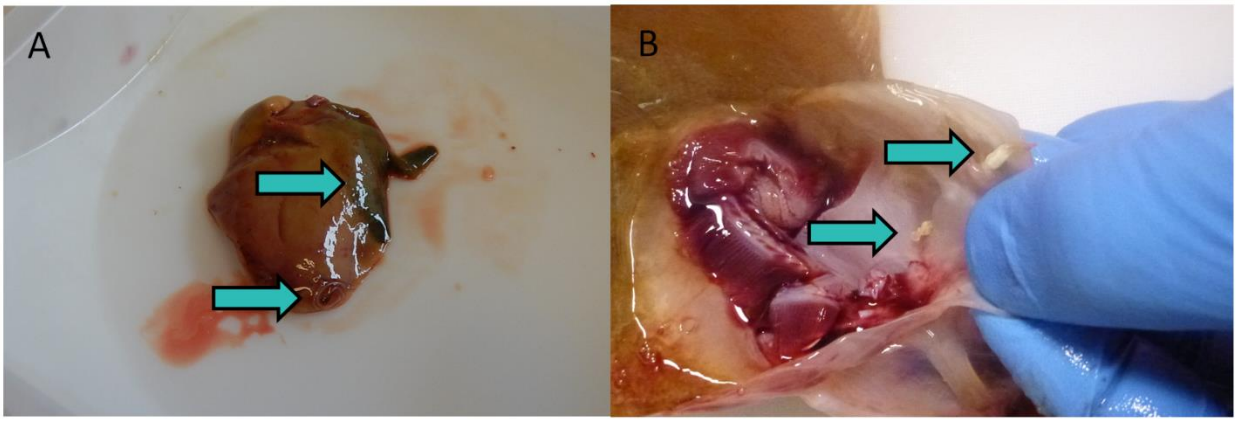


Figure 6-11 Examples of gross pathologies observed among American Plaice from the Hebron Platform EEM biological survey: nematode and green discolouration present on liver (A), and parasitic copepod (*Acanthochondria* spp.) (B).

Table 6-19 Pathologies and health assessment index of male (top) and female (bottom) American Plaice from the Hebron Platform and Reference Area in 2020.

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Male	**Hebron Platform (n=3)**		**Reference Area (n=3)**			
Fins	0	0	0	0	-	-
Spleen	0	0	0	0	-	-
Hindgut	0	0	0	0	-	-
Kidney	0	0	0	0	-	-
Skin	0	0	0	0	-	-
Liver	0	0	1	33	-	-
Eyes	0	0	0	0	-	-
Gills	0	0	0	0	-	-
Parasites	1	33	2	67	-	-
Male	**Hebron Platform (n=3)**		**Reference Area (n=3)**		**p-value**	**Test used**
HAI	3.3 ± 5.8		23.3 ± 5.8		-	-
Modified.HAI.1	3.3 ± 5.8		23.3 ± 5.8		-	-
Modified.HAI.2	0 ± 0		10.0 ± 17.3		-	-
Female	**Hebron Platform (n=67)**		**Reference Area (n=67)**		**p-value**	**Test used**

Parameter	**Fish with Variable Condition**	**Prevalence (%)**	**Fish with Variable Condition**	**Prevalence (%)**	**p-value**	**Test used**
Fins	0	0	0	0	1.000	Fisher's
Spleen	0	0	0	0	1.000	Fisher's
Hindgut	3	4	3	4	1.000	Fisher's
Kidney	0	0	0	0	1.000	Fisher's
Skin	0	0	0	0	1.000	Fisher's
Liver	35	52	25	37	0.118	Fisher's
Eyes	0	0	0	0	1.000	Fisher's
Gills	0	0	0	0	1.000	Fisher's
Parasites	49	73	48	72	1.000	Fisher's
Female	**Hebron Platform (n=57)**		**Reference Area (n=47)**		**p-value**	**Test used**
HAI	28.6 ± 17.8		22.4 ± 15.4		**0.040**	ANOVA
Modified.HAI.1	28.4 ± 17.8		22.4 ± 15.4		**0.040**	ANOVA
Modified.HAI.2	16.4 ± 15.3		11.6 ± 14.4		0.066	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 from 2018 to 2020 (no gross pathology data was available for 2015). Male fish significantly differed between years for the HAI and mod. 1, but not for mod. 2 (Table 6-20,Figure 6-12). The small sample size for male fish in 2020 leads to little statistical confidence in this difference. For female fish, significant differences were found between sites for all three HAI modifications; however, no significant interaction terms were detected (Table 6-20, Figure 6-13).

Table 6-20 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 from 2018 to 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male American Plaice					
Health Assessment Index (HAI)					
Site	1	281.3	281.3	0.922	0.340
Year	2	2443.9	1222.0	4.004	**0.022**
Site*Year	2	970.4	485.2	1.590	0.211
Residuals	72	21976.2	305.2		
HAI Modification 1 (Removed skin and fins)					
Site	1	293.2	293.2	0.912	0.342
Year	2	2198.4	1099.2	3.419	**0.038**
Site*Year	2	907.6	453.8	1.411	0.250
Residuals	72	23149.6	321.5		
HAI Modification 2 (Removed skin, fins, and parasites)					
Site	1	39.6	39.6	0.166	0.685
Year	2	1208.0	604.0	2.530	0.087
Site*Year	2	849.7	424.8	1.779	0.176
Residuals	72	17189.9	238.8		
Female American Plaice					
Health Assessment Index (HAI)					
Site	1	3149	3149	10.250	**0.001**
Year	2	608	304	0.990	0.373
Site*Year	2	106	53	0.173	0.841
Residuals	336	103213	307		
HAI Modification 1 (Removed skin and fins)					
Site	1	2974	2974	9.657	**0.002**
Year	2	539	270	0.875	0.418
Site*Year	2	73	37	0.119	0.888
Residuals	336	103490	308		
HAI Modification 2 (Removed skin, fins, and parasites)					
Site	1	1080	1080	4.503	**0.035**
Year	2	389	195	0.812	0.445
Site*Year	2	225	112	0.469	0.626
Residuals	336	80606	240		
Notes: Bolded p-value denotes a significant result (α=0.05)					

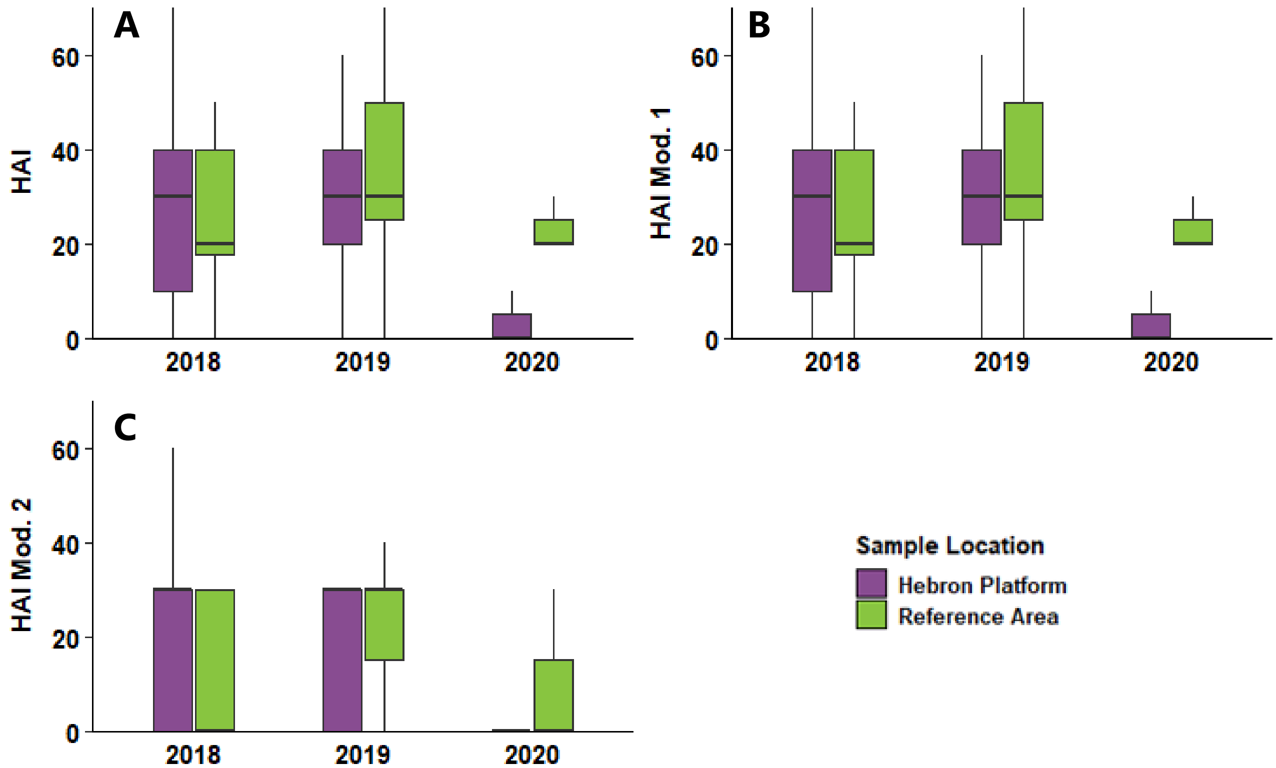


Figure 6-12 Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for male American Plaice sampled at the Hebron Platform and Reference Area from 2018 to 2020.

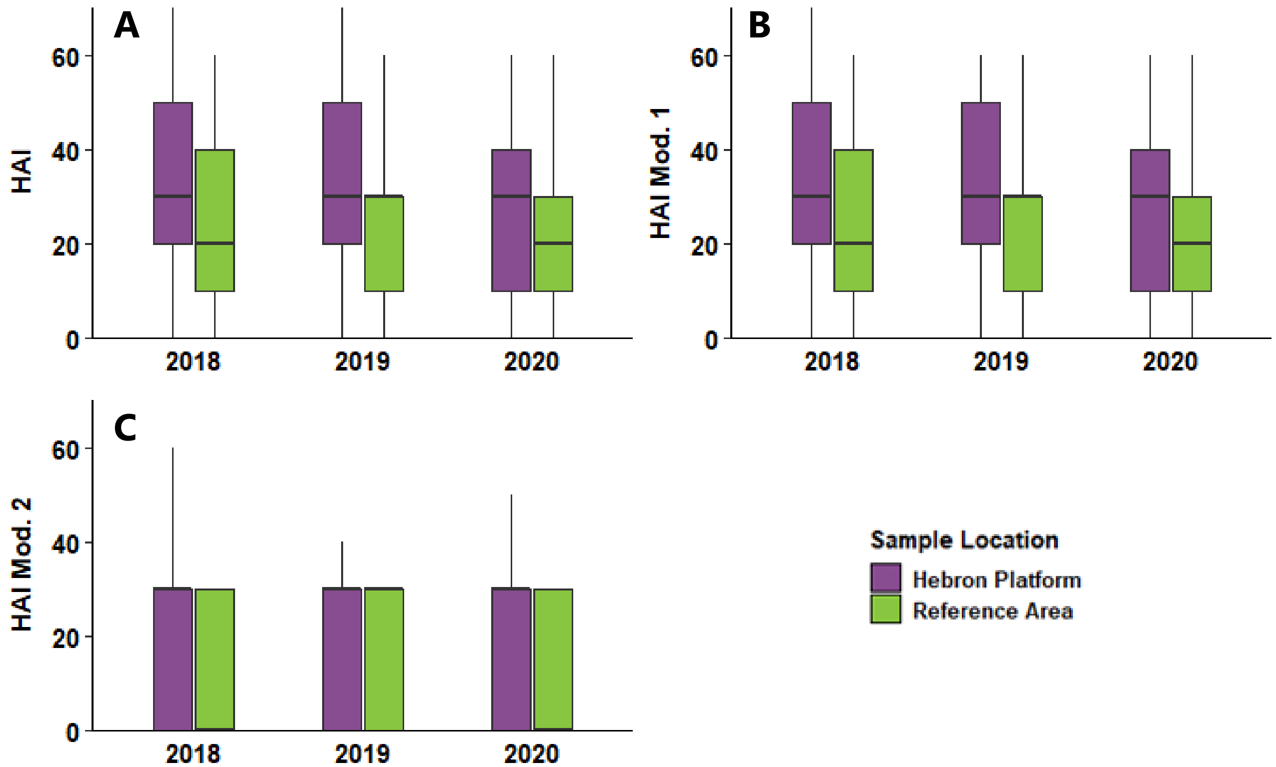


Figure 6-13 Health assessment indices (HAI (A), mod. 1 (B), and mod. 2 (C)) for female American Plaice sampled at the Hebron Platform and Reference Area from 2018 to 2020.

Haematology

Blood smears were collected from 50 fish at both the Hebron Platform and Reference Area in 2020, and examples of each cell type can be found in Figure 6-14. These counts were used to prepare percentages of these cell types in a minimum of 200 white blood cells.

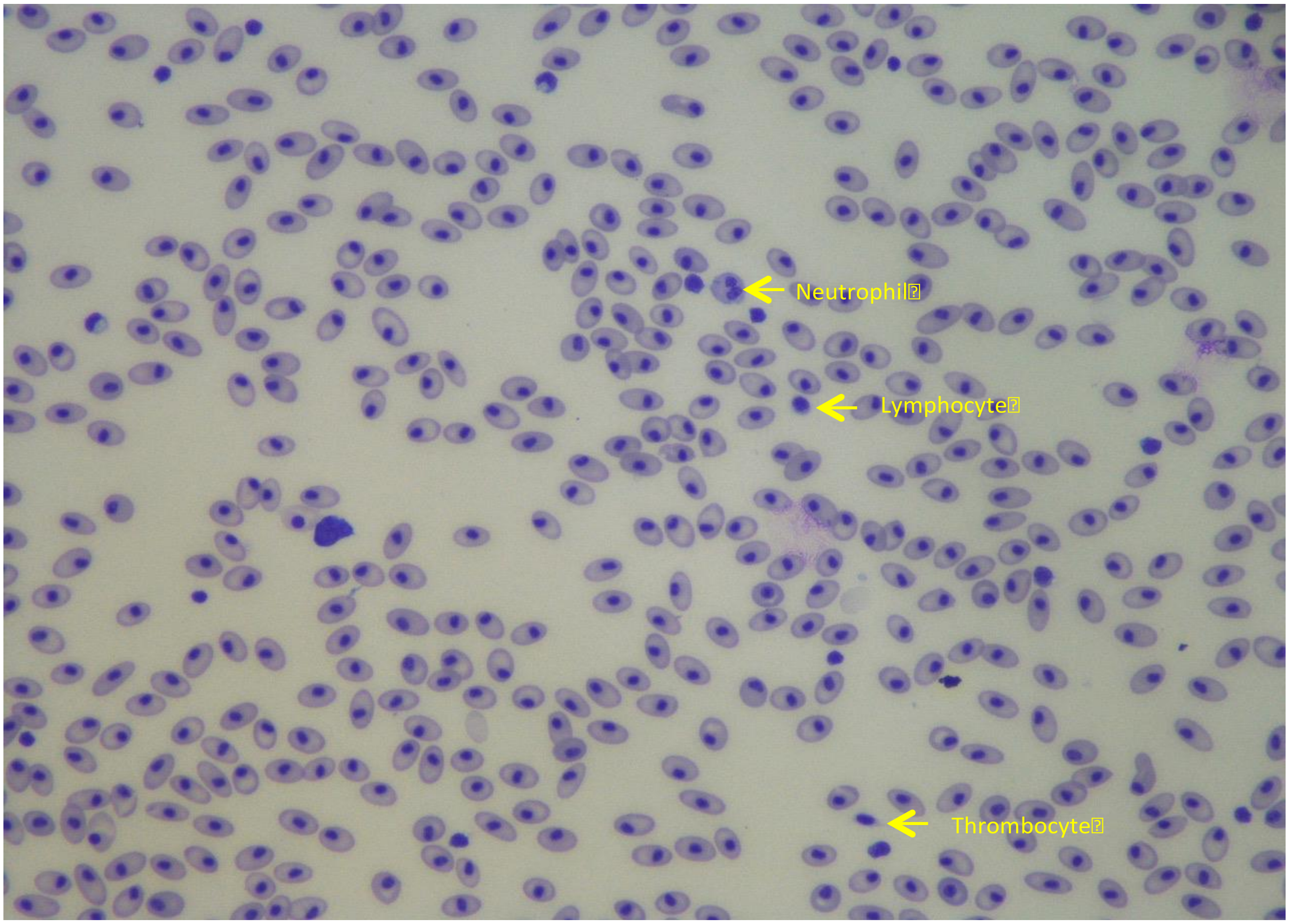


Figure 6-14 Example of cell types in blood smear from American Plaice sampled during the Hebron EEM. Arrows indicate a neutrophil (top), lymphocyte (middle), and thrombocyte (bottom). Image provided by CDRF (MUN).

2020 Results

No significant differences were found between the Hebron Platform and Reference Area for any blood cell type (neutrophils, lymphocytes, and thrombocytes; Table 6-21).

Table 6-21 Frequencies of blood cell types in American Plaice from the 2020 Hebron biological survey.

Cell Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Lymphocytes (%)	97.7 ± 2.04	96.7 ± 4.13	0.138
Neutrophils (%)	0.66 ± 0.76	0.60 ± 0.79	0.728
Thrombocytes (%)	1.64 ± 2.00	2.68 ± 4.11	0.116

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 were by year (Hebron Platform only in 2015 compared to Hebron Platform/Reference Area combined in 2018 to 2020) and by site (Hebron Platform 2015 to 2020 combined compared to Reference Area for 2018 to 2020), with the interaction term only valid for the 2018 to 2020 data. Significant differences were found between sites for all three cell types (Table 6-22), with the Hebron Platform having a greater percentage of neutrophils and thrombocytes, and the Reference Area having a higher percentage of lymphocytes (Figure 6-15). The interaction term was significant for thrombocytes, indicating a potential project-induced change (Table 6-22,Figure 6-15).

Table 6-22 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 2020. No data exists for the Reference Area in 2015, and so interaction terms only apply from 2018 to 2020 data.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Neutrophils (%)					
Site	3	72.07	24.02	29.031	**<0.001**
Year	1	2.59	2.59	3.133	0.078
Site*Year	2	2.39	1.19	1.441	0.238
Residuals	342	283.01	0.83		
Lymphocytes (%)					
Site	3	2360.4	786.8	46.143	**<0.001**
Year	1	14.6	14.6	0.856	0.356
Site*Year	2	77.1	38.6	2.261	0.106
Residuals	342	5831.5	17.1		
Thrombocytes (%)					
Site	3	1672.7	557.6	35.015	**<0.001**
Year	1	29.5	29.5	1.852	0.174
Site*Year	2	104.3	52.1	3.274	**0.039**
Residuals	342	5445.8	15.9		
Notes: Bolded p-value denotes a significant result (α=0.05)					

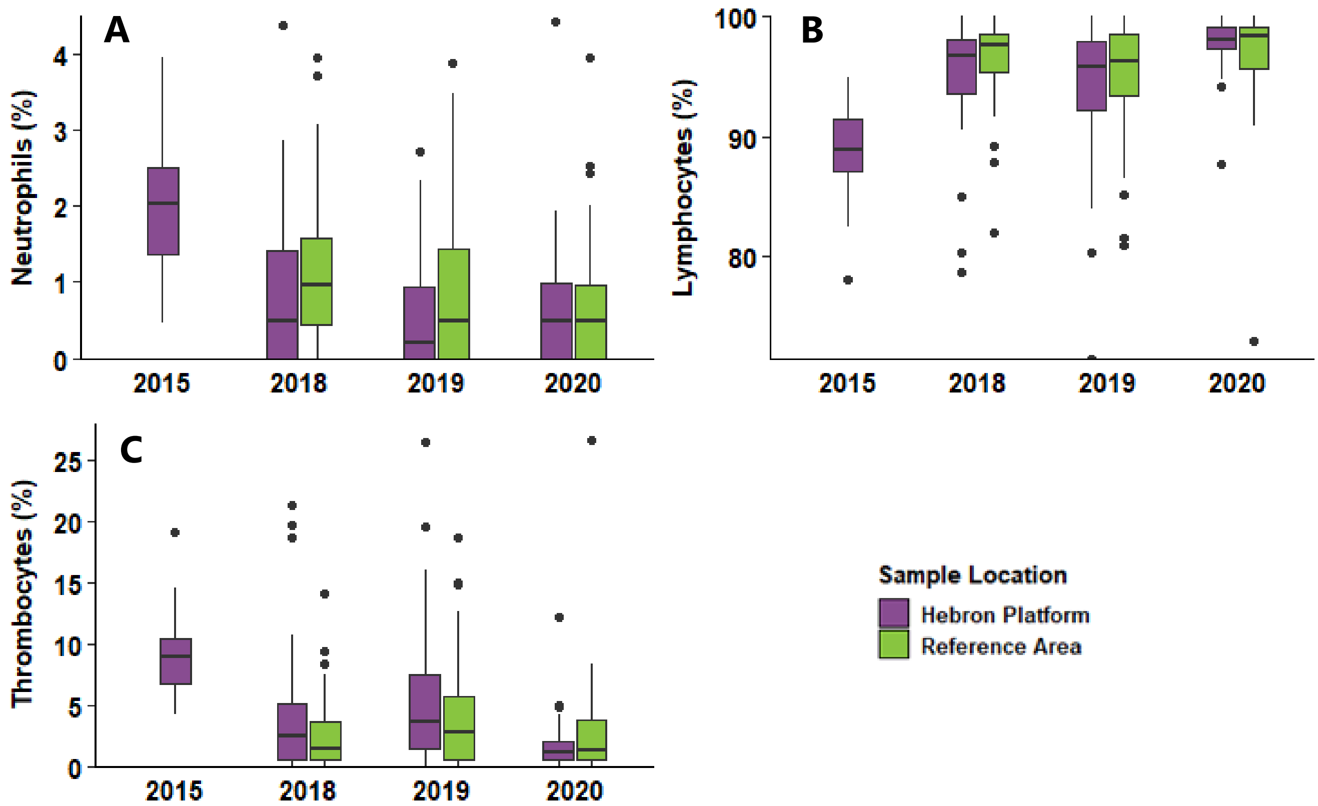


Figure 6-15 Boxplots of the percentage of neutrophils (A), lymphocytes (B), and thrombocytes (C) from blood smears of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2020. No data exists for the Reference Area in 2015.

Mixed Function Oxygenase Activity

2020 Results

No significant differences in MFO activity were found between female American Plaice collected from the Hebron Platform and the Reference Area (p=0.358,Table 6-23). No significant difference in MFO activity was found for male fish between sites (p=0.070; Table 6-23), though statistical power was low with low male American Plaice sample sizes.

Table 6-23 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 2020.

Mixed Function Oxygenase (pmol resorufin / mg protein / min)			
Male	**Hebron Platform (n=3)**	**Reference Area (n=3)**	**p-value**
MFO (EROD)	38.53 ± 15.31	46.04 ± 35.45	0.753
Female	**Hebron Platform (n=47)**	**Reference Area (n=47)**	**p-value**
MFO (EROD)	17.70 ± 12.80	15.41 ± 11.27	0.358
Notes: All data expressed as mean percentage ± standard deviation Bolded p-value denotes significant result (α=0.05)			

Across-year Comparison

Two-way ANOVAs were used to compare MFO activity across both sites (Hebron Platform and Reference Area) and years (2015 to 2020) for male and female American Plaice. Both analyses had significant results in their interaction terms and between years (Table 6-24). Figure 6-16 shows the cause of the significant interactions, with much higher results in 2019 relative to other monitoring years, and variation in whether the Hebron Platform or Reference Area fish have a higher mean in a given year.

Table 6-24 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 2020.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male					
Site	1	457	456.8	1.5438	0.217
Year	3	80292	26764.1	90.4561	**<0.001**
Site*Year	3	9186	3062.1	10.3492	**<0.001**
Residuals	104	30771	295.9		
Female					
Site	1	387	387	2.4221	0.121
Year	3	204089	68030	426.1292	**<0.001**
Site*Year	3	2685	895	5.6075	**<0.001**
Residuals	279	44534	160		
Notes: Bolded p-value denotes a significant result (α=0.05)					

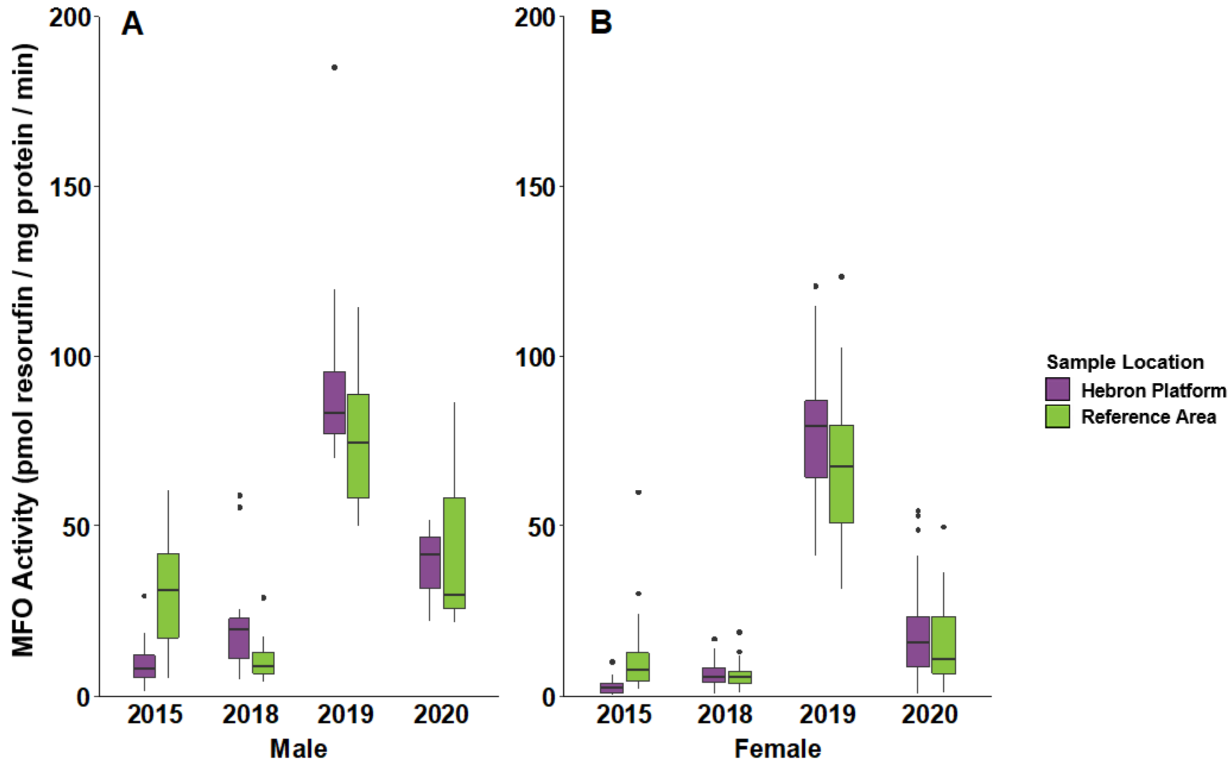


Figure 6-16 Boxplot of mixed function oxygenase (MFO) activity (pmol resorufin / mg protein / min) collected from male (A) and female (B) American Plaice at the Hebron Platform and Reference Area from 2015 to 2020.

Histopathology

The histological parameters examined for American Plaice tissue samples collected for the 2020 Hebron EEM program were assessed microscopically for the presence of different lesions summarized in the tables below and defined according to standard methods (Khan and Kiceniuk 1984, Khan 1990, 1995, Khan et al. 1994, Stentiford et al. 2003, Agamy 2012). Examples of liver pathologies are shown in Figure 6-17, and examples of gill pathologies in Figure 6-18.

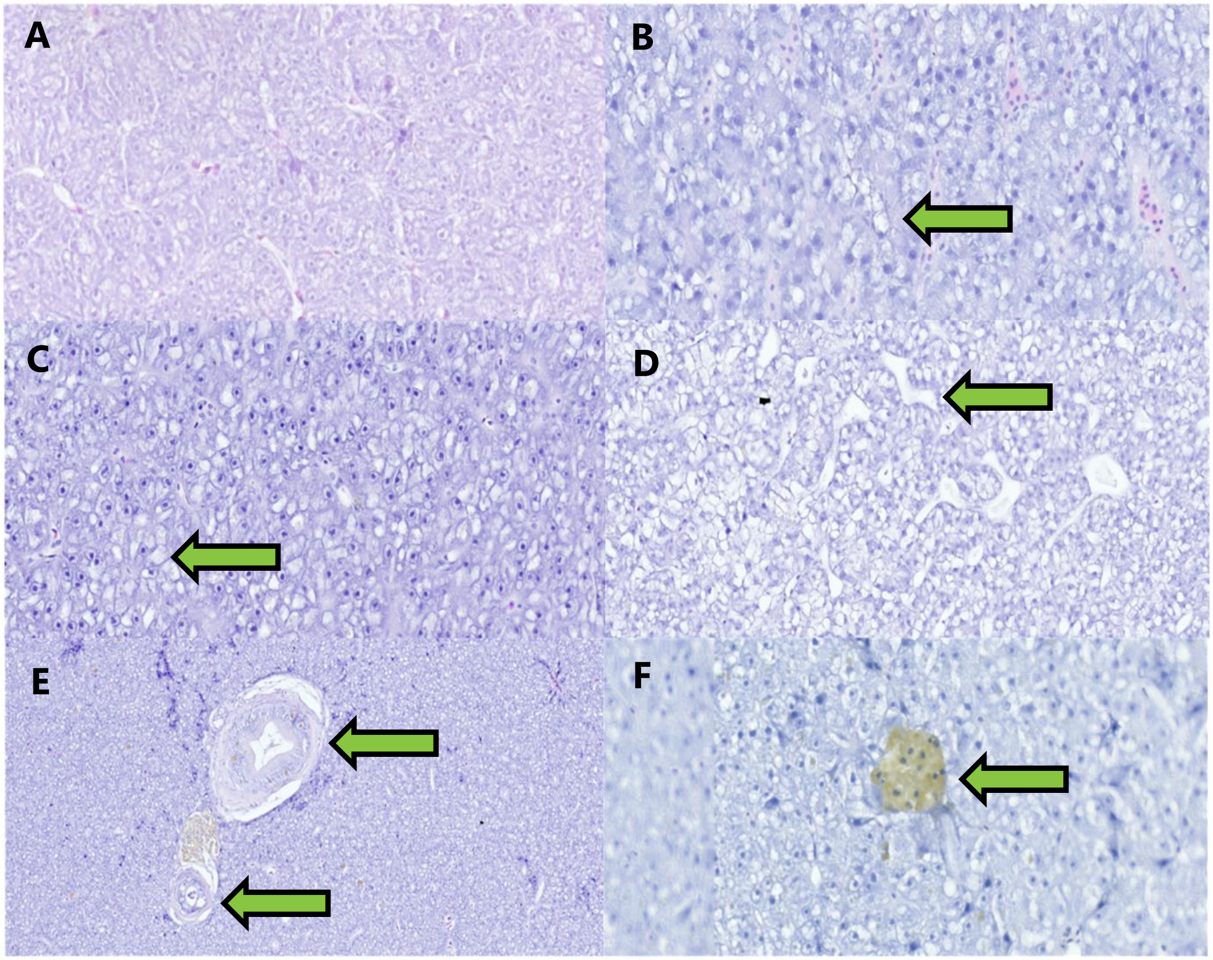


Figure 6-17 Examples of liver pathologies: normal liver tissue (A), small hepatocellular vacuoles (B), medium hepatocellular vacuoles (C), large hepatocellular vacuoles (D), bile duct hyperplasia (E), and macrophage aggregate (F). Images provided by the CDRF (MUN) from example American plaice.

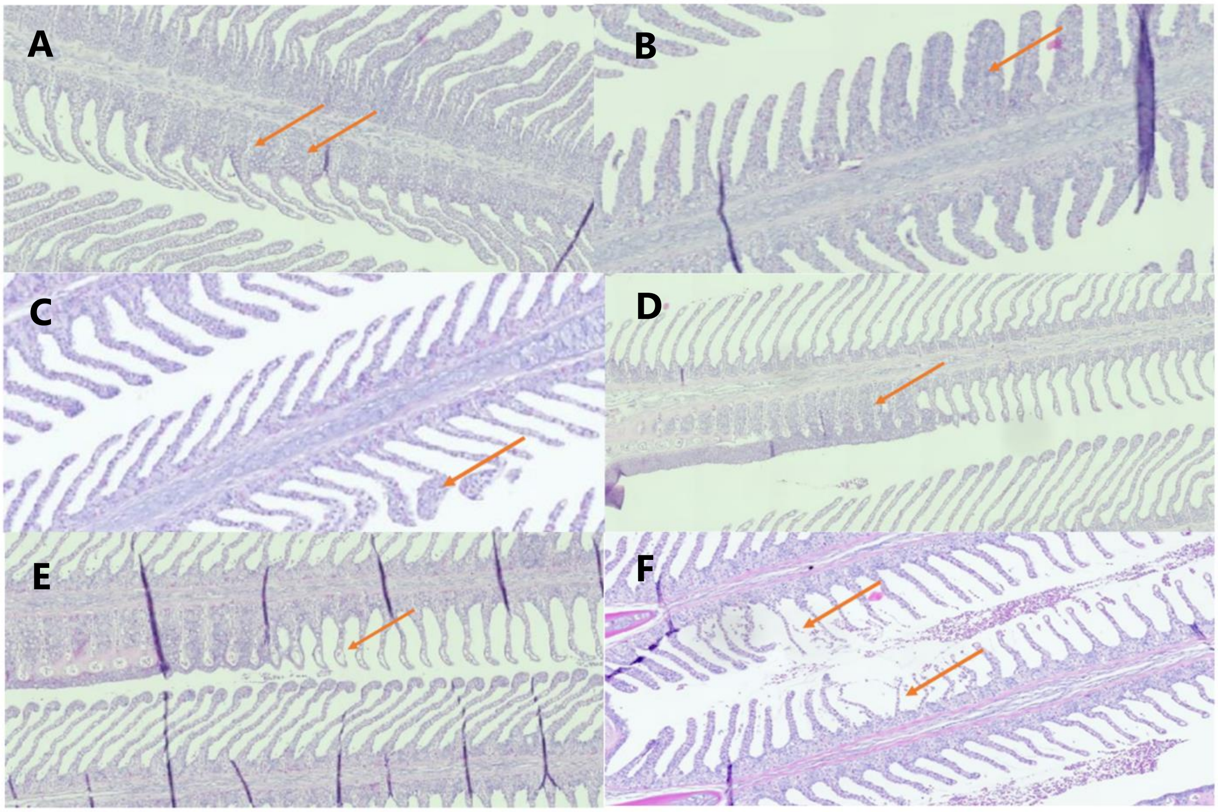


Figure 6-18 Examples of gill pathologies: basal hyperplasia (A), distal hyperplasia (B), tip hyperplasia (C), fusion (D), epithelial lifting (E), and thin filaments (F). Images provided by the CDRF (MUN) from example American plaice.

2020 Liver Histopathology Results

Several hepatic lesions were observed in American Plaice in 2020, including bile duct hyperplasia (Figure 6-17), hepatocellular carcinoma (not shown), macrophage aggregates (Figure 6-17), and hepatocellular vacuoles (Figure 6-17, Table 6-25). There were no significant differences among lesion types between the Hebron Platform and the Reference Area (Table 6-25).

Table 6-25 Number and frequency of American Plaice with hepatic lesions from the Hebron Platform and Reference Area in 2020.

Lesions	Hebron Platform (n=50)		Reference Area (n=50)		p-value
	Fish Affected	Prevalence (%)	Fish Affected	Prevalence (%)	
Normal	3	6	9	18	0.121
Nonspecific necrosis	0	0	0	0	1.000
Bile duct hyperplasia	17	34	19	38	0.835
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	20	40	13	26	0.202
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	0	0	0.242
Macrophage aggregates[b]	0	0	0	0	1.000
Hydropic vacuolation	0	0	0	0	1.000
Hepatocellular vacuoles S	1	2	4	8	0.362
Hepatocellular vacuoles M	19	38	20	40	1.000
Hepatocellular vacuoles L	6	12	3	6	0.487
Hepatocellular vacuoles A	26	52	27	54	1.000

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)

Across-year Liver Histopathology Comparison

A multivariate analysis of variance (MANOVA) was performed using the factors listed in Figure 6-25 that were detected in fish (i.e., excluding those with no fish affected). This left six factors: bile duct hyperplasia, hepatocellular carcinoma, macrophage aggregates (0-3), hepatocellular vacuoles (small), hepatocellular vacuoles (medium), and hepatocellular vacuole (large). All hepatocellular vacuoles could not be included in the MANOVA due to autocorrelation with the other hepatocellular vacuole factors. Figure 6-26 (top) presents the results of the

MANOVA, with significant differences between site (p=0.001), year (p=<0.001), and the interaction term (p=<0.001). Two-way ANOVAs were then run on each individual factor to determine which were contributing to the significance in the MANOVA. Figure 6-26 (bottom) shows the individual ANOVAs, with six factors having significant results: bile duct hyperplasia, hepatocellular carcinomas, macrophage aggregates (0-3), small hepatocellular vacuoles, medium hepatocellular vacuoles, and large hepatocellular vacuoles. The interaction term was significant for all factors analyzed except for bile duct hyperplasia.

Figure 6-19 shows each of the six factors with significant results found in Figure 6-26. Bileduct hyperplasia significantly varied by year, with a higher prevalence in 2019 relative to other years. Medium hepatocellular vacuoles also significantly varied by year, with a higher prevalence in 2020 relative to other years. Hepatocellular carcinoma had a significant interaction term, as incidence has increased at the Hebron Platform over time and not at the Reference Area up to 2019. Similarly, moderate prevalence was observed at both the Hebron Platform and Reference Area in 2020. Macrophage aggregates and small hepatocellular vacuoles also had significant interactions terms, and both varied in whether the Hebron Platform or Reference Area had 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 and 2020.

Table 6-26 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)					
Site	1	6	0.054	3.724	**0.001**
Year	3	18	0.361	8.826	**<0.001**
Site*Year	3	18	0.138	3.126	**<0.001**
Residuals	392				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Bile duct hyperplasia					
Site	1	0.007	0.007	0.038	0.846
Year	3	4.659	1.553	7.922	**<0.001**
Site*Year	3	0.110	0.037	0.187	0.906
Residuals	392	76.653	0.196		
Hepatocellular carcinoma					
Site	1	3.016	3.016	15.652	**<0.001**
Year	3	4.638	1.546	8.023	**<0.001**
Site*Year	3	2.077	0.692	3.592	**0.014**
Residuals	392	75.351	0.193		

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Macrophage aggregates (0-3)					
Site	1	0.024	0.024	0.344	0.558
Year	3	0.902	0.300	4.365	**0.004**
Site*Year	3	0.686	0.229	3.314	**0.020**
Residuals	392	29.980	0.069		
Hepatocellular vacuoles (small)					
Site	1	0.429	0.429	5.765	**0.017**
Year	3	0.141	0.047	0.632	0.595
Site*Year	3	0.607	0.202	2.720	**0.044**
Residuals	392	29.094	0.074		
Hepatocellular vacuoles (medium)					
Site	1	0.001	0.001	0.007	0.934
Year	3	2.129	0.710	3.666	**0.013**
Site*Year	3	0.479	0.160	0.824	0.481
Residuals	392	75.697	0.194		
Hepatocellular vacuoles (large)					
Site	1	0.008	0.008	0.052	0.820
Year	3	10.279	3.427	22.927	**<0.001**
Site*Year	3	5.206	1.736	11.612	**<0.001**
Residuals	392	58.436	0.150		
Notes: Bolded p-value denotes a significant result (α=0.05)					

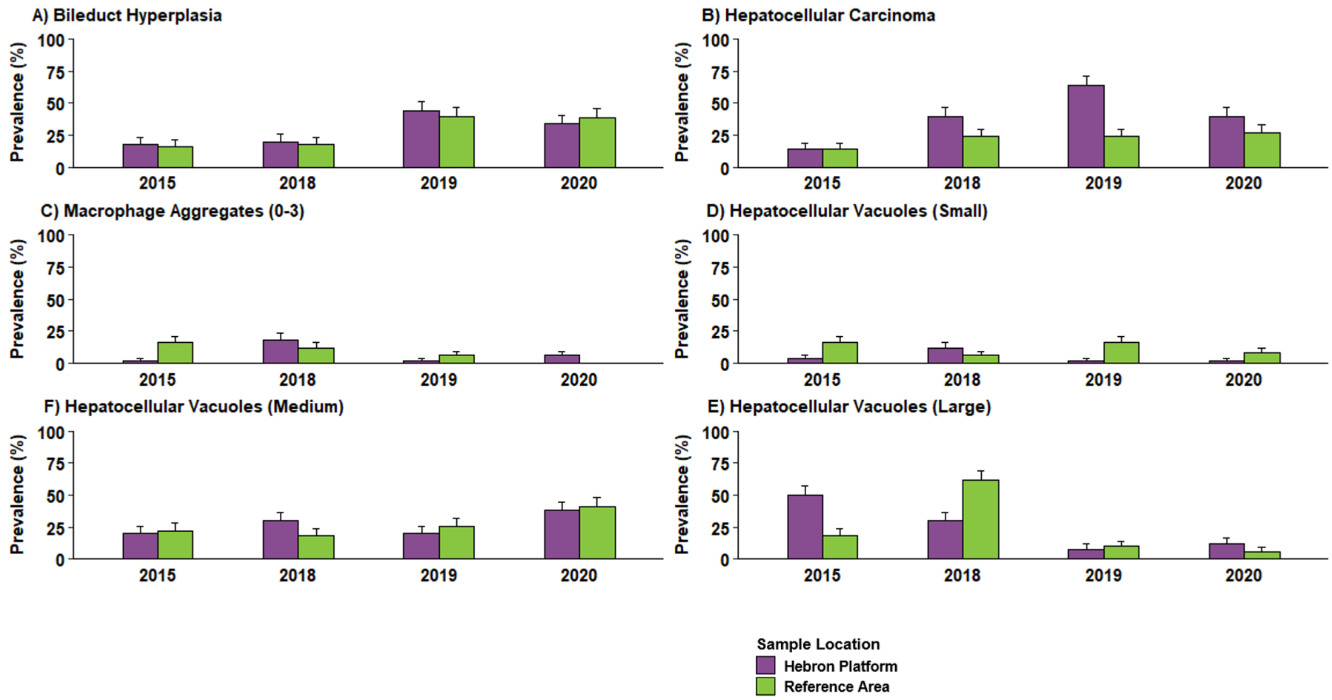


Figure 6-19 Bar graphs of the prevalence (%) of bile duct hyperplasia (A), hepatocellular carcinoma (B), macrophage aggregates (0-3) (C), small hepatocellular vacuoles (D), medium hepatocellular vacuoles (E), and large hepatocellular vacuoles (F) from livers of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2020. Bars indicate standard error.

2020 Gill Histopathology Results

Gill abnormalities were observed in fish from both areas, though no significant differences were noted between the Hebron Platform and the Reference Area (Table 6-27

Table 6-27 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 2020.

Lesion Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Percentage of Secondary Lamellae Affected by Lesions			
Normal	98.01 ± 3.57	98.69 ± 2.58	0.286
Tip Hyperplasia [a]	0.21 ± 0.44	0.10 ± 0.38	0.203
Basal Hyperplasia [b]	0.69 ± 2.33	0.15 ± 0.45	0.114
Distal Hyperplasia [c]	0.09 ± 0.33	0.09 ± 0.20	0.984
Fusion	0.82 ± 1.84	0.47 ± 1.53	0.307
Telangiectasia	0.02 ± 0.12	0 ± 0	0.320
Thin Lamellae	0.01 ± 0.03	0.06 ± 0.41	0.368
Epithelial Lifting	0.16 ± 0.54	0.44 ± 1.21	0.134
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.26 ± 0.63	0.22 ± 0.67	0.761

Notes:
All data are mean percentage or scale 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 Gill Histopathology Comparison

Due to the large number of gill histology factors, a MANOVA was performed using the factors listed in Table 6-27 excluding oedema as it is a measure of the scale of affected lesions. The remaining seven factors were used: hyperplasia (tip, basal, and distal), fusion, telangiectasia, thin lamellae, and epithelial lifting. Table 6-28 (top) shows the results of the MANOVA, with significant differences between sites (p=0.001), years (p=<0.001) and the interaction term (p=0.033). Two-way ANOVAs were then run on each individual factor to determine which are driving the significance in the MANOVA. Table 6-28 (bottom) shows the individual ANOVAs, with six factors having significant results: tip, basal, and distal hyperplasia, fusion, telangiectasia, and epithelial lifting.

Figure 6-20 shows each of the six factors with significant results found in Table 6-28. Tip hyperplasia had a significant year and interaction term, with incidence being lower in 2020 compared to 2018 and 2019. Basal hyperplasia significantly differed between sites and years, with 2020 values higher than 2019, and higher at the Hebron Platform. Distal hyperplasia significantly differed for all three terms, with lower values in 2020 compared to all other monitoring years, and generally higher at the Hebron Platform though not in 2020. Fusion and epithelial lifting significantly differed between years, with fusion lower in 2020 compared to other years, and epithelial lifting highest in 2020. Telangiectasia significantly differed between sites and was higher at the Hebron Platform compared to the Reference Area in all years.

Table 6-28 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 2020.

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
MANOVA (7 factors)					
Site	1	7	0.064	3.726	**0.001**
Year	3	21	0.325	6.706	**<0.001**
Site*Year	3	21	0.087	1.648	**0.033**
Residuals	390				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Hyperplasia (tip)					
Site	1	0.817	0.817	1.601	0.207
Year	3	21.075	7.025	13.769	**<0.001**
Site*Year	3	5.295	1.765	3.460	**0.017**
Residuals	390	198.983	0.510		
Hyperplasia (basal)					
Site	1	14.54	14.538	7.355	**0.007**
Year	3	91.39	30.463	15.411	**<0.001**
Site*Year	3	6.59	2.195	1.111	0.345
Residuals	390	770.90	1.977		
Hyperplasia (distal)					
Site	1	5.10	5.100	4.717	**0.030**
Year	3	28.94	9.647	8.924	**<0.001**
Site*Year	3	8.79	2.932	2.712	**0.045**
Residuals	390	421.63	1.081		
Fusion					
Site	1	10.88	10.878	1.770	0.184
Year	3	312.78	104.259	16.960	**<0.001**
Site*Year	3	16.46	5.487	0.893	0.445

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Residuals	390	2397.42	6.147		
Telangiectasia					
Site	1	0.389	0.389	9.154	**0.003**
Year	3	0.163	0.054	1.281	0.280
Site*Year	3	0.137	0.046	1.076	0.359
Residuals	390	16.558	0.043		
Thin lamellae					
Site	1	<0.001	$3.5x10^{-5}$	$3.0x10^{-4}$	0.987
Year	3	0.192	0.064	0.517	0.671
Site*Year	3	0.766	0.255	2.060	0.105
Residuals	390	48.324	0.124		
Epithelial lifting					
Site	1	1.272	1.273	3.188	0.075
Year	3	4.117	1.372	3.438	**0.017**
Site*Year	3	1.231	0.411	1.028	0.380
Residuals	390	155.668	0.399		
Notes: Bolded p-value denotes a significant result (α=0.05)					

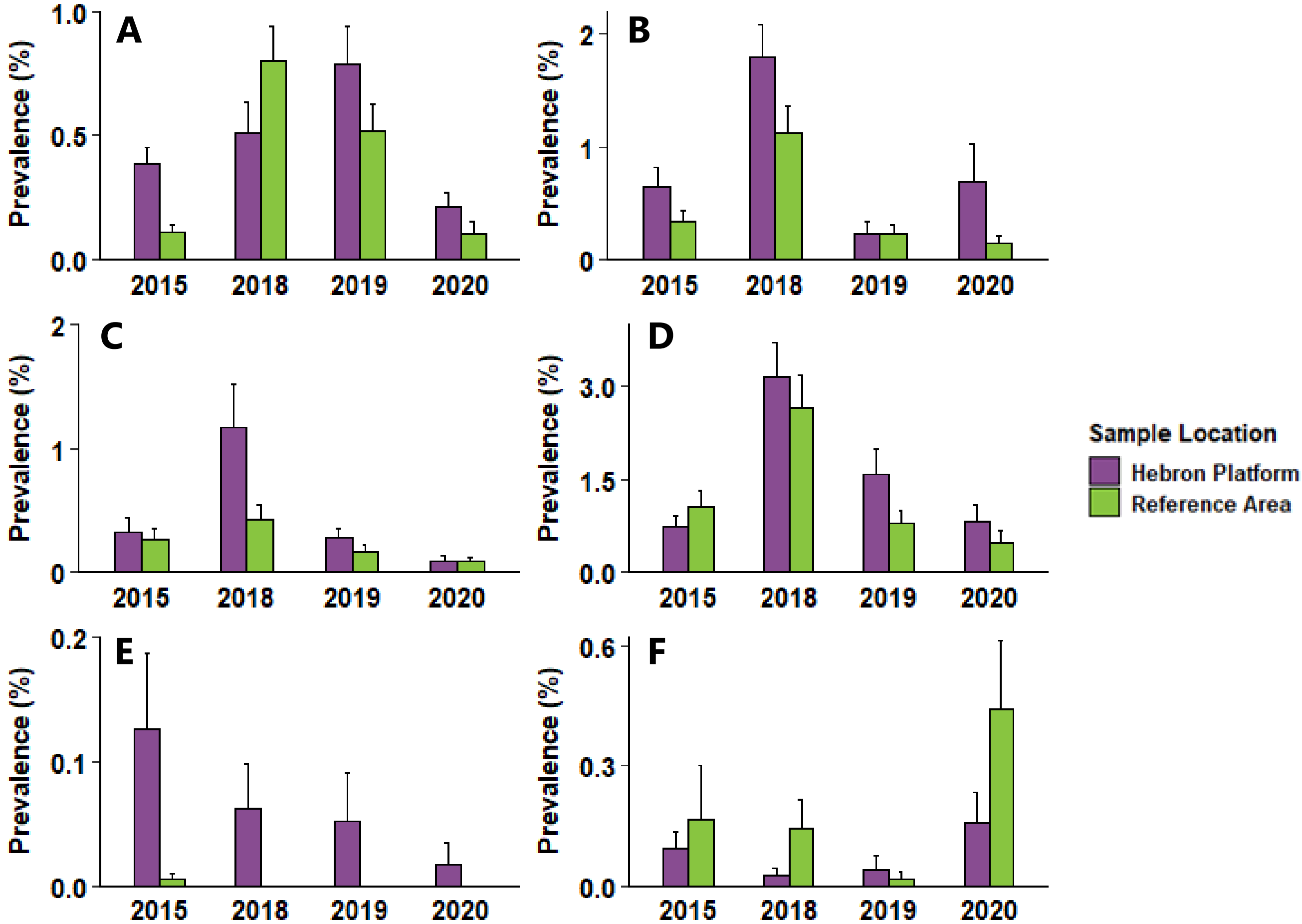


Figure 6-20 Bar graphs of the prevalence (%) of tip hyperplasia (A), basal hyperplasia (B), and distal hyperplasia (C), fusion (D), telangiectasia (E), and epithelial lifting (F) from livers of American Plaice taken from the Hebron Platform and Reference Area from 2015 to 2020. Bars are standard error.

6.3 Summary of Results

6.3.1 Summary of Chemical Profiles of American Plaice

Consistent with past EEM years, composite American Plaice tissue sampled at the Hebron Platform and Reference Area in 2020 had arsenic, mercury, and zinc above their RDLs in all samples. In 2020, significantly higher concentrations of mercury and zinc were detected at the Hebron Platform. Comparison across all EEM years found a significant difference between years for zinc, with lower values in 2018 and higher values in 2020 though generally similar to 2015 results.

For liver composites, eight metals have been consistently detected in all EEM years, with three other metals occasionally above their RDLs. In 2020, several metals significantly differed between sites, but all were higher at the Reference Area compared to the Hebron Platform. No difference between years, sites, or site-year interaction was observed for mercury. Arsenic, cadmium, iron, and selenium were significantly different between both sites and years with general decreasing trends from 2015 to 2020 and generally higher results at the Reference Area. Copper, manganese, and zinc had significant interaction terms, indicating a potential project-induced change.

Hydrocarbons in all three ranges (>C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32}) were screened in for 2020, with significantly higher values at the Reference Area for >C_{10}-C_{16} and >C_{21}-C_{32} hydrocarbons. Hydrocarbons in the >C_{16}-C_{21} range significantly differed by year and have been steadily increasing in both areas since 2015. Hydrocarbons in the >C_{21}-C_{32} range significantly differed by site and year, with 2018 having the lower concentration and 2020 the highest, with values typically elevated at the Reference Area compared to the Hebron Platform. Hydrocarbons in the >C_{10}-C_{16} range significantly differed by site, year, and the interaction term and this indicates a potential project-induced change. No PAHs were detected in any fillet or liver composite in 2020, 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 2020 (Table 6-29). As few male fish were caught in 2020, statistical comparisons were not completed due to the small sample size.

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2020 for the second maturing in present year code (Mat B-P, code 530) and spent in present year (Spent P, code 560). Code 530 was higher at the Reference Area in 2020, and code 560 was higher at the Hebron Platform. For biological characteristics, female fish significantly differed in all biological characteristics with the exception of age. Those that differed were higher at the Hebron Platform compared to the Reference Area. After accounting for covarying factors using ANCOVAs, female gutted weight and liver 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 including: male HSI differing between sites (higher at the Hebron Platform) and years (higher in 2020 compared to past years), and GSI differed between years, with higher values in 2019 compared to other EEM years. Female plaice significantly differed between sites and years for Fulton's condition index and had significant interaction terms for both HSI and GSI, indicating a potential project-induced change.

No significant differences were found between the areas for any pathology in female fish (males not statistically compared in 2020). Female American Plaice 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), but not the second modification (removal of skin, fins, and parasites).

For haematology, no differences were detected in the 2020 EEM program. For the cross-year comparison, significant differences were found between sites 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. The interaction term was significant for thrombocytes, indicating a potential project-induced change.

For MFO activity, neither male or female American Plaice significantly differed between the Hebron Platform and Reference Area in 2020. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish.

For liver histopathology, fish from the Hebron Platform and Reference Area did not differ significantly for any lesions in 2020. A MANOVA with six liver histology factors showed significant differences between sites, years, and in the interaction term. Bile duct hyperplasia significantly varied by year, with a higher incidence in 2019 compared to other monitoring years. Hepatocellular carcinoma, macrophage aggregates, and small and large hepatocellular vacuoles all had significant interactions terms.

For gill histopathology, no conditions significantly differed in 2020. However, a MANOVA for seven gill histology factors detected significant results across site, year, with a significant interaction term. Significant differences between sites was largely due to basal and distal hyperplasia, telangiectasia, and epithelial lifting (all higher at the Hebron Platform). Significant differences between years was driven by tip (lower in 2020), basal (higher in 2020), and distal hyperplasia (lower in 2020), fusion (lower in 2020), and epithelial lifting (higher in 2020). Tip and distal hyperplasia had significant interaction terms.

Table 6-29 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	2020
Maturity Stages	-	Yes	Yes	Yes	Yes
Fish length	Yes	No	Yes	No	Yes
Fish weight	No	No	Yes	No	Yes
Gutted weight (post-ANCOVA)	-	No	No	No	Yes
Liver weight (post-ANCOVA)	-	Yes	No	Yes	Yes
Gonad weight (post-ANCOVA)	-	No	No	Yes	No
Age	-	No	Yes	Yes	No
Hepatosomatic Index	No	Yes	No	Yes	Yes
Gonadosomatic Index	No	No	No	Yes	Yes
Mixed-function oxidase	Yes	Yes	Yes	Yes	No
Liver Histopathology	Yes	Yes	Yes	Yes	No
Gill Histopathology	Yes	Yes	No	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 2017a). 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 water quality chemistry.

Table 7-1. Hebron Platform Program sediment, water and biological sampling program component parameters and analysis.

Program Component	Parameters	Analyses
Sediment Quality	Chemistry	General parameters (e.g., particle size, sulphide, redox potential), metal and hydrocarbon concentrations
	Toxicity	PetroTox threshold, Amphipod bioassay
	Benthic Community Structure	Species richness, abundance, biomass
Water Quality*	Chemistry	Metal and hydrocarbon concentrations
Commercial Fish (American Plaice)	Body Burden	Metal and hydrocarbon concentrations
	Sensory Evaluation	Triangle Test, hedonic scaling
	Fish Health	General parameters (e.g., size, weight, sexual maturity, condition indices), haematology, histopathology, stress enzyme activity

Note:
*CTD profiles are used for assessment of sampling depths in the field using dissolved oxygen and pH profiles.

7.1 Sediment Component

7.1.1 Physical and Chemical Characteristics

A total of 20 analytes were screened-in for further analysis. Spatial patterns of analyte concentrations observed in the 2020 EEM were similar to those observed in previous EEM years and baseline. As in previous EEM years (and baseline), sand was the primary particle size reported followed by gravel and precent fines. Concentrations of gravel and percent fines were mainly higher in the northeast cluster. Reported percent fine mean concentration in 2020 increased from previous survey levels (EEM years and baseline). Changes in particle size concentrations or distributions could affect the benthic environment and concentrations of other analytes. Some analytes (particularly barium and hydrocarbons) adhere to the more ionically charged finer particle sizes and percent fines was positively correlated to barium, the extractable metals, TOC, and redox potential. Within 1,000 m of the Hebron Platform, station 8-250 had a relatively higher concentration of percent fines (4.7 percent). The drillmud and cuttings discharge point (cuttings chute) is located to the northwest of the Platform directly across from this station.

Station 8-250 had the highest concentrations of several analytes including barium, lube and fuel range hydrocarbons, and the extractable metals. The barium concentration at this station was the highest observed compared to previous EEMs surveys (2014: 99 mg/kg, 2018: 1100 mg/kg, 2019: 990 mg/kg, 2020: 12000 mg/kg) however station 8-250 was a relative outlier. Barium concentrations at other stations ranged between 46 mg/kg (B-250) and 300 mg/kg (4-250). The highest concentrations of barium (230 mg/kg to 12000 mg/kg) were within 750 m from the Platform (although the distance of statistical significance is 500 m; see section 4.3.1). Concentrations of barium were negatively correlated with distance from the Hebron Platform with the highest concentration occurring within 500m which explained the greatest variance in the model which is within the predictions made in the CSR. In addition to precent fines, barium concentrations were also positively correlated to the fuel and lube range hydrocarbons, and the extractable metals.

Concentrations of fuel and lube range hydrocarbons were below the 75 percent of stations above RDL criteria and were instead screened-in as they are an expected release from the Platform. Elevated concentrations of these hydrocarbons occurred at stations within 750 m of the Platform. The highest concentrations of both lube and fuel range hydrocarbons occurred at stations 8-250 (432 mg/kg and 14 mg/kg, respectively). This was similarly observed in previous EEM survey years (2018 and 2019). Hydrocarbon concentration ranges in 2020 increased from those observed in previous EEM survey years and baseline. Concentrations of C_{10}-C_{21} hydrocarbons ranged between 0.25 and 66.9 mg/kg in 2019, 0.25 and 17.30 mg/kg in 2018, and 0.125 and 1.3 mg/kg at baseline. When station 8-250 is considered separately, C_{10}-C_{21} hydrocarbon concentrations for the 2020 survey ranged between 0.25 and 43.1 mg/kg which is similar to the 2019 EEM survey. Similarly, concentrations of C_{21}-C_{32} hydrocarbons in 2019 were between 0.25 and 3 mg/kg, 0.25 and 1.7 mg/kg in 2018, and 0.125 and 0.87 mg/kg at baseline. Treating station 8-250 as an outlier and considering it separately, the range for C_{21}-C_{32} hydrocarbon concentrations is 0.25 to 1.8 mg/kg which is comparable to previous EEM surveys. However, the number of stations reporting hydrocarbon concentrations below RDL increased in 2020 compared to the 2019 EEM survey. Changes in hydrocarbon means compared to previous EEM surveys were mainly influenced by the outlier station 8-250. From threshold regression models, it is evident that most variance for both lube and fuel range hydrocarbons occurs within 500m. These results are within the predictions made in the CSR.

In addition to station 8-250, extractable metal concentrations were also relatively higher at stations more than 3,000 m from the Hebron Platform and in the northeast cluster. In previous EEM years, concentrations of extractable metals were also higher at station 8-250 and within the northeast cluster.

Moisture, redox potential, sulphide, sulphur, and ammonia were also screened-in for further analysis. These analytes could affect the benthic environment and be influenced by discharges from the platform. The concentration range for moisture is slightly narrower in 2020 than those reported in previous years (2020: 15 to 19 percent, 2019: 13 to 20 percent, 2018: 14 to 19 percent, 2014: 11 to 18 percent). Precent moisture was not correlated to distance from either the Hebron Platform or the Terra Nova area. It was only positively correlated to lube range hydrocarbons. No negative redox potential values were recorded in 2020 (58 to 297 mV). Negative redox readings could indicate a reducing environment or anoxic conditions within the sediment. The first instance of a negative redox potential value was reported in 2019; however, the negative readings did not appear to be a project-induced change. Redox potential values were similarly not correlated to distance from either the Platform or the Terra Nova area. The highest concentrations of sulphide occurred within 750 m from the platform. Concentrations of sulphide decreased with increasing distance along radial 8 (8-250: 15.5 µg/g, 8-

750: 15.3 µg/g, 8-1250: 5.8 µg/g). The highest concentration of sulphur was reported at station 8-250. This is a similar trend noted in previous EEM years. Ammonia concentrations were highest in the northeast cluster which is consistent with previous EEM survey years (ammonia levels were not reported at baseline).

Multivariate statistical analysis for multi-year comparisons showed a difference between the factor Year relative to the covariate factor Field (distance bin from the Hebron Platform). There was a statistically significant difference between years and fields ($p=0.004$ and $p=0.001$ respectively). The interaction term Field x Year was not statistically significant. There was a statistically significant difference between stations in the Far-field and those in the Near-and Mid-fields ($p=0.001$ and $p=0.002$ respectively). Near-field stations and specifically station 8-250 had higher analyte concentrations in both 2018, 2019, and 2020 EEM surveys when compared to baseline levels. This is an expected observation and within the predictions made in the CSR. Predictions in the CSR were that potential project-induced changes may occur <2 km from the platform.

7.1.2 Toxicity

Four stations were screened-in for toxicity testing, all were deemed non-toxic from amphipod bioassay. To date all sediment samples from the Hebron EEM surveys (including baseline) have been deemed non-toxic (EMCP 2016a, 2019, 2020). All but one sediment sample collected in 2020 were below PetroTox levels with concentrations ranging between 0.25 and 432.0 mg/kg. For all EEM years including baseline, all sediment samples more than 500 m from the Hebron Platform were below the PetroTox threshold thus, only stations ≤500 m underwent toxicity testing. In 2020 (EEM Year Three), amphipod percent survivability ranged between 79 to 99 percent which is comparable to previous survey results. In previous EEM years, percent survivability ranged between 97 to 100 percent. Ammonia and sulphur concentrations as well as redox potential levels were also similar to previous EEM years and did not impact the toxicity of the samples. Similar to 2019, a sulphur odor was detected in a station 8-250 sample. It was not detected in any other year including baseline.

7.1.3 Benthic Community Structure

Analysis of benthic community structure is the third component of the sediment triad. The six community monitoring parameters have been assessed every survey year including baseline (excluding total biomass). In 2020, of the six monitoring parameters, the stations with the lowest values were mainly found in the Near-field while those with the highest were found in the Far-field. This trend was also observed in previous EEM years. However, in the baseline survey while the highest values were mainly in the Far-field, the lowest values for the number of taxa, abundance, and species richness were distributed throughout all distances from the Platform. The means for three of the parameters have slightly increased in 2020 from baseline levels; number of taxa, evenness and Shannon-Weiner diversity index. The diversity index values indicate how diverse and equally distributed taxa are within a benthic community. Taxa which are present in low-diversity, unequally distributed communities have adapted to the conditions which cause the reduced diversity. Here we discuss the taxa reported from the 2020 EEM samples and subsequent survey years.

Polychaetes are a major component of marine benthic communities (Dean 2008) and comprise more than 50 percent of the Grand Banks macrobenthos community, particularly the families Syllidae and Spionidae (Pocklington and Hutcheson 1983). Polychaetes are also used as indicator taxa for the presence or absence 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). In 2020, the class Polychaeta accounted for 42 percent of all taxa observed followed by Clitellata at 24 percent, and the arthropods Amphipoda and Maxillopoda at 8 percent each. Polychaetes were also the top contributors to overall abundance in previous EEM surveys and baseline. Within Polychaeta, the Spionid *Prionospio steenstrupi* was the most abundant species observed (n=533) particularly in the northeast cluster. Capitellidae, the most commonly used indicator taxa of marine pollution world-wide, was not relatively abundant in 2020 or previous survey years (2020: 0.88 percent contribution, 2019: 0.38 percent, 2018: 0.75 percent, 2014: 0.43 percent). E*xogone hebes*, *Harmothoe imbricata*, and *Polycirrus eximius* were all observed at least once within the survey area in the year three survey. *E. hebes* (synonymous with *Parexogone hebes*) was the most widely distributed and abundant of the three species being observed at least once at all stations. The highest abundances were also observed in the northeast cluster. *H. imbricata* (in the Polynoidae family) was observed at seven stations in low abundances (n<11). *P. eximius* (in the Terebellidae family) was only observed at five stations, all within the northeast cluster.

In 2020, Near-field stations had some of the lowest diversity index values, and from SIMPER analysis these stations were 46.59 percent similar. The top four species (all annelids) contributed over 50 percent to the group similarity. The top four species were Naididae (indeterminate) (23.15 percent), *Tharyx* sp. (15.55 percent), Clitellata (indeterminate) (8.10 percent), and *Exogone hebes* (7.07 percent). These species were also top contributors to Near-field similarity in previous EEM years and baseline. The annelid class Citellata (includes the family Naididae) are recognized as an opportunist re-colonizers and high abundances of these taxa may indicate altered sediments. This class of annelids was specifically reported in the baseline survey however, the subclass Oligochaeta was reported and widely distributed (in relatively high abundances) throughout the survey area. This is similarly observed in subsequent survey years. The highest relative abundances were reported at station 4-750 (50 percent). However, these taxa were also observed at stations in the Mid- and Far-fields. 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). These taxa could not be taken to the species level, which is important for further analysis, as pollution tolerances vary per species in this class. *Tharyx* sp. and *E. hebes* are polychaetes associated with transitional zones (i.e., areas between polluted and unpolluted) (Word et al. 1977; Mair et al. 1987; Dean 2008). The stations with the highest abundance of these species (in the Near-field) were FL-500 and 8-750. However, these species were present throughout the survey area in similar abundances and in previous survey years.

Stations 1,000 m to 2,000 m from the platform (Mid-field) had an average similarity of 58.01 percent. Six taxa contributed to 52.94 percent of the similarity. The top two contributors were also Naididae (indeterminate) (16.30 percent) and *Tharyx* sp. (8.85 percent). The other four species included the arthropod *Leptognathia caeca* (8.03 percent), and the annelids *Scoloplos armiger* (7.26 percent), *Aricidea catherinae* (6.42 percent), and *Prionospio steenstrupi* (6.08 percent). As stated before, Naididae taxa have tolerance levels that are species specific. *Tharyx* sp. is associated with transitional zones. The station with the highest abundance of *Tharyx* sp. reported in the survey occurred at 8-1250. *P. steenstrupi* are characteristic of secondary colonizers (Pocklington 1989) and some *Prionospio* sp. are reported after the decline of early re-colonizers such as *Capitella* sp. and *Polydora* sp. Within the Mid-field, *Prionospio* sp. were reported at every station with highest occurring at 6-1500. Tolerances for *A. catherinae* are largely unknown. Stations more than 2, 000 m from the platform (Far-field) had an average similarity of 39.71 percent. Nine species contributed to 52.02 percent of the overall similarity. The top seven contributing species to Far-field station similarity were also present in the Near- and Mid-field main contributing species. The other two species were the arthropods *Priscillina armata* (3.55 percent), and *Eudorellopsis deformis* (2.82 percent). The environmental tolerances of these species are largely unknown.

Species which are present in low-diversity communities must endure the conditions which may cause the reduction in diversity. The station with the lowest diversity value was Station 8-250 (H'= 1.42). Station 8-250 had some of the highest reported concentrations of several analytes and is located closest to the Platform discharge point for drill mud and cuttings. The benthic community was mainly comprised of 17 taxa with the highest abundances from the families Balanidae (N=83), Phyllodocidae (N=12), and Naididae (N=8). The barnacle *Balanus crenatus* was the most abundant species (N=83) observed at this station. This species was not recorded at station 8-250 in the baseline survey but was recorded at relatively high abundances in the northeast cluster. The tolerance of this species is largely unknown. The polychaete family Phyllodocidae is considered tolerant to enrichment effects (Paine et al. 2014). This family has been reported at Near-field stations since baseline and abundance has increased in subsequent surveys (baseline: n=14, 2018: n=10, 2019: n=29, 2020: n= 40). In 2020, stations located 250 m from the Platform had higher reported abundances with station 8-250 having the most (n=12). This is an increase from previous survey years but not unexpected. In the Terra Nova field, abundances of Phyllodocidae were higher near active drill centers (Paine et al. 2014). The abundance of Capitellidae within 1,000 m from the Platform have increased in subsequent survey years, appearing once at FL-500 (n=1) in 2014, at 5 stations in 2019 (n=14), and at four stations in 2020 (n=15) (this family was not reported in the Near-field in 2018). In 2018, Capitellidae were mainly reported at stations more than 3,000 m from the Platform. Capitellidae and specifically the pollution indicator species *Capitella capitata* was reported only once at station 8-250 in 2020 which is a decrease from 2019 reported abundances (n=6). This species was not recorded at this station in either baseline or the 2018 EEM.

Multivariate analysis demonstrated community structure differed between distance bins (Table 4.11), and the influence of screened-in analytes were examined separately by distance bin in addition to the whole survey field analysis. Family assemblages were compared to screened-in analytes at each station. In 2020, concentrations of gravel and C_{21}-C_{32} hydrocarbons explained 52 percent of the observed variation in the Near-field, (Table 4.12). C_{21}-C_{32} hydrocarbons only explained 37.3 percent of the variability in the community structure. Station 8-250 was closely associated with concentrations of C_{21}-C_{32} hydrocarbons compared to other Near-field stations (Figure 4-30, A). In the Mid-field, four variables explained 90 percent of the variation, C_{21}-C_{32} hydrocarbons, TOC, manganese, and strontium. C_{21}-C_{32} hydrocarbon concentrations explained 35.1 percent of community structure variation. In the Far-field, three variables (gravel, chromium, and aluminum) explained 46.4 percent of the community variation. Gravel concentrations explained 30.4 percent of the variation observed in the Far-field. Stations within the northeast cluster were closely associated with concentrations of gravel while, stations within 6,000 m of the platform were more closely associated with chromium concentrations (Figure 4-30, C). When all survey stations are examined, three variables explained 37 percent of the variation. Gravel contributed 25 percent of the explained variance followed by C_{10}-C_{21} hydrocarbons (7 percent), and uranium (<4 percent). Station 8-250 was closely associated with the concentration of C_{10}-C_{21} hydrocarbons, while stations in the northeast cluster were associated with gravel concentrations (Figure 4-30, D). Particle size is a key factor in explaining benthic infauna community variation for instance some taxa (e.g., barnacles) only inhabit hard substrates and would be more abundant in areas with higher concentrations of large particle sizes (e.g., gravel).

7.2 Water Quality Component

The water sampling/monitoring program at Hebron is designed to assess the CSR predictions with respect to produced water and other liquid discharges discussed in Section 5.0. Water samples were tested for metals and hydrocarbons. 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. Metal levels generally showed a trend of increasing concentrations with sampling depth. Boron was the only analyte with levels that were significantly different among Sites, with higher levels at the Hebron Platform relative to the Reference Site. However, Site differences are not likely to be a project-induced change based on relative boron levels in produced water prior to discharge. 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). As hydrocarbons were not detected in any water samples these results indicate that the produced water dilutes rapidly following discharge.

7.1 Commercial Fish Program

American Plaice is a species of commercial importance in the Newfoundland offshore that are monitored in all EEM programs in the Newfoundland Offshore Area. This chapter seeks to describe data collected on body burden of metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAH), as well as reporting catch numbers and species for trawls, taint / taste testing, and several components of fish health. Several statistically significant differences were found in the 2020 data, and in comparisons to past EEM years. The 2015 fish characterization had several methodological differences compared to the 2018-2020 EEM programs, and so greater weight in this discussion will be given to differences from the past three years (2018-2020).

7.2.1 Catch Data

Sixteen different taxa were caught as part of the 2020 Hebron EEM program (Table 6-3, Figure 6-3, Figure 6-4). The most caught fish species were American Plaice followed by Yellowtail Flounder, and the most common invertebrate was Snow Crab (Figure 6-3). These results are similar to those in previous years, but the trawl type and cod end mesh size used in 2020 led to fewer small bodied species (e.g., Capelin, Sand Lance) being caught, and greater numbers of American Plaice and similar sized fish (EMCP 2016b, EMCP in prep.). Due to the changed survey method from previous years, CPUE was not compared over time for 2020 though previous values are reported (Table 6-6). In general, CPUE was higher for all species including American Plaice at the Hebron Platform in all years except the 2015 fish characterization. This may be indicative 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 attracting 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 using similar methodologies at these sites may yield better insights.

7.2.2 Body Burden

For American Plaice fillets, three metals were detected above their RDLs in the 2020 EEM program: arsenic, mercury, and zinc (Table 6-7). Values for mercury and zinc were significantly higher at the Hebron Platform compared to the Reference Area in 2020 (Table 6-7). Cross-year comparison showed no significant difference between sites or years for arsenic or mercury, but zinc had a significant difference across years (Table 6-9, Figure 6-6). Zinc in fillets was generally lower in 2018 and higher in 2020 but this was likely not a project-induced change. These analytes are also consistent with other platforms, including Terra Nova (DeBlois et al. 2014c) and Hibernia (HMDC 2017, 2019). No hydrocarbons or PAHs were above their RDLs in fillets in 2020. This is consistent with past EEM results, with the same three metals detected. These values appear steady across years and sites 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 2020 program (Table 6-8). Within the 2020 program, all screened-in metals but mercury and iron significantly differed between the Hebron Platform and Reference Area, and all were higher at the Reference Area which suggests higher concentrations are not project-induced. No difference between years, sites, or site-year interaction was observed for mercury (Table 6-10). For metals in liver with significant results across either site or year, many were not indicative of a project-induced change (i.e., higher at the reference area or in past EEM years), and these included arsenic, cadmium, iron, and selenium (see Section 6.2.2.1.2). Copper, manganese and zinc had significant interactions terms, indicating potential project-induced changes (i.e., differences between the Hebron Platform and Reference Area across EEM years).

These results for American Plaice livers closely match results from the 2019 EEM program. Copper has been steadily decreasing since the 2015 fish characterization, and with the exception of that study, copper has been higher at the Reference Area compared to the Hebron Platform (Figure 6-7). This difference between the 2015 study and subsequent EEM years is likely the cause of the significant interaction term and is not likely to be a project-induced change. Manganese values from 2018 to 2020 were elevated compared to the 2015 fish characterization. Manganese had consistently been elevated at the Hebron Platform compared to the Reference Area, even in the 2015 fish characterization study, though the opposite trend was noted in 2020. This reversal is likely a large cause for the continued significant interaction term for manganese in liver composites. Sediment data collected in 2020 shows high levels of manganese found at station 8-250 (near field), as well as some distant stations (Figure 4-10). Manganese has also been consistently detected in the livers at other platforms including Hibernia but varies significantly between years with no particular trend (HMDC 2017).

Similar to manganese, zinc values in livers have varied significantly over EEM years. Unlike manganese, zinc values were lower in 2020 compared to 2015-2019, and have been elevated at the Reference Area compared to the Hebron Platform for all years except the 2015 fish characterization suggesting higher zinc levels are naturally occurring. Zinc was not screened in for the sediment program in 2020 as it is not typically above its RDL in sediment. Sample size for liver composites was changed in 2020 for the third time in the four years of the Hebron monitoring program, though the larger sample size being used going forward should allow for better statistical power and confidence in the results. Comparing the 2020 sample size to smaller sample sizes may be contributing to the detected significance, as there is less variance for the test to act on in past years, in addition to making the test uneven. Longer term monitoring for manganese and zinc is needed to determine any persistent trend.

Hydrocarbons in all three ranges (>C_{10}-C_{16}, >C_{16}-C_{21}, and >C_{21}-C_{32}) were screened in for 2020, with significantly higher values at the Reference Area for >C_{10}-C_{16} and >C_{21}-C_{32} hydrocarbons (Table 6-8). Comparing across years, hydrocarbons in the >C_{16}-C_{21} range significantly differed by year and have been steadily increasing in both areas since 2015 (Figure 6-8). Hydrocarbons in the >C_{21}-C_{32} range significantly differed by site and year, with 2018 having the lowest concentration and higher values in 2020, with values typically elevated at the Reference Area compared to the Hebron Platform. Hydrocarbons in the $>C_{10}$-C_{16} range significantly differed by site, year, and the interaction term and this indicates a potential project-induced change although that change would be a reduction in hydrocarbon concentrations around the platform. No PAHs were above RDL in 2020, though two (acenaphthylene and fluorene) were screened in for 2018.

An increase was observed in the sediment data for hydrocarbons in both the fuel and lube range within 750 m of the platform, with one station in particular directly northeast of the Hebron Platform (8-250) showing large increases (Figures 4-16, Figure 4-17). This sediment station is the closest to the drill mud and cuttings discharge point. Fuel range hydrocarbons ($>C_{10}$-C_{21}) occurring at this site are likely associate with the drilling base fluid. In 2020, both ranges of hydrocarbons were significantly corelated with distance from the Hebron Platform. Values in 2020 for both hydrocarbons are higher than previous EEMs, though only 45-50 percent of samples were above their RDL. For liver composites, these results are similar to those in 2018 and 2019, with a general upward trend in all hydrocarbon ranges, though values are typically similar between the two sites or higher at the Reference Area which suggests that it is not a project-induced change. Similar to the discussion above for manganese and zinc, only five composite samples were taken in 2018-2019 and ten in 2020, 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. 2014c). Longer term monitoring of these variables is needed to capture potential natural variation before any further recommendations can be made.

7.2.3 Sensory Evaluation

For the 2020 EEM program, no significant difference was detected between the Hebron Platform and the Reference Area in either the triangle test or the hedonic scaling. These results are consistent with findings in 2015 and 2018 (no taste panels were completed for the 2019 EEM).

7.2.4 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 hyrocarbons on fish. Factors analyzed include general biological characteristics, gross pathology of organs, white blood cells counts, mixed-function oxygenase activity, 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 2020. Male and female fish were assigned sexual maturity codes based on their condition using the index provided in Templeman et al. (1978). Due to the small sample size of male fish in 2020, no statistical comparisons were made. Female fish differed in the maturing in current year (B) and spent in current year maturity codes, with higher incidences at the Reference Area for maturing in current year (B) and higher incidences at the Hebron Platform for spent in current year (Table 6-15). Maturing in current year codes (A, B, and C) are different progress stages towards full maturity in the present year (Templeman et al. 1978). Delayed maturity is expected when fish are exposed to contamination such as spilled oil (Sol et al. 2000), but in 2020 it appeared that fish in the Reference Area were still maturing while fish at the Hebron Platform had already spawned. Even within a population, spawn timing is not always consistent across space and time (Zheng et al. 2020), and so observed differences in sexual maturity is likely not evidence of project-induced change.

Certain biological characteristics were found to differ between sites in the 2020 EEM program. While male fish were not compared in 2020, female plaice significantly differed for all variables except age, and all were higher at the Hebron Platform compared to the Reference Area (Table 6-16)). Adjustment of p-values for co-variates had gutted and liver weight remain significant for female fish (Table 6-17). 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 additional food sources, though no significant difference in fish age between sites was noted. Many studies have shown both current and decommissioned oil platforms can 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 had 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 energy reserves in fish near the platform (Jan and Ahmed 2016), while variations in gonad weight and GSI 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 differences. For male fish, significant differences included male HSI differing between sites (higher at the Hebron Platform) and years (higher in 2020 compared to past years), and GSI differed between years, with higher values in 2019 compared to other EEM years (Table 6-18, Figure 6-9). However, due to the small sample size in 2020, there is little statistical confidence in these values. Female plaice significantly differed between sites and years for FCI and had significant interaction terms for both HSI and GSI, indicating a potential project-induced change (Table 6-18, Figure 6-10). Similar results were found for the 2018 and 2019 EEM program, with significantly higher HSI values for male fish at the Hebron Platform and GSI varying across years. Female plaice in 2019 also had significant interaction terms for HSI and GSI. EEM results from Hibernia occasionally find significant differences in biological characteristics, but they were not significant in the most recent published report (HMDC 2017). The Hibernia EEM also had similar difficulties collecting enough male American Plaice to analyse and so no results were reported. Longer term monitoring for these variables is needed to see if these trends continue over time or simply represent natural variation.

No significant results were found in 2020 for gross pathology, though differences did exist for the HAI values (Table 6-19). While no comparisons were completed for male American Plaice, female fish had significantly higher HAI and the first HAI modification values at the Hebron Platform compared to the Reference Area, but the second HAI modification that excludes parasites was not significantly different (Table 6-19). Similar results were found in 2019 for HAI values, though parasite loading differed in 2019 among sites which was not the case in 2020. The three HAI indices were compared across years (2018-2020, no gross pathology was completed in 2015), as they incorporated all gross pathologies with scores given for severity of various pathologies (Goede and Barton 1990, Adams et al. 1993). Male fish significantly differed between years for the HAI and first modification with lower values in 2020, though no significant difference was found in 2019 and the small sample size in 2020 may be driving this effect. Female fish had significantly higher values for all three HAIs at the Hebron Platform compared to the Reference Area (Table 6-20). Mathieu et al. (2011) observed very few, if any, gross pathologies in American Plaice taken as part of the Terra Nova EEM program. Hibernia has reported similar pathologies, and incidence rates, to those in this EEM, with parasites typically the most common recorded 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 can also cause stress responses within infected fish and therefore lead to false positives relative to project changes (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 2020 no age difference was noted between sites. As discussed above, the Hebron Platform may be acting as an artificial reef and attracting greater densities of American Plaice than the Reference Area, and this can lead to increased parasite transmission and/or crowding and subsequent decreased immune capacity (De Roij and MacColl 2012, Michel et al. 2016). 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 2020 EEM for neutrophils, lymphocytes, or thrombocytes (Table 6-21). Cross-year comparisons, however, founds significant differences between sites for all three cell types (Table 6-22), with the Hebron Platform having a greater percentage of neutrophils and thrombocytes, and the Reference Area having a higher percentage of lymphocytes (Figure 6-15). The interaction term was significant for thrombocytes, indicating a potential project-induced change. The majority of these significant results are likely driven by the 2015 data, as it differs greatly from 2018-2020 data for all three cell types, while 2018 to 2020 data appears 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 2020, neutrophils and thrombocytes were higher. No difference was detected between sites from the 2018 to 2020 EEMs, and 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 ethoxyresorufin-O-deethylase (EROD), is used to measure industrial contamination as it acts to detoxify the liver (Hodson et al. 1991, Westernhagen et al. 1999, Van Der Oost et al. 2003). Specific contaminants stimulate the release of MFOs designed to increase the solubility, and therefore excretability, of a given substance (Hodson et al. 1991). In the 2020 EEM, neither male or female plaice had significantly different EROD values between the Hebron Platform and Reference Area (Table 6-23). However, statistical power for assessing differences among male American Plaice was low with small sample sizes. Cross-year comparisons showed a significant difference between years, and a significant interaction term, for both sexes (Table 6-24). Both sexes had the highest MFO value in 2019 compared to any other EEM year, with values higher at the Hebron Platform in some years and at the Reference Area in other years (Figure 6-16). Both Terra Nova and Hibernia have found differences in some years between platform and reference sites, but there was no clear pattern long-term trend (Mathieu et al. 2011, HMDC 2017). EROD activity has been shown to be correlated with tissue concentration of PAHs (e.g., phenanthrene, fluoranthene, pyrene) in other flatfishes (Westernhagen et al. 1999). As PAHs were not detected in American Plaice fillet or liver tissue from either sampling site, the EROD values and variation in MFO activity at both the Hebron Platform and Reference Area may point to natural fluctuations with no consistent trends across monitoring years to date.

No significant differences among sites in 2020 were found among the 19 different liver histopathology lesions assessed (Table 6-25). A MANOVA comparing across sites and years found significant differences across sites and years, with a significant interaction term (Table 6-26). Each term in the MANOVA was subjected individually to a two-way ANOVA (Figure 6-19). Bile duct hyperplasia and medium hepatocellular vacuoles had significantly higher prevalence in 2019 and 2020, respectively, compared to other monitoring years. 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-induced change (Table 6-26, Figure 6-19). Hepatocellular vacuoles are 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 there was no consistent increasing trend for lesion prevalence at the Hebron Platform. The same laboratory completes liver histopathology for the Hibernia Platform EEM, and very similar pathologies and incidence rates were observed in the 2016 and 2018 programs (HMDC 2019b, unpublished data), though these rates were 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 2020 EEM, with no significant differences between sites (Table 6-27). A seven factor MANOVA was used to compare the sites between years, and a significant difference was found between sites, years, as well as the interaction term indicating a potential project-induced change (Table 6-28). Two-way ANOVAs for each factor were used to determine which factors contribute to the differences. Significant differences between sites were due to basal and distal hyperplasia, telangiectasia, and epithelial lifting (all higher at the Hebron Platform). Significant differences between years were due to tip and distal hyperplasia, and fusion (all lower in 2020), as well as basal hyperplasia and epithelial lifting (both higher in 2020). Tip and distal hyperplasia had significant interaction terms. In fish, the gills are a major uptake site for contaminants present in water and gill histology can be an early warning before other organs show symptoms (Stentiford et al. 2003). While hyperplasia can be present due to metal contamination or hydrocarbons, it can also be present due to gill parasites and other stressors (Mallatt 1985). Fish at the Hebron Platform and Reference Area showed 98.0 percent and 98.7 percent normal gill histologies, respectively (Table 6-27). Though some histologies were higher in 2020 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 6-20). A longer time series is needed to verify the direction of these changes.

Histopathology results for the 2020 Hebron EEM program for both liver and gill are similar to findings from the Hibernia and Hibernia South Extension EEM results in 2016 and 2018 (HMDC 2019b, 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) which historically has had higher rates of discharges of synthetic-based cuttings (both Hibernia and Hebron reinject a majority of their synthetic-based cuttings). Throughout the course of the Hibernia EEM program, large differences in reported histologies have been detected with different observers (Wolf et al. 2015, HMDC 2019b). Hebron and Hibernia EEM programs have both used the same laboratory for gill and liver histopathology since 2015 and therefore likely have more comparable results.

7.3 EEM Interpretation

Monitoring hypotheses are established to assess predictions made in the original environmental assessment (CSR) for the project (EMCP 2011). The monitoring hypothesis for sediment quality, water quality, and commercial fish are provided below and assessed based on the results of this report.

7.3.1 Sediment Quality Hypothesis

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 project-induced changes predicted in the CSR included 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 changes occurred within 1,000 m of the Hebron Platform which was predicted in the CSR. Concentrations of barium, C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons, and sulphur were negatively correlated with distance from the Hebron Platform. These results found a decrease in analyte concentration with increasing distance from the Hebron Platform which is what would be predicted in a project-induced change. No statistical differences were noted for PetroTox or amphipod survival. Differences were noted between years for benthic community with some transitional zone (i.e., the border between altered and unaltered areas) species increasing in abundance in Near-field stations. These changes occurred within 2,000 m of the platform and aligned with the predictions in the CSR. Therefore, the sediment quality null hypothesis is not rejected for the 2020 EEM program.

7.3.1 Water Quality Hypotheses

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. Among Hebron Platform and Reference Site water samples, there was no interaction between Site and Water Depth indicating no project-induced changes. In addition, there were no clear patterns for differences in analyte levels for both within year and across year analyses among sampling sites. This indicates that the potential effects on the environment may be highly localized and variable. Therefore, the water quality null hypothesis is not rejected for the 2020 EEM program.

7.3.2 Commercial Fish Hypothesis

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.*

The CSR predicted no significant effects on commercial fish. This was assessed by catchability. Other aspects related to commercial fish, but not specifically identified in the CSR are taint of flesh, contaminant loads and prevalence of disease. The catchability (assessed by catch per unit effort) was higher at the platform for the American Plaice as compared to the reference area. As with previous years, there were no significant differences between the Hebron Platform and Reference Area for the 2020 EEM taste panel results. Therefore, the first commercial fish null hypothesis is not rejected for the 2020 EEM program.

For contaminant loading, no significant differences were seen for most of the chemical profiles of American Plaice between stations, though some variation existed between years; such as zinc in fillets being higher in 2020 compared to 2018, significant interaction terms for manganese and zinc in livers, and significant interaction term for hydrocarbons in the $>C_{10}$-C_{16} range. These findings are not consistent across EEM years and may be a product of changing sample sizes between years or natural variation. For prevalence of disease and fish health, several components had statistically significant differences in 2020 including biological characteristics of female fish, the interaction term for thrombocytes, MFO interaction terms for both male and female fish, interaction terms for several liver histopathology conditions, and tip and distal hyperplasia interaction terms. These conditions are not consistent across EEM years and may be associated with naturally occurring factors. A longer time series is required to further assess the natural variation and potential project-induced changes. Therefore, the second commercial fish null hypothesis is not rejected for the 2020 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 some of the high density of stations sampled in the northeast cluster in subsequent EEM years. Specifically, stations A-500, A-1000, A-1500, B-250, B-750, B-1250, B-3000, C-500, D-250, D-750 have been identified for removal based a statistical review (Power Analysis) of the 2020 sediment chemistry results. The results of the Power Analysis indicate that the removal of the identified stations would not significantly affect the outcome of the standard statistical analyses carried out upon sediment samples as part of the EEM program. If, in future, there are plans to develop this area all sampling stations within the Northeast Cluster will be re-instated as part of the EEM Program.

8.2 Water Quality Component

As this was the only the second year of water column sampling, the water quality component will be further reviewed to ensure that the sampling design and analysis is robust enough to capture any potential project-induced changes to the receiving environment.

8.3 Biogenic and Petrogenic Hydrocarbons

Hydrocarbons detected in fish may be naturally occurring or may be associated with Hebron Platform discharges. It is recommended to determined through more detailed laboratory analysis of the hydrocarbons detected in fish at both the Reference Area and the Platform Area are biogenic or petrogenic in nature.

9.0 CLOSURE

This report on the Hebron 2020 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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