Hebron Platform Environmental Effects Monitoring Program (2018) Volume I – Interpretation

Hebron 2018 EEM Report

Volume 1

Prepared for:

ExxonMobil Canada Properties
20 Hebron Way
St. John's, NL
Canada A1A 5G9

Prepared by:

Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited
133 Crosbie Road
St. John's, NL
Canada A1B 4A5

Copyright and non-disclosure notice

Third-party disclaimer

Document no.	Review No.	Drafted/Revised By:	Reviewed By:	Date (YY-MM-DD)
TA1878308-4200-01	1.0	K. Millar/L. Miles	J.So/J. McCarthy	19-06-18
TA1878308-4200-02	2.0	M. Teasdale	M. Quilty	19-11-13
TA1878308-4200-03	Final	K. Millar/L. Miles	M. Teasdale	21-03-23

EXECUTIVE SUMMARY

Hebron is committed to conducting an environmental effects monitoring (EEM) program designed to detect changes in the surrounding environment that may be attributed to the project. The EEM program consists of sediment, water (not implemented in 2018 with no continuous produced water discharge), and commercial fish sampling components to assess the chemistry and toxicity of sediment quality, and the health, size, taste, and body burden chemistry of fish. The 2018 program represents the first year of EEM sampling for the Hebron Platform, with sediment and fish characterization studies conducted in 2014 and 2015 respectively.

SEDIMENT COMPONENT

Sediment was collected using a boxcorer at predetermined sites as set out in the EEM design plan. As the Hebron Platform is a single point source for discharges, sediment stations are arranged in radii at various distances between 250 and >6,000 m from the platform. The primary stations are set in four main lines radiating out from the platform, and a cluster of secondary stations to the northeast (which are similarly arranged with four radiating lines). Sampled sediments are analyzed for particle size, total metals (including barium), hydrocarbons (total petroleum and polycyclic aromatic), total inorganic (TIC) and organic (TOC) carbon, sulphide, and ammonia (as nitrogen). Sediment collected is also used to assess potential toxicity on amphipod survival, and the structure of the benthic community at each station is assessed. Data analysis and comparisons were made between distance bins including Near-field (<1,000 m), Mid-field (1,000-2,000 m), Far-field (>2,000 m) and Total.

Physical and Chemical Characteristics

Analysis of physical and chemical analytes showed some differences between 2018 and 2014 samples. Clay was the only sediment fraction to increase in all distance bins between 2018 and 2014. These increases occurred at sites to the west and south of the platform. There was no change in sand or gravel percentage near the platform. Overall silt and clay distribution patterns saw higher concentrations to the south and southwest of the platform and to the northeast at distances >6,000 m.

There was a slight increase in barium concentration from samples taken in the Near-field between 2014 and 2018. Lead concentrations also increased between sample years. There was no difference in concentration between years for iron or manganese. Hydrocarbons $>C_{10}$-C_{21} and $>C_{21}$-C_{32} concentrations were similar between 2014 and 2018, except for site 8-250. Site 8-250 had increases of percent clay, percent silt, concentrations of barium, iron, lead, $>C_{10}$-C_{21}, $>C_{21}$-C_{32}, total sulphur, and total organic carbon. These results are expected as the sediment sampling station is in close proximity to the point of drill cuttings discharge from the Hebron Platform and agree with the effects predicted in the CSR.

Toxicity

All 2018 sediment samples passed Petrotox screening. Of the obligatory sediment samples tested (<500 m), all were determined to be non-toxic from amphipod survival assays.

Benthic Community Structure

Overall, there were fewer occurrences of organisms and taxon observed in 2018 than 2014. While overall abundance and taxa count decreased between years, the spatial distributions were similar between years. In 2014, Near-field sites had lower taxa and abundance compared to other distance bins and this trend was unchanged in 2018. Cluster analysis shows a distinction between Far-field sites to the northeast of the platform and sites at Near-field and Mid-field distance bins towards the south and west. After examining the faunal and environmental data through multivariate analysis, clustering is influenced by percent total organic carbon, sand,

gravel, and redox potential. These variations, however, may be natural and so a longer data series is needed to further assess any potential effects.

Taxa widely used as indicators of pollution effects (Spionidae and Clitellata) decreased between 2014 and 2018 samples. In both sampling years, sites farthest from the platform (>6,000 m) reported relatively high abundances of Spionidae polychaetes. Clitellata abundances decreased in 2018 from 2014 levels for all sites sampled. The most commonly used indicator of marine pollution world-wide, Capitellidae, were not abundant in 2014 or 2018 samples within the sampling area. Monitoring for changes in benthic community structure will continue in subsequent sampling years.

WATER COMPONENT

As produced water was not continuous in 2018, the water component was not a part of the 2018 EEM and will be addressed in subsequent EEM reports.

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 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. Therefore, Reference Area data from the 2015 Hibernia EEM program was used for statistical comparisons where appropriate. Chemical profiling is done using composites of fillets and liver tissues taken from fish in both areas, and total metals and hydrocarbons (including PAHs) are analyzed. For the fish health component, maturity stage, biological characteristics, gross pathology, haematology, mixed-function oxygenase, and gill and liver histopathology are compared between areas. Comparisons are also made between years for certain components, where appropriate.

Chemical Profiles of American plaice

Composite American plaice tissue sampled at the Hebron Platform and Reference Area in 2018 consistently showed the presence of arsenic, mercury, and zinc. No hydrocarbons were detected in fillets. Aside from lower zinc values in 2018, these results are consistent with the results from 2015. For liver composites, eight metals have been consistently detected in both 2015 and 2018, with three other metals occasionally above their RDLs. Metal concentrations were either similar across years or lower in 2018, with the exception of manganese which was higher in 2018. Hydrocarbons in the lower fuel range (>C10-C16) were not detected, while those in the upper fuel range (>C16-C21) were significantly higher in 2018, and those in the lube range (>C21-C32) were significantly lower in 2018. Acenaphthylene and fluorene levels were above their respective RDLs in 2018 but were not in the previous monitoring year.

Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2018. No significant results were detected for gross pathology.

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2018 for the second of three maturing codes (Mat B-P, code 530) stage. For biological characteristics, even with analysis of covariance (ANCOVA) removing variance from covariate factors, male fish significantly differed for total body weight and female fish differed in fish length, total weight, and age between sites. Cross-year comparisons between 2015 and 2018 for three indices (Fulton's condition index (FCI), hepatosomatic index (HSI), and

gonadosomatic index (GSI)) had significant results for male FCI (higher in 2018 than 2015), and male HSI higher at the Hebron Platform compared to the Reference Area. Female HSI was higher in 2018 compared to 2015.

For haematology, no differences were detected in the 2018 EEM program. However, cross-year comparisons had significant results between sites for neutrophils, leucocytes, and thrombocytes, and between years for thrombocytes. However, there were no results for 2015 at the Reference Area making comparison sample sizes uneven.

For mixed-function oxygenase (MFO), male fish significantly differed between the Hebron Platform and Reference Area in 2018. Cross year comparisons had significant results across years and significant interaction terms for both male and female fish, though this is likely natural variation based on findings from other operations.

For liver histopathology, the Hebron Platform and Reference Area significantly differed for large hepatocellular vacuoles in 2018. A multivariate analysis of variance (MANOVA) with eight liver histology factors showed significant differences between years and in the interaction term. Significant differences between years existed for hepatocellular carcinoma (higher in 2018), large hepatocellular vacuoles (higher in 2018), and all hepatocellular vacuoles combined (higher in 2018). Significant interactions were observed in liver tissue for macrophage aggregates (0-3), and small, large, and all hepatocellular vacuoles.

For gill histopathology, no significant differences were found in 2018. However, a MANOVA for seven gill histology factors detected significant results across sites and years, with a significant interaction term. Significant differences between sites largely due to basal and distal hyperplasia (both at Hebron Platform), and telangiectasia (higher at Hebron Platform). Significant differences between years were driven by tip, distal, and basal hyperplasia (all higher in 2018), and fusion (higher in 2018). Significant interactions in gill tissue were observed for tip hyperplasia and thin lamellae.

CONCLUSION

Overall, project-related effects observed in the sediment monitoring program are consistent with results predicted in the Comprehensive Study Report (CSR; EMCP 2011), as well as results observed at other offshore oil and gas development installations that show localized changes among key sediment analytes. Specific analytes (TPH, barium, metals) were higher in the Near-field, especially at the site closest to the drill cuttings deposition. The results of the commercial fish component found minor differences between the Hebron Platform and the Reference Area, including larger fish and higher MFO at the platform. Larger fish are likely due to the physical structures acting as an artificial reef, and higher MFO activity is likely natural variation. Moreover, fish from either sampling area were indistinguishable in the taint (taste) test. Therefore, all three null hypotheses of the EEM Program will not result in significant adverse environmental effects on marine fish, fish habitat, or taint of fish and are not rejected based on the 2018 EEM survey.

ACKNOWLEDGEMENTS

The 2018 Hebron EEM program was conducted under contract to ExxonMobil Canada Properties Ltd. (EMCP) under the guidance of Mike Quilty, Environmental Advisor for EMCP, and managed by Kevin Baldwin as Associate / Program Manager, Metocean Services, at Wood Environment and Infrastructure Services, a Division of Wood Canada Limited (Wood), in St. John's, Newfoundland and Labrador Canada.

The biological survey program was conducted aboard the Fisheries Research Vessel the FRV *Nuliajuk* with Captain Robert Bennet and crew. Fish processing and sampling was conducted by Wood personnel including Justin So, Shaun Garland, and Randy Norman. Fish health samples were processed, and gill samples were analyzed by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University and managed by Stephen Hill, and liver samples were analyzed by Dr. Rasul Khan.

The sediment sampling program was conducted aboard the Atlantic Raven with the assistance of her crew. Fugro Geoservices Inc. provided geopositional services for sediment collections by Alyssa Dalton and Evan Ryan. Narcissus Walsh (Narwhal Environmental Consulting Services, St. John's Newfoundland and Labrador) provided logistical expertise for deployment and recovery of the boxcorer on deck. Wood sampling crew included Michael Teasdale and Shaun Garland in the laboratory and James Loughlin, Randy Norman, and Andrew Peddle on deck.

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

ACRONYMS, ABBREVIATIONS, AND UNITS

Acronyms and Abbreviations	
2D	Two-Dimensional
AIC	Akaike information criterion
AKA	Also known as
ANCOVA	Analysis of Co-Variance
ANOVA	Analysis of Variance
$BaSO_4$	Barium sulphate, also known as barite
BTEX	Benzene, toluene, ethylbenzene, and xylene
C	Carbon
CAPP	Canadian Association of Petroleum Producers
CCME	Canadian Council of Ministers of the Environment
CDRF	Cold-Ocean Deep-Sea Research Facility
CEAA	*Canadian Environmental Assessment Act*
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CNSOPB	Canada Nova Scotia Offshore Petroleum Board
CPUE	Catch per Unit Effort
CRI	Cuttings Re-Injection
CSR	Comprehensive Study Report
DFO	Fisheries and Oceans Canada
DISTLM	Distance-Based Linear Modelling
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
FRV	Fisheries Research Vessel
GBS	Gravity Based Structure
GSI	Gonadosomatic Index
H_0	Null Hypothesis
HAI	Health Assessment Index
HEB	Hebron Platform
HSD	Honest Significant Difference (or Tukey HSD)
HSE	Hibernia Southern Extension
HSI	Hepatosomatic Index
ISQG	Interim Sediment Quality Guidelines
MANOVA	Multivariate Analysis of Variance
MFO	Mixed-Function Oxygenases
MUN	Memorial University of Newfoundland
N	Nitrogen
NA	Not Applicable
NAF	Non-Aqueous Fluids

NaOH	Sodium hydroxide
NEB	National Energy Board
NL	Newfoundland and Labrador
nMDS	Non-metric multidimensional scaling
OCNS	Offshore Chemical Notification Scheme
OWTG	Offshore Waste Treatment Guidelines
PAH	Polycyclic Aromatic Hydrocarbons
PEL	Probable Effect Levels
PIRI	Partnership in Risk-Based Corrective Action Implementation
PSA	Particle Size Analysis
QA/QC	Quality Assurance/Quality Control
RAB	Reference Area for the Hebron Platform
RDL	Reported Detection Limits
Redox	Oxidation/Reduction Potential
SBM	Synthetic-Based Mud
SDL	Significant Discovery Licence
SIMPER	Similarity Percentage Analysis
TBD	To Be Decided
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
US EPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator
VPH	Volatile Petroleum Hydrocarbons
WBM	Water-Based Mud
Units	
%	Percent
°C	Degrees Celsius
µm	Micrometre
cm	Centimetre
d	Margalef's Species Richness
g	gram
H'	Shannon-Weiner Diversity Index
hr	Hour
J'	Pielou's Evenness
kg	Kilogram
km	Kilometre
L	Litre
m	Metre
mg	Milligram
mm	Millimetre
mV	Millivolt
n	Sample Size
pmol	Picomole
ppm	Parts per Million

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 INTRODUCTION

ExxonMobil Canada Properties (EMCP) is committed to conducting an environmental effects monitoring (EEM) program to detect potential project-induced effects from the Hebron offshore platform. The results will enable an assessment of the need for additional mitigations (EMCP 2017). This report presents the results of the 2018 field program for the Hebron Platform based on the approved methods and plans from the Hebron Offshore EEM Plan (EMCP 2017). For the Hebron Platform, the 2018 program represents the 1st Production-Phase EEM field program.

1.1 Report Structure

The Hebron EEM Program 2018 (Volume I) has been structured to provide a logical sequence of information including an EEM program overview, summary of project activities and discharges, and potential effects on the receiving environment. Due to the scope and complexities of the EEM program, the methods, results, and analysis are presented in individual component sections (sediment, water, commercial fish). The analysis provides statistical interpretation of the spatial and temporal trends that may occur in association with drilling and production activities at the Hebron Platform. Particular emphasis is given to parameters associated with drilling and production operations, such as barium, hydrocarbons and produced water analytes (EMCP 2011). As the data analysis is highly technical, a summary of results is presented at the end of individual component sections. The discussion section provides an overall assessment of the potential project effects relative to monitoring hypotheses. Additional detailed descriptions of sampling and handling methods, quality assurance and quality control, along with raw data and supporting information are provided in Volume II (Supporting Information).

1.2 Project Setting and Field Layout

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

The oil field was first discovered in 1980 and is estimated to contain more than 700 million barrels of recoverable resources. The Hebron Unit currently contains three discovered fields (the Hebron Field; the West Ben Nevis Field and the Ben Nevis Field) and incorporates four Significant Discovery Licenses (SDLs) (SDL 1006, SDL 1007, SDL 1009 and SDL 1010), with ownership varying in each SDL. These four SDLs contain the most likely extent of the oil for the delineated pools within the Hebron Unit. The Hebron field is being developed using a stand-alone concrete gravity-based structure (GBS), a tall (120-130 m) cement column constructed to store approximately 1.2 million barrels of crude oil (Figure 1-2). 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.

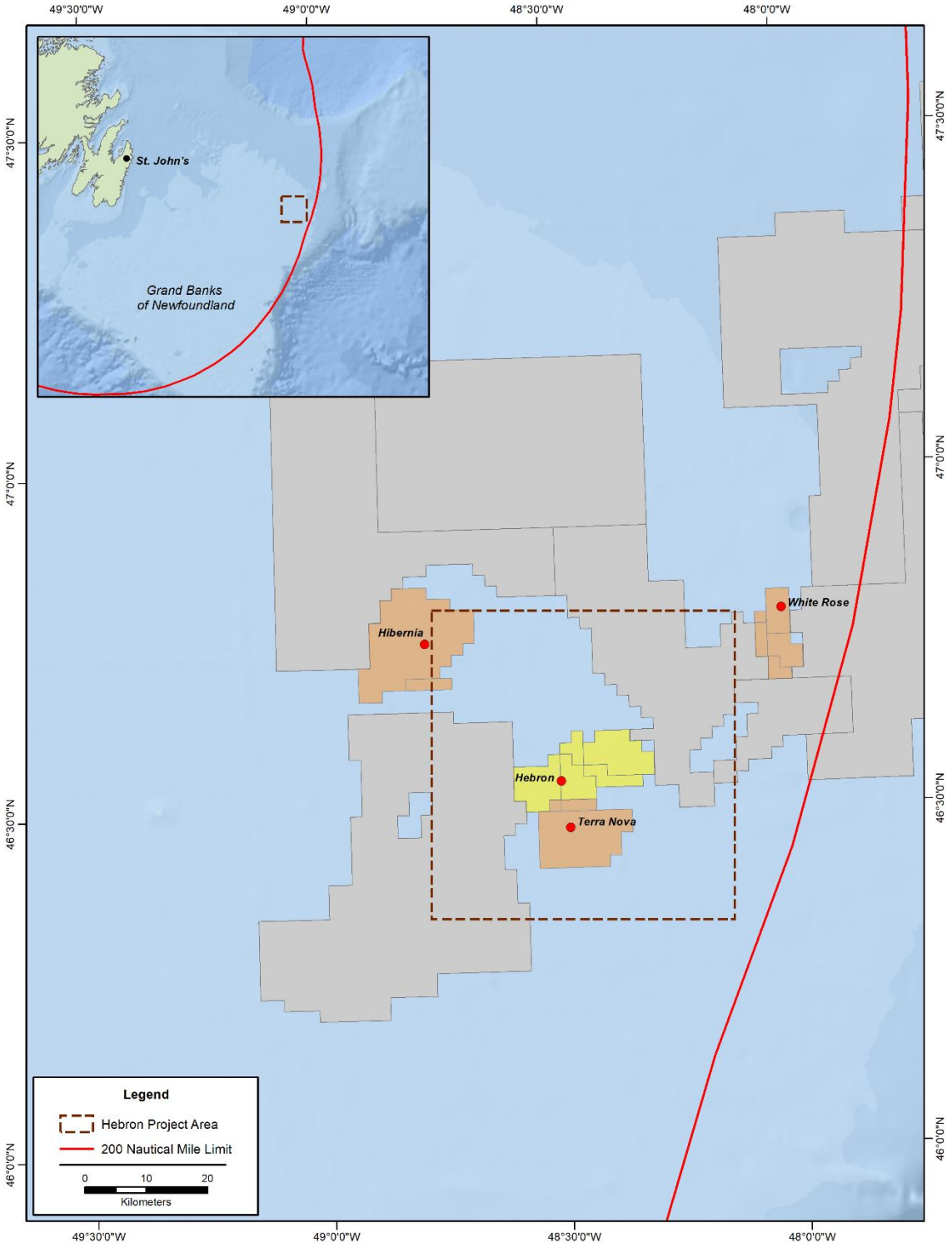

Figure 1-1 Location of the Hebron oil field in relation to St. John's, Newfoundland and Labrador, and proximity to other offshore production operations on the Grand Banks.

Figure 1-2 Hebron Platform in July 2018 with the MV Atlantic Heron offshore supply vessel on the right.

1.3 Project Commitments

EMCP is committed to conducting an EEM program to detect potential changes in the surrounding environment that can be attributed to the project (EMCP 2017). Therefore, a monitoring design plan was developed, adaptively revised, reviewed and approved by the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) that includes the prescriptive monitoring requirements for the Hebron Platform (EMCP 2017). The purpose of this EEM is to validate the Hebron Comprehensive Study (CSR) predictions that are relevant to effects related to marine discharges (EMCP 2017). Complementary to that purpose, the EEM Plan will serve to fulfill regulatory information requirements associated with the Hebron Development Application Decision Report 2012.01 C-NLOPB 2012) and to comply with follow-up requirements of the *Canadian Environmental Assessment Act* (CEAA).

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 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 on a continuous basis according to Operator's Environmental Compliance Monitoring Plan (a component of the Environmental Protection Plan). The discharge locations for the Hebron Platform are illustrated in Figure 2-1 and Figure 2-2. Discharges are separated into solid (muds and cuttings) and liquid discharges.

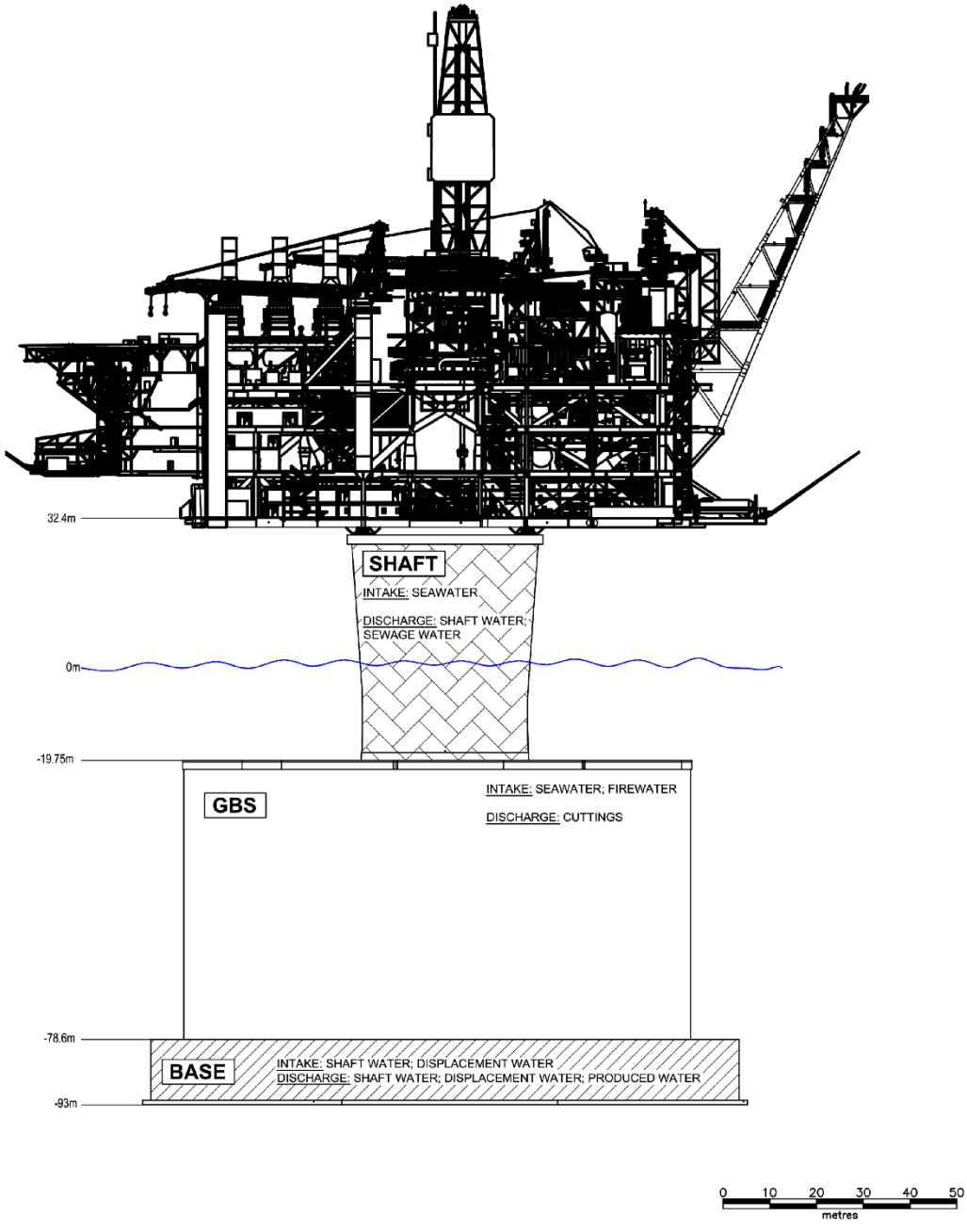

Figure 2-1 Discharges for the Hebron Platform; modified from EMCP (2017).

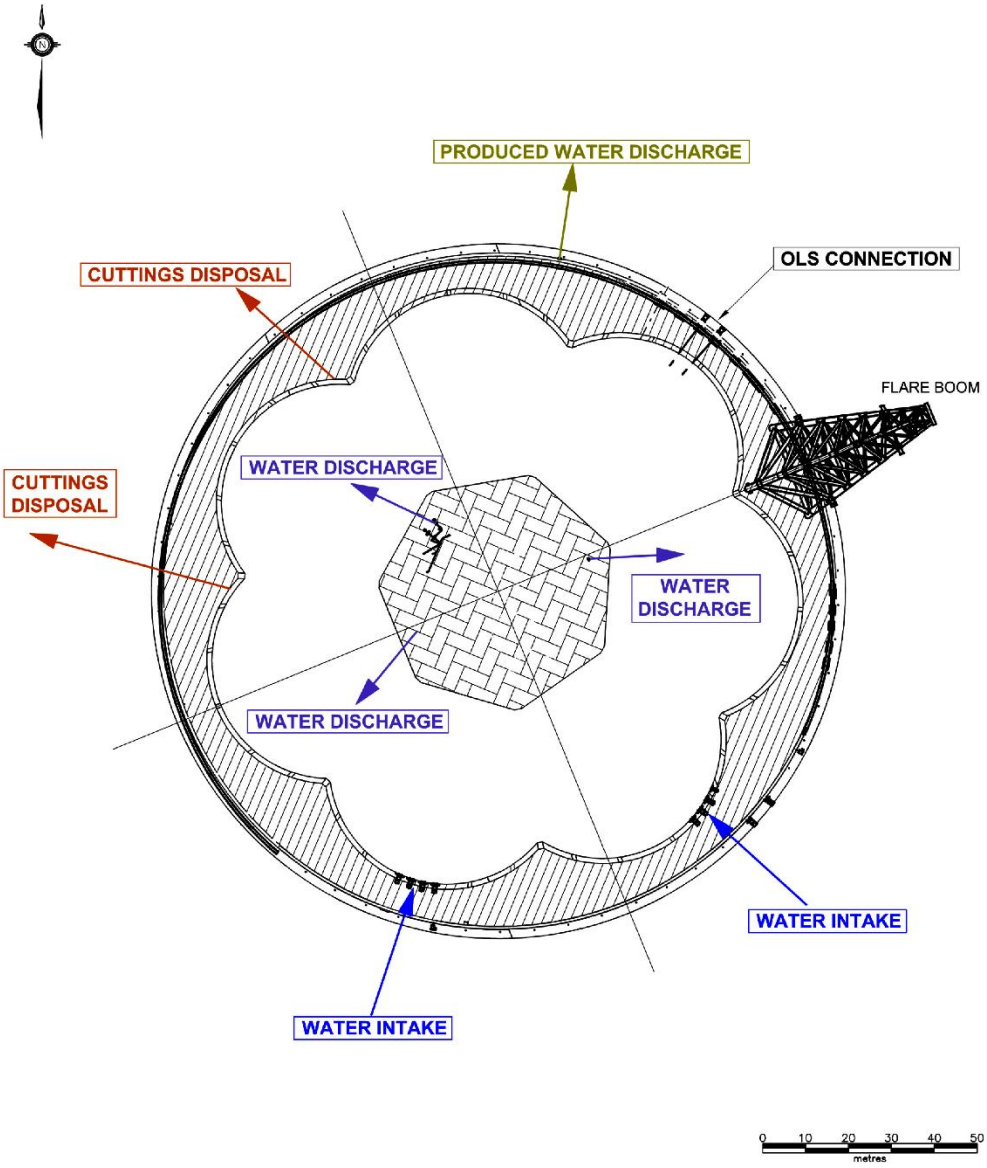

Figure 2-2 Discharge Orientations for the Hebron Platform. All discharges are below the water line. Purple discharges are from shaft and rest on from GBS itself or the base. Modified from EMCP (2017).

2.1 Construction and Operation Activities

Key dates for construction and operation activities are identified in Table 2-1 with a focus on activities with discharges into the marine environment that have the potential to have effects identified in the EEM.

Table 2-1 Schedule of Construction and Operation Activities.

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

Notes:
*There was no produced water discharge during 2018
OLS – Offshore Loading System
SBMs- Synthetic-based Muds
WBMs- Water-based muds

2.2 Drilling Discharges

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

The primary constituents of WBMs are water, barium sulphate (a.k.a. barite or $BaSO_4$) as a weighting agent, and bentonite clay as a viscosifier (Trefry et al. 2013, DeBlois et al. 2014b). Depending on the composition of the bedrock formation being drilled, various salts and organic gels may also be added (Trefry et al. 2013). For example, sodium hydroxide (NaOH) and lime are included as a minor fraction (<10% of WBM) at the Terra Nova production field (DeBlois et al. 2014b). As WBMs primarily water and barite, barium is the main contaminant of WBM-on-drill cuttings (Whiteway et al. 2014). For Hebron, WBM cuttings are separated from the drilling fluids and discharged overboard (EMCP 2017).

In contrast, the primary constituents of NAFs (or SBMs) are organic fluid, barite, saltwater, emulsifiers, gelificants and other chemical additives (reviewed by Peralba et al. 2010). The base (organic) fluid is Petro-Canada Puredrill IA-35LV (EMCP 2017), a synthetic isoalkane that is completely colourless, odorless readily biodegradable and non-toxic to humans and marine wildlife (Talalay and Pyne 2017). Puredrill IA-35LV complies with US Food and Drug Administration Regulations for pharmaceuticals while in oil-form and

has the same molecular stability and non-reactivity that allows the material to be classed as food grade status for human consumption to assure low toxicity for marine organisms (EMCP 2017). It is composed of aliphatic hydrocarbons in the fuel range (>C10-C21) and contains no aromatic hydrocarbons (DeBlois et al. 2014b). This base fluid is used at the Hibernia Platform as well as the Terra Nova production field (EMCP 2017, DeBlois et al. 2014b). Puredrill IA 35LV is also rated as a Category E product (least hazardous) in the Offshore Chemical Notification Scheme (OCNS) (DeBlois et al. 2014a).

For Hebron Platform drilling, SBM cutting re-injection (CRI) equipment is currently operating with a majority of SBM drill cuttings and solids from the platform being reinjected into the formation. Limited discharges of SBM cuttings into the marine environment happens on occasion per approval from the C-NLOPB for certain situations (casing shoe tracks, cement plugs) to ensure the integrity of the CRI system. The majority of SBM cuttings, however, are reinjected via the CRI system. Table 2-2 lists the SBM discharges for 2017-2018 for the Hebron Platform.

Table 2-2 Synthetic-based mud drill cuttings discharges from the Hebron Platform (2017-2018).

Discharge Period		**Oil on Cuttings Concentration (mg/L) 48 Hr Rolling Average**	**Calculated Oil Released (m^3)**	**Daily Average Cuttings Discharged (tonnes)***
July 20, 2017	Sept 16, 2017	0	0	0
Sept.17, 2017	Nov.24, 2017	13.88	2.58	15.33
Nov. 25, 2017	Jan. 21, 2018	0	0	0
Jan. 22, 2018	Apr.15, 2018	6.83	2.22	26.79
Apr. 16, 2018	Jun.2, 2018	6.76	0.99	12.04
Jun. 3, 2018**	Aug.31, 2018**	6.85	0.73	8.77
Sept. 1, 2018	Oct.24, 2018	6.46	3.82	44.38
Oct.25, 2018	Dec.26, 2018	8.7	0.94	8.93
Total (2017-2018)		**-**	**11.28**	**116.24**

Notes:
*Daily discharge cuttings are based on the cumulative cuttings discharged volume (from diameter of drill bit and length of the hole) divided by number of days in the discharge period
* 2018 EEM sampling was completed in June and June/July for sediment and fish 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 as per the Hebron Offshore Chemical Management System. Produced water contains minor amounts of natural organic (petroleum hydrocarbons, organic acids, alklyphenols) 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).
There were no produced water discharges prior to or during the 2018 EEM sampling program and any produced water collected at that time was batch stored and not released.

2.4 Other Waste Discharges

2.4.1 Storage Displacement Water

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

The storage displacement water is tested to a regulatory limit of 15 mg/L residual average daily oil concentration. As part of environmental compliance monitoring, displacement water is collected at the outlet from the platform for analysis (Figure 2-2). Table 2-3 shows the 2018 oil concentration and flow rates for Hebron Storage Displacement Water Discharges.

Table 2-3 Storage displacement water discharges (2018).

Month (2018)	Average Daily Oil Concentration (mg/L) Limit = 15	Range (mg/L)	Flow-Avg (m^3/day)	Range (m^3/day)
January	1.2	0-6.6	3996	2558-5939
February	0.3	0-2.3	7488	3339-10267
March	0.4	0-3.1	8034	3825-8569
April	0.2	0-0.9	9029	4147-11944
May	0.4	0-2	11205	7870-12254
June*	0.2	0-1.1	11226	6808-11811
July*	0.4	0-1.6	11313	8468-11654
August	0.3	0-1.4	11259	9173-11614
September	0.3	0-1.9	10915	7806-11682
October	0.1	0-1.1	11362	10265-14280
November	0.3	0-1.7	11912	484-15916
December	0.3	0-2.1	13209	42-15321
2018	0.4	0-6.6	10093	42-15916

Notes:
* 2018 EEM sampling was completed in June and June/July for sediment and fish cruise, respectively

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 contaminants such as cleaning detergents and dispersants, small amounts of hydrocarbons and

other chemicals such as lubricants (Yang et al. 2011). On the Hebron Platform, deck drain effluent is segregated, collected and treated by two separate systems: the Process Area and Drilling Area drains.

The Process Area drains collect all drainage on the platform not directly related to drilling. They can contain both hazardous (high-pressure systems; typically related to crude processing) and non-hazardous (lower pressurized systems) drainage. Oil, water, and solids are separated with partial oil recovery. The Process Area Hazardous drains collect effluent including oily water from processing equipment, pig launchers as well as receiver and contaminated water from the chemical laydown area. The Process Area non-hazardous drains include drainage from potable and service water facilities, chemical injection package water, coarse water strainers, diesel storage tanks, pipe rack area and the weather deck of the living quarters module. Recovered oil from non-hazardous drain tanks is pumped to the hazardous drain tank. Drainage from the helideck and fuel tote tank storage area are routed directly overboard to prevent jet fuel from entering the drain system (EMCP 2018).

Drilling Area drains handle both hazardous and non-hazardous effluent that is directly related to drilling. The Drilling Area hazardous drain effluent contains sea water, rainwater, chemical and mud components, cuttings, weighing agents, lubricants and crude hydrocarbons (EMCP 2017). The Drilling Area non-hazardous drain effluent consists of sea water, minimal hydrocarbons and mud components (EMCP 2017). The daily mean oil concentrations for process and area drain water are presented in Table 2-4; note that there was no Drilling Area drain discharge in 2018.

Table 2-4 Process Area Drainage water discharges (2018). There were no Drilling Area drains discharges in 2018.

Month (2018)	Average Daily Oil Concentration (mg/L) Limit = 15	Daily Range (mg/L)	Daily Average Flow (m^3/day)	Daily Flow Range (m^3/day)
January	6.1	1.2-10.7	132	28-298
February	6.4	0-12.5	114	0-244
March	5.6	1.0-12.2	106	0-234
April	4.3	0.9-12.6	118	33-321
May	4.3	0-11.0	110	42-222
June*	6.9	1.0-19.9	74	3-483
July*	6.3	1.3-15.0	131	29-258
August	4.1	1.4-9.7	160	23-366
September	3.9	0.4-8.7	118	49-210
October	4.8	1.3-11.1	156	98-253
November	4.4	1.2-10.5	191	114-300
December	5.5	1.6-12.7	186	104-308
2018	**5.3**	**0-19.9**	**132**	**0-483**

Notes:
* 2018 EEM sampling was completed in June and June/July for sediment and fish cruise, respectively

2.4.3 Seawater Return

Cooling water consists of sea water that has been chlorinated and pumped onto the platform and passed through heat exchangers to remove heat from processes on the installation. A portion of that water is used for other processes (storage displacement water, domestic sewage, drain effluent, seawater injection)

with the rest routed to the seawater return line and discharged via the three water discharge points identified in Figure 2-2. The seawater return is monitored for residual chlorine with a limit of 2.0 mg/L (EMCP 2017). Table 2-5 presents the mean residual chlorine concentrations of the seawater return discharge for 2018.

Table 2-5 Sea water return discharges (2018).

Month (2018)	**Average Daily Free Chlorine Concentration (mg/L) Limit = 2.0**	**Range (mg/L)**
January	1.17	0.03-1.64
February	1.41	1.17-1.65
March	1.39	0.26-1.59
April	1.37	0.03-1.57
May	1.46	0.54-1.74
June*	1.14	0.34-1.67
July*	0.89	0-1.56
August	0.72	0.30-1.54
September	0.70	0.24-1.64
October	0.45	0-1.47
November	1.6	1.44-1.78
December	1.5	0.02-1.83
2018	**1.14**	**0-1.83**
Notes: * 2018 EEM sampling was completed in June and June/July for sediment and fish cruise, respectively		

2.4.4 Sanitary and Domestic Wastes

Sanitary and domestic wastes include human wastes and all liquids originating from domestic facilities (e.g., kitchen, showers) and are not monitored directly. Sanitary and domestic wastes must be macerated to a particle size of six mm or less (NEB et al. 2010). Domestic effluents are also treated to remove grease and screened to remove plastic and metals (EMCP 2017).

2.5 Contamination versus Pollution

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

In order to determine whether any contaminant identified in samples might have a negative biological effect (i.e., is pollution), its bioavailability is included within the assessment. Bioavailability of a contaminant can vary depending on several factors such as chemical form, modifying environmental factors, environmental niche and the behavioral and physiological reactions of exposed biota (Chapman 2007). Therefore, the detection of chemical analytes (contaminants) in the environment alone does not identify a pollutant, rather, effects-based measures such as bioavailability and toxicity assays are also required to determine pollution status (Chapman 2007). Moreover, linkages must be established between

environmental levels of exposure and internal levels of tissue contaminant concentrations to indicate an injurious effect of a substance in the marine ecosystem (van der Oost et al. 2003). The use of biomarkers (changes in a biological response) provide insight regarding potential mechanisms of contaminant effects on an organism (van der Oost et al. 2003). The incorporation of such assays is included in the EEM design to monitor for potential adverse environmental conditions and are discussed in later chapters.

3 ENVIRONMENTAL EFFECTS MONITORING SUMMARY

3.1 Program Objectives

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

- Fulfill Condition 2012.01.07 of the Hebron Development Application Decision Report 2012.01 (Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) 2012) (listed in Section 3.2);
- Fulfill the commitments regarding the offshore environmental effects monitoring plan made in Section 15 of the CSR report (ExxonMobil Canada Properties (EMCP 2011); and
- Comply with the follow-up requirements of the *Canadian Environmental assessment Act* (CEAA).

3.2 Environmental Assessment Predictions

In 2009, the Canadian Environmental Assessment Act prescribed a comprehensive study-level environmental assessment (EA) for an 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 Canadian Environmental Assessment Act and the Development Plan Guidelines. The CSR and subsequent EA Amendment included an EA of potential effects on valued ecosystem components. Valued ecosystem components addressed within the context of the Hebron EEM program were Fish and Fish Habitat and Commercial Fisheries (EMCP 2011). As such, predictions on alterations to physical and chemical characteristics of sediment and seawater (as components of fish habitat), and predictions on effects to benthos, fish and fisheries, apply to the EEM program.

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

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

3.2.1 Sediment Quality Predictions and Assessment

The CSR and subsequent EA Amendments concluded that the potential geographical extent of effects for ‘operations and maintenance’ and ‘decommissioning and abandonment’ activities associated with sediment quality relating to fish and fish habitat are in the 1- 10 km^2 category (CSR; Table 7-12 and Table 7-13) (EMCP 2011). This equates to a distance from the platform of <2 km where potential affects may occur.

It was further predicted, largely based on sediment dispersion modelling (detailed above) and review of drill cuttings effects from other projects, that the ~0.8 km^2 of seafloor area around the platform could be

affected by project activities (pg. 7-100 of CSR) (EMCP 2011). This would translate to seafloor within ~500 m of the platform.

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

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

3.2.2 Commercial Fisheries Prediction and Assessment

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

3.2.3 Water Quality Assessment and Conclusions

The CSR concluded that the potential geographical extent of effects for 'operations and maintenance' and 'decommissioning and abandonment' activities associated with water quality relating to fish and fish habitat are in the 1-10 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 effects may occur.

It was further predicted in the CSR, largely based on produced water modelling (detailed above) and review of effects from other projects (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 in up to 500m 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).

The EEM sampling plan has taken these conclusions and predictions into consideration by focusing on monitoring for the potential effects of produced water once the produced water rates are large enough where changes to the receiving environment could be detected. The exact parameters and locations of the Hebron EEM water sampling is detailed in Section 7.0 of this document.

3.3 Program Components

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

3.4 Monitoring Hypotheses

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

3.4.1 Sediment Quality Hypotheses

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

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

3.4.2 Commercial Fish Hypotheses

Generic monitoring hypotheses for the commercial fish component are:

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

3.4.3 Water Quality Hypotheses

As outlined in the Hebron EEM Plan, water sampling will commence when the produced water is continuous. The Hebron produced water was not continuous for 2018. The water sampling hypothesis and planning will be discussed in subsequent Hebron EEM reports.

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	Sediment Cruise Dates	Biological Cruise Dates
Baseline (sediment)	2014	Aug. 26-Sep. 04	-
Baseline (fish)	2015	-	Jun. 3 – Jun. 27
Year 1	2018	Jul. 26- 28	Jun. 27 -Jul. 11
Year 2	2019	TBD	TBD
Year 3	2020	TBD	TBD
Notes: Hebron began operations in June of 2017, began drilling in July of 2017, and started production in November of 2017. TBD – To be decided			

3.5.2 Parameters

The EEM program consists of sediment, water and commercial fish sampling components to assess the chemistry and toxicity of sediment and water quality, and the health, size and body burden chemistry of fish (summarized in Table 3-2). The complete rationale for the selection of parameters as well as the various design changes are available within the EEM Design Plan (EMCP 2017).

Table 3-2 Hebron Platform Program sediment, water and biological sampling program component parameters and analysis.

Program Component	Parameters	Analysis
Sediment Quality	Chemistry	Particle size, organic and inorganic carbon, metals, hydrocarbons, ammonia, and sulphide concentrations
	Toxicity	Amphipod survival
	Community	Benthic invertebrate community sampling
Commercial Fish (American plaice)	Tissue Chemical Profiles	Body burden (metals, hydrocarbons, ammonia and sulphide concentrations)
	Sensory Evaluation	Taint / taste testing
	Health Indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity
Water Quality*	Chemistry	Metals, hydrocarbons, nutrients
	CTD	Dissolved oxygen, temperature, salinity, and pH profiles
Notes: * Water quality has not been initiated as the produced water is not yet continuous		

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	Total Inorganic Carbon (TIC) / Total Organic Carbon (TOC)
	Metals	Arsenic Barium Cadmium Chromium Copper	Iron Lead Manganese Mercury Selenium Zinc
	Hydrocarbons	<u>Total Petroleum Hydrocarbons (C6-C32)</u> BTEX (benzene, toluene, ethylbenzene, and xylene) C6-C10 (less BTEX) C10-C21 (Fuel Range) C21-C32 (Lube Range)	
		<u>Polycyclic Aromatic Hydrocarbons (PAHs)</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
Biological	Toxicity	Amphipod Toxicity for all stations <500m. reference sites, 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 Fish Quality Component for Hebron EEM.

Variable Type	Commercial Fish Component	Specific Constituents	
Sensory Evaluation	Taste Tests	Triangle Test Hedonic Scaling Test	
Fish Health	General	Total body weight, Gutted body weight, Length, Liver weight, Gonad weight Lipid/ Moisture Content	Age/sex Condition index (gutted weight) Hepato-somatic index Gonado-somatic 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 Cadmium Chromium Copper Iron	Lead Manganese Mercury Selenium Zinc
	Hydrocarbons	<u>Total Petroleum Hydrocarbons (C6-C32)</u> C6-C10 C10-C21 (Fuel Range) C21-C32 (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 used for sediment sampling and commercial fish surveys are illustrated in Figure 3-1. and Figure 3-2**,** respectively. There was no water sampling in Year 1 as there was no continuous discharge of produced water.

Note that the cluster of stations northeast of the Hebron Platform ('Northeast Cluster') is outside the drill cutting footprint and these stations 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.

Table 3-5 Field distance definitions.

Field distance descriptors	Distance from Hebron Platform	Line Type and Prefixes	2018 EEM Program Stations
Near-field	≤1,000 m	Primary (4-, 6-, 8-, FL-)	250, 500, 750, 1000
Mid-field	>1,000 m to ≤2,000 m	Primary (4-, 6-, 8-, FL-)	1250, 1500, 2000
Far-field	>2,000 m	Primary (4-,6-, 8-) Secondary (FL-)	4000, 6000 3,000
		Secondary (2-, A-, B-, C-, D-, FL-)	250, 500, 750, 1000, 1250, 1500, 2000, 3000, 6000
Total-field	All	All	All

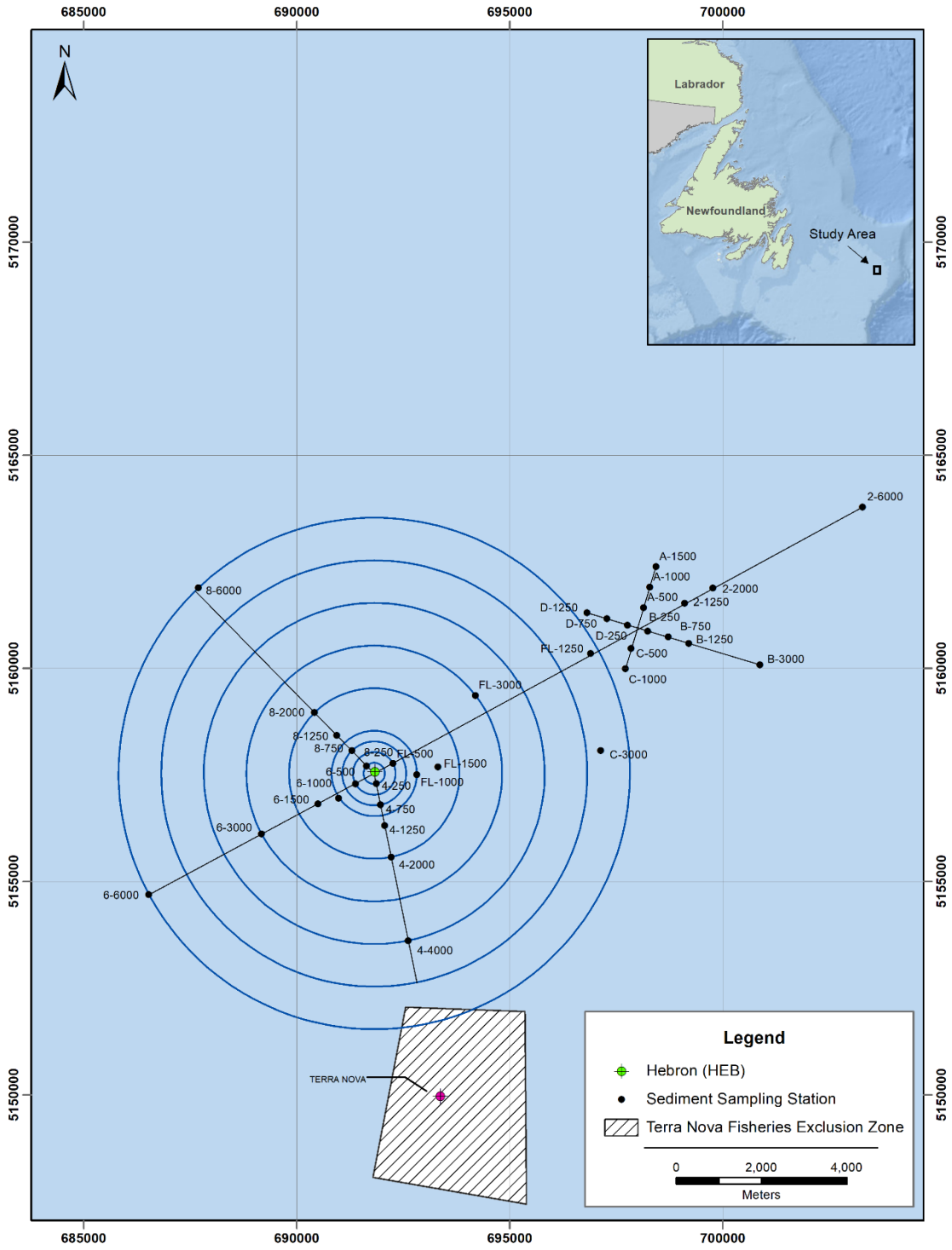

Figure 3-1 Map of 2018 sediment sample stations for Hebron EEM.

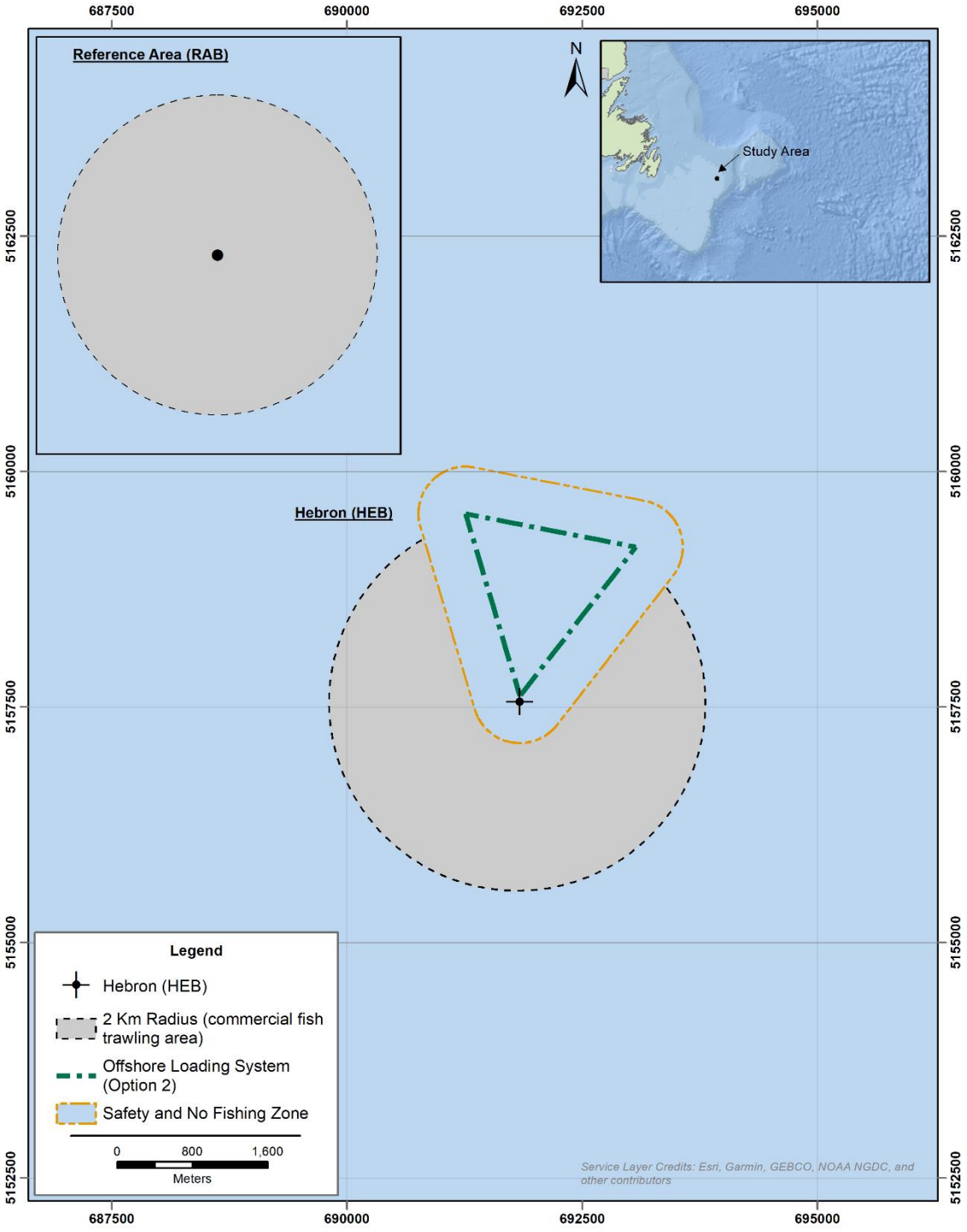

Figure 3-2 Map of available survey trawling area for the Hebron EEM.

4 SEDIMENT COMPONENT

4.1 Field Collection

The 2018 survey was conducted by Wood field staff from July 26 to July 30 aboard the supply vessel *Atlantic Raven*, under contract to ExxonMobil Canada Properties (EMCP). The vessel arrived at Hebron on the morning of July 26, 2018 and 4 stations were completed that day. Sediment sampling continued through July 27, 2018 (24 stations) and was completed on July 28, 2018. Sediment samples were collected utilizing a large-volume box corer (Figure 4-1). Figure 4-2 shows an example of a sediment sample recovered with the box corer.

Sediment samples were collected on a 24-hour basis when weather was suitable, and the vessel was not required for higher priority operations (e.g., spill or safety response), therefore, two complete (three-person) Wood teams were required. The vessel's deck hands and the Wood team worked in a complimentary fashion with the ship's watch system. The deck hands worked 6-hour shifts; the Wood crews worked 12-hour shifts.

Each 12-hour shift was directed by the team leader. A toolbox safety meeting was conducted at the start of every 12-hour shift. Each three-person Wood team was on deck and responsible for sediment and water sample collection and processing. Two Wood personnel were responsible for the arming, loading, and unloading of the box corer. The third Wood team member was responsible for sub-sampling recovered box-corer samples and data recording. Sediment samples were collected using a box corer within a 25 m radius of established station coordinates. The positioning of box corer deployment was coordinated through the crew leader and a Fugro offshore surveyor.

The crew of the *Atlantic Raven* 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 Wood team during the deployment and retrieval of the box corer. The Captain had authority in matters of safety.

The Fugro offshore surveyors ensured sampling occurred in the specified locations. The offshore surveyors operated on the bridge and were responsible for logging the actual position and time of sediment sampling.

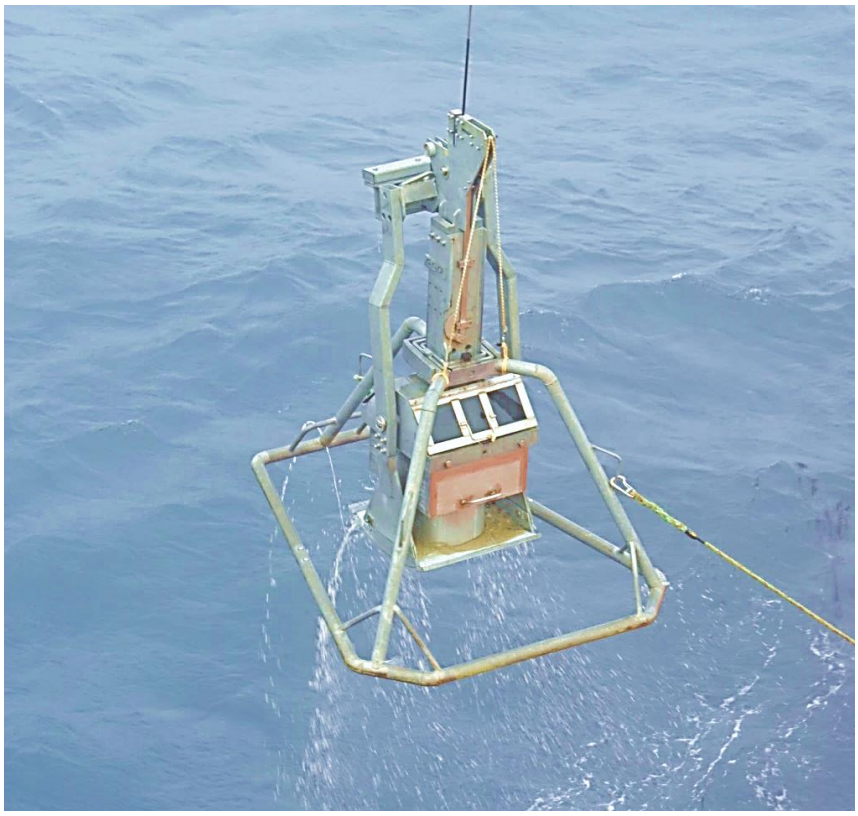

Figure 4-1 Large volume box corer retrieval.

Figure 4-2 Example photo of sediment recovery with large volume box corer.

Predictions from the EA estimate that effects are most likely to occur within one to two km from the platform. To assess potential effects around the platform, sampling stations were arranged on radii, to a distance of 2 km (Figure 3-1). Secondary stations greater than 2 km from source were incorporated with the goals of assessing and interpreting potential alterations and/or effects extending beyond 2 km from the platform.

Two box corer samples were collected at each station. An additional sample was collected at stations 4-1250, 4-2000, 8-250, A-1000, C-1000, for quality assurance / quality control (QA/QC) purposes. Three sample locations were relocated when in the field:

- 6-1000 and 8-600 were moved 50 meters away from FibreOp cable and
- station 6-3000 was moved away from wave rider buoy.

Table 4-1 presents the coordinates (proposed and actual) for 2018 Hebron sediment sampling locations.

Table 4-1 Coordinates (proposed and actual) for 2018 Hebron sediment sampling locations.

Station ID	Station Type	Proposed Coordinates		Station Order	Actual Coordinates	
		Easting	Northing		Easting	Northing
2-1250	Secondary Station	699103	5161535	24	699104	5161534
2-2000	Secondary Station	699768	5161890	25	699765	5161890
2-6000	Secondary Station	703285	5163791	26	703284	5163788
4-1250 QA/QC	Primary Station	692071	5156315	32	692068	5156317
4-2000 QA/QC	Primary Station	692220	5155580	33	692226	5155580
4-250	Primary Station	691868	5157299	7	691866	5157299
4-4000	Secondary Station	692620	5153620	34	692620	5153620
4-750	Primary Station	691968	5156809	29	691969	5156805
*6-1000	Primary Station	690938	5157069	30	690997	5156978
6-1500	Primary Station	690501	5156830	31	690505	5156829
*6-3000	Secondary Station	689179	5156121	36	689265	5156002
6-500	Primary Station	691379	5157299	6	691378	5157298
6-6000	Secondary Station	686535	5154701	35	686534	5154701
8-1250	Primary Station	690942	5158431	3	690947	5158430
8-2000	Primary Station	690417	5158970	2	690417	5158968
8-250 QA/QC	Primary Station	691643	5157718	5	691642	5157716
*8-6000	Secondary Station	687617	5161821	1	687626	5161831
8-750	Primary Station	691293	5158081	4	691294	5158079
A-1000 QA/QC	Secondary Station	698284	5161911	22	698284	5161910
A-1500	Secondary Station	698430	5162390	23	698430	5162391
A-500	Secondary Station	698142	5161432	21	698142	5161431
B-1250	Secondary Station	699199	5160590	15	699202	5160584
B-250	Secondary Station	698240	5160880	17	698241	5160881
B-3000	Secondary Station	700872	5160089	27	700868	5160088
B-750	Secondary Station	698720	5160741	16	698724	5160746

Station ID	Station Type	Proposed Coordinates		Station Order	Actual Coordinates	
		Easting	Northing		Easting	Northing
C-1000 QA/QC	Secondary Station	697718	5159992	13	697719	5159991
C-3000	Secondary Station	697136	5158081	28	697139	5158081
C-500	Secondary Station	697854	5160472	14	697853	5160473
D-1250	Secondary Station	696810	5161309	20	696809	5161306
D-250	Secondary Station	697763	5161022	18	697762	5161021
D-750	Secondary Station	697286	5161171	19	697286	5161170
FL-1000	Primary Station	692821	5157510	9	692823	5157520
FL-1250	Secondary Station	696904	5160350	12	696905	5160351
FL-1500	Primary Station	693315	5157690	10	693314	5157687
FL-3000	Secondary Station	694196	5159371	11	694195	5159369
FL-500	Primary Station	692260	5157781	8	692266	5157783

Notes:
*6 1000 was moved 50 meters away from FibreOp cable
*8-6000 was moved 50 meters away from FibreOp cable
*6-3000 was moved away from wave rider buoy.
All coordinates presented in UTMs, Zone 22, NAD83

Field measurements (temperature, redox potential, sediment description and photograph) were conducted on each box corer sample. Sub-samples from each sediment core were taken for chemistry, BTEX / Volatile Petroleum Hydrocarbons (VPH), PAHs, sulphide, particle size, sample archive, amphipod toxicity, and benthic community analysis. Samples were collected as follows:

- Chemistry and archive samples were collected from one half of the box corer #1 sample as presented in Figure 4-4 from the upper 5.0 cm.
- Toxicity samples were collected from the other half of the core #1 sample from the upper 7.5 cm.
- Benthic community sampling was collected from the upper 15 cm from box corer sample #2.
- All samples and measurements were collected from an undisturbed area of the sample.
- Dates and times were noted on all sample labels.

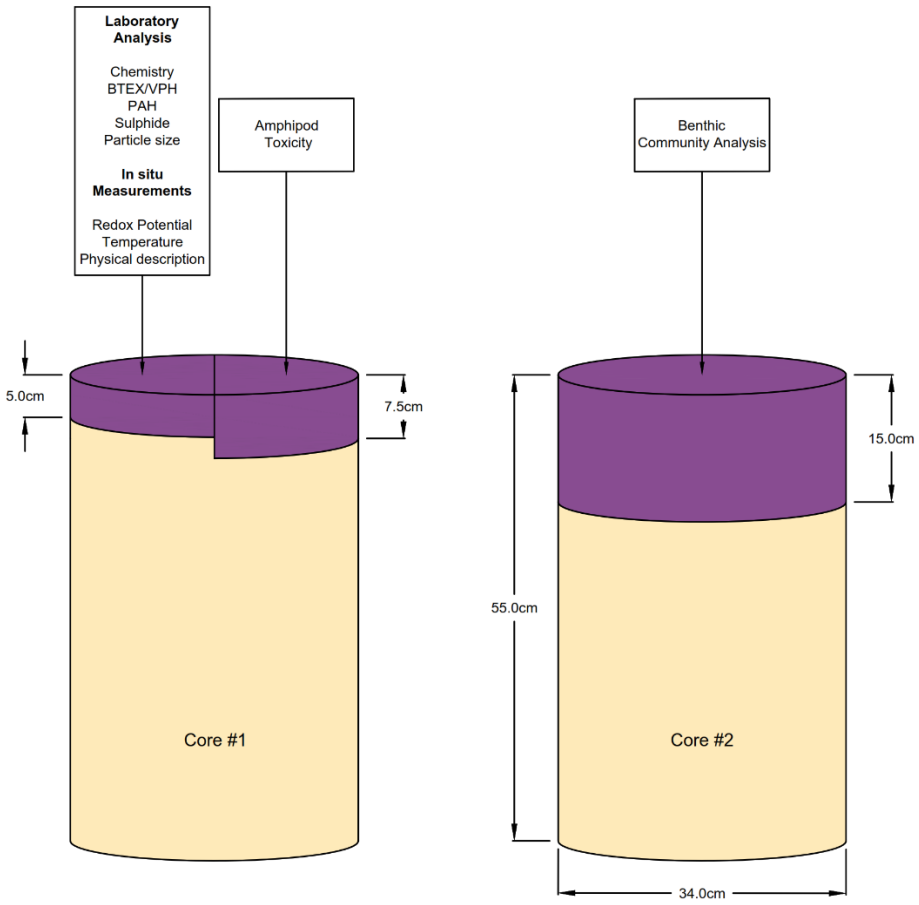

Figure 4-3 Sediment sample collection from each box corer sample.

4.2 Analyses

Monitoring variables included in the sediment quality component of this EEM are sediment physical characteristics, sediment chemistry, sediment toxicity, and benthic community structure. Samples collected in 2014 were used for comparison to the samples collected in 2018. Sediment physical and chemical analytes of interest and those with at least 50 percent of samples with reported levels at or above the reported laboratory detection limits (RDL) are discussed in the following sections and subject to exploratory and statistical analysis (EMCP 2017). Several analytes that were analyzed for the 2014 report were screened out in the 2018 analysis. In 2014, the selection criteria were 75 percent of samples at or above RDL while in 2018 the selection criteria were 50 percent of samples at or above RDL.

Analytes of interest include sediment fractions, hydrocarbons, and barium which are known project discharges and were included in 2D spatial plots and statistical analysis.

4.2.1 Data Analysis

4.2.1.1 Physical and Chemical Characteristics

Each sample location had sediment analyzed for the following:

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

Analytes with less than half of all total samples at or above RDL were screened out of further analysis except for sediment fractions and hydrocarbons. Previously, the RDL for perylene was 0.01 mg/kg, this changed to 0.005 mg/kg for the 2018 analysis. The following analytes were screened out of further analysis:

- Sulphide
- Cadmium
- Zinc
- All PAHs (including perylene)

Table 4-2 summarizes the RDL, number of samples analyzed, the number of stations with detected values (equal to, below, and above RDL), as well as 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.

Table 4-2 Summary of detectable physical and chemical data from the 2018 Hebron EEM sediment samples.

Parameter	RDL	Units	No. Samples	No. =RDL	No. <RDL	No. >RDL	Mean	St. Dev.	Median	Min	Max	ISQG[1]	PEL[1]
PARTICLE SIZE ANALYSIS													
Clay	0.1	%	36	0	0	36	1.203	0.297	1.2	0.15	1.8	-	-
Silt	0.1	%	36	1	22	13	0.144	0.147	0.1	0.1	0.95	-	-
Sand	0.1	%	36	0	0	36	95.306	6.537	99	73	100	-	-
Gravel	0.1	%	36	1	15	20	3.580	6.367	0.165	0.1	26	-	-
TOTAL EXTRACTABLE METALS													
Barium	5	mg/kg	36	0	0	36	155.000	168.482	120	69	1100	-	-
Iron	50	mg/kg	36	0	0	36	1167.222	362.945	1050	550	2100	-	-
Lead	0.5	mg/kg	36	0	0	36	1.917	0.542	1.8	1.2	3.6	30.2	112
Manganese	2	mg/kg	36	0	0	36	30.917	12.413	31	11	68	-	-
HYDROCARBONS													
C_{10}-C_{16} Hydrocarbons	0.25	mg/kg	36	0	22	14	0.749	1.830	0.25	0.25	11	-	-
C_{16}-C_{21} Hydrocarbons	0.25	mg/kg	36	0	22	14	0.542	1.036	0.25	0.25	6.3	-	-
C_{21}-C_{32} Hydrocarbons	0.25	mg/kg	36	0	4	32	0.501	0.284	0.41	0.25	1.7	-	-
TIC/TOC													
Total Organic Carbon	0.2	g/kg	36	0	0	36	0.706	0.242	0.7	0.32	1.1	-	-
OTHER													
Ammonia	0.3	mg/kg	36	0	2	34	2.982	2.765	2.15	0.3	15	-	-
Total Sulphur	0.01	%	36	1	5	30	0.023	0.009	0.02	0.01	0.05	-	-
Total Sulphur	100	mg/kg	36	0	5	31	227.611	77.203	236	100	454	-	-
Moisture	1	%	36	0	0	36	17.028	1.207	17	14	19	-	-

Notes:
1) ISQG- Interim Sediment Quality Guidelines and PEL-Probable Effect Levels as specified in the Canadian Environmental Quality Guidelines, Canadian Council of Ministers of the Environment (CCME 1999, updated 2001)
Analytes detected at or above RDL are reported here, All PAHs analyzed were below RDL
PetroTox risk assessment threshold screens in all sediment samples ≥150 mg/kg of >C_{10}-C_{21} for toxicity analysis (EMCP 2017, Stantec 2013).

For this report, sediment grain size classification for the particle size analysis (PSA) utilized a modified Udden-Wentworth scale (1922, Blair and McPherson 1999; Table 4-3).

Table 4-3 Grain size scale (mm) adapted from Udden-Wentworth (1922) (Blair and McPherson 1999).

Grain Type	Diameter (mm)
Gravel	2.0-4096 mm
Sand	0.0625-2.0 mm
Silt	0.004-0.0625 mm
Clay	<0.004 mm

To detect any spatial or temporal variations in physical or chemical characteristics, spatial and temporal patterns between years for all sediment fractions and select analytes are represented in two-dimensional scatter plots. Plots were generated using the R statistical software (R Core Team 2018). The X and Y axes represent the east-west and north-south distances in meters from the Hebron Platform. The Hebron Platform is indicated by a "+" in the plots. Sampling stations are represented by dots and color represents reported concentrations at each site. The legend for each plot reports the upper limit of the concentration range represented by color. For the 2D plots, analyte values below RDL (<RDL) were expressed as half (0.5) RDL. These plots are for illustrating patterns of changing analyte concentrations over successive survey programs only and no statistical inferences were made. Analyte concentration ranges depicted in the 2D spatial plots state the upper range limits within the legend; however, the lower range limit is the previous upper limit.

To detect changes at different distances, primary and secondary stations sampled in both survey years were binned into three distance-from-source categories: Near-field (≤1,000 m), Mid-field (1,000-2,000 m), Far-field (>2,000 m), and Total. Screened-in analytes (log_{10} transformed) were evaluated for correlations with sediment grain sizes (arcsine transformed) with Pearson correlations. For analytes that did not have a large positive correlation (r<0.5), a two-way analysis of variance (ANOVA) was performed using the R statistical software. For analytes with a large positive correlation (r>0.5) and analysis of covariance (ANCOVA) was conducted. If the interaction term between Year and either Field or Distance and the covariate was significant ($p<0.05$), the ANCOVA was deemed inappropriate and an ANOVA was conducted instead. Graphical representations (boxplots) of concentration differences between years for each analyte analyzed were generated in R statistical software. If only one year was available for analysis, then a box plot showing the differences between distance categories was generated. A possible project-related effect was indicated if the interaction term was significant between years for each distance from source.

4.2.1.2 Toxicity

All sediment samples within 500 m of the platform and all samples above the Petrotox threshold of 150 mg/kg (C_{10}-C_{21}) within 3 km of the source were submitted for toxicity testing (e.g., amphipod bioassays). Results from the Petrotox risk assessment study for PureDrill IA35-LV undertaken at the Hibernia project (Stantec 2013) is used as a screening tool for toxicity testing. The threshold for effects at total petroleum hydrocarbon (TPH) concentrations in sediment samples is ≥150 mg/kg of >C_{10}-C_{21} (EMCP 2017). All sediment samples above this threshold will be screened-in for amphipod testing. Sediment toxicity analyses were conducted by Avalon Laboratories (Paradise, Newfoundland and Labrador). Amphipod bioassays test the survival rate of organisms

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

The bioassay procedure is thus, each sediment sample is divided into five replicate containers with 20 amphipods (*Rhepoxynius abronius*) each. The amphipods are exposed for ten days, after which the percent survival is examined between the test and control samples. Sediment sample toxicity was compared to the toxicity results of a control consisting of reference sediment. The reference sediment is natural sediment obtained from the amphipod collection site and was provided by the amphipod supplier. Survival rates of sediment samples were compared to the control sediment and analyzed using Dunnett's t-test. Sediment sulphide, ammonia, and redox potential concentrations for each sample were also compared to a control sample.

4.2.1.3 Benthic Community Structure

Benthic community samples were collected and processed in accordance with the Standard Methods 10200 (APHA 1995). This included preserving samples in 11L buckets with 10% buffered formalin, then sieved with a 0.5 mm mesh screen. Sediment samples from 36 sites were sent un-sieved and preserved in 10 percent buffered formalin for species identification and QA/QC. Species identification and preliminary statistics were conducted by Bio Tech Taxonomy (Hampton, New Brunswick) while initial sediment processing and QA/QC were conducted by Envirosphere (Windsor, Nova Scotia). Samples were washed through a 0.5 mm sieve. Organisms were blotted with paper towels to remove surface water, weighed to the nearest mg, and identified to the lowest possible taxonomic level. Foraminifera and nematode (meiofauna) presence were noted but not counted.

Samples were analyzed for number of taxa, total abundance, total biomass, species richness, and community structure. Benthic community structure parameters reported for 2018 are: number of taxa (S), total abundance (N), total biomass (g), species richness (d), evenness (J'), and Shannon-Weiner diversity index (h') (Table 4-21). Number of taxa indicate the number of species found at each site. Total abundance is the number of individuals (all species) found at each site. Biomass is the wet weight of all individuals found at each site. Species richness (d) considers the number of taxa (S) and number of individuals (N) present in a sample. The higher value (d) indicates the greater taxa richness. Evenness (J') indicates how evenly the number of individuals is distributed among the species present. Low scores (J') indicate more variation in abundances between taxa at each site. The Shannon-Wiener diversity index (H') is a measure of both abundance and evenness of species present at each site. A high value (H') indicates a highly diverse and equally distributed where no one taxa is dominant.

Benthic community data collected in 2014 were used as a baseline. Analysis focused on change in the main indices of community structure as a measure of habitat disruption. Hebron EEM 2018 sediment and chemistry data were transformed as needed and normalized while faunal data was square root transformed. Univariate and multivariate statistics were conducted on the benthic community data using PRIMER with PERMANOVA+(ver. 6.1.15, PRIMER-E Ltd, Plymouth, UK; Clarke and Warwick 2001). The sediment and chemistry data were compared to family abundance data for 2018 samples using a multivariate distance-based linear model (stepwise, AICc) (Anderson et al. 2008). This allows for the detection of individual sites that deviate from the expected in large-

scale monitoring programs (Anderson et al. 2008). Sediment and chemistry data was log transformed and normalized as part of the Distance-Based Linear Modelling (DISTLM; Anderson et al. 2008).

4.3 Results

4.3.1 Physical and Chemical Characteristics

Chemical profiles can be strongly influenced by sediment particle size, compositional characteristics, and the surface area of the sediment type (Horowitz 1985; Herut and Sandler 2006). Finer particle sizes, especially clay and silt, have been shown to have higher concentrations of phyllosilicates and organic matter (Herut and Sandler 2006). Discharged drill cuttings primarily consist of finer particle sizes which can carry "markers" of drilling activity beyond the platform, thus it is important to monitor changes within the survey area.

Percent concentration clay particle levels changed between 2014 and 2018. Spatial plots are for both sampling years are presented in Figure 4-4 and the change between years is represented in Figure 4-5. Clay particle percent concentration reported from 2014 samples range between 0.15 to 1.80 percent. Sites near the platform were between 0.15 to 0.45 percent, with sites reporting higher concentrations located >6,000 km towards the northeast of the platform (Figure 4-4, A). In 2018, samples collected near the platform and several >6,000 m reported an overall increase to >0.90 percent concentration (Figure 4-4, B). There was only one report of concentrations below 0.90 percent clay which was collected at Site 4-4000, southwest from the platform. Changes in percent clay concentration ranged between -0.55 to 1.21 percent with most sites reporting an increase in percent clay concentration between 2014 and 2018 (Figure 4-5). The increases occurred at sites close to the platform (<4,000 m) and Site 6-1500 reported the highest increase of 1.21 percent.

Concentrations of silt varied per site and distance from platform between 2014 and 2018 sampling years. Silt concentrations reported in 2014 around the platform ranged from 0.05 to 0.52 percent with higher concentrations (1.03 percent) reported at two stations (6-3000 and 4-2000) towards the southeast (Figure 4-6, A). Samples collected >6,000 m towards the northeast of the platform had concentrations ranging between 0.05 to 1.03 percent. However, in 2018, sites sampled around the platform and at distances >6,000 m had concentrations ranging between 0.05 to 0.26 percent (Figure 4-6, B) with Site 8-250 reporting a concentration of 1.03 percent. This site also had the highest reported change between years at 0.74 (Figure 4-7). Other sites reported either no change in levels or a decrease from 2014 to 2018.

Sand is the dominant sediment fraction in samples collected in 2014 and 2018. Samples ranged between 72.00 to 100.00 percent sand (Figure 4-8). Spatial differences in sand concentration between years were observed at sites >6,000 m (Figure 4-9). A slight increase of sand concentration was reported at sites 2-1250 and B-3000, and slight decreases at sites B-1250 and D-250.

Gravel concentration was reported at zero percent around the platform in 2014 and 2018 (Figure 4-10). Samples collected in the northeast at distances >6,000 m reported levels between 0.00 to 26.70 percent in 2014 and 2018. There were changes reported at several sites in the northeast sampling area between years (Figure 4-11). Site B-1250 had the highest increase in gravel concentration with sites A-1500 and D-250 also reporting slight increases. Sites 2-1250 and B-3000 reported decreases in gravel concentration.

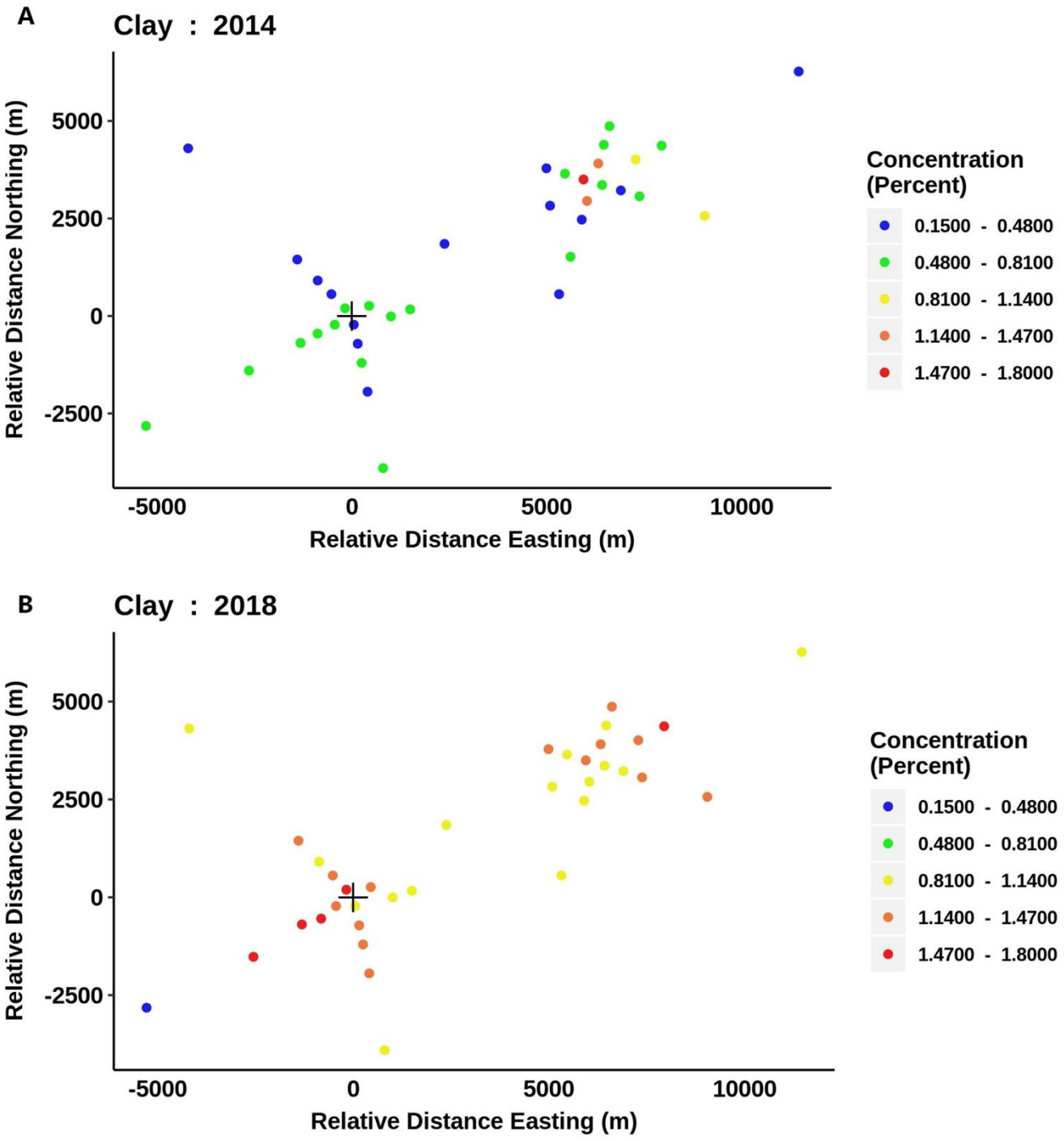

Figure 4-4 Spatial pattern of clay (percent composition) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

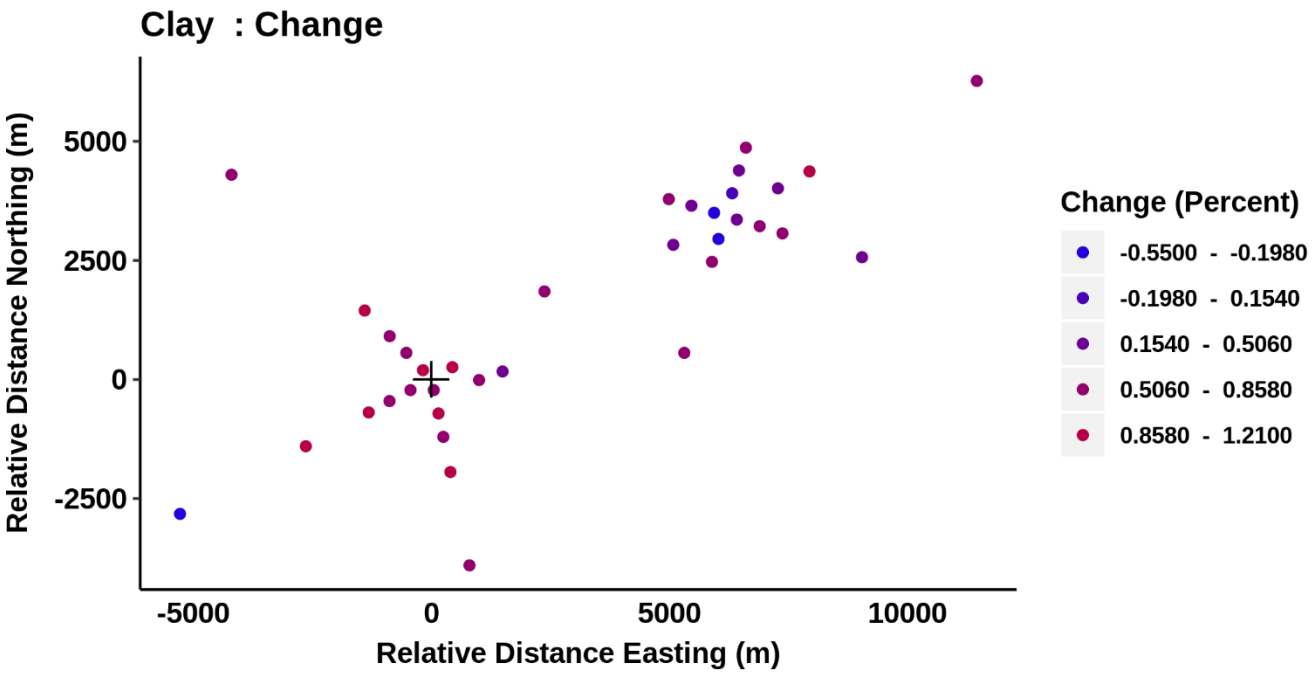

Figure 4-5 Spatial pattern of clay (percent composition) change between 2014 and 2018 levels surveyed around the platform (cross).

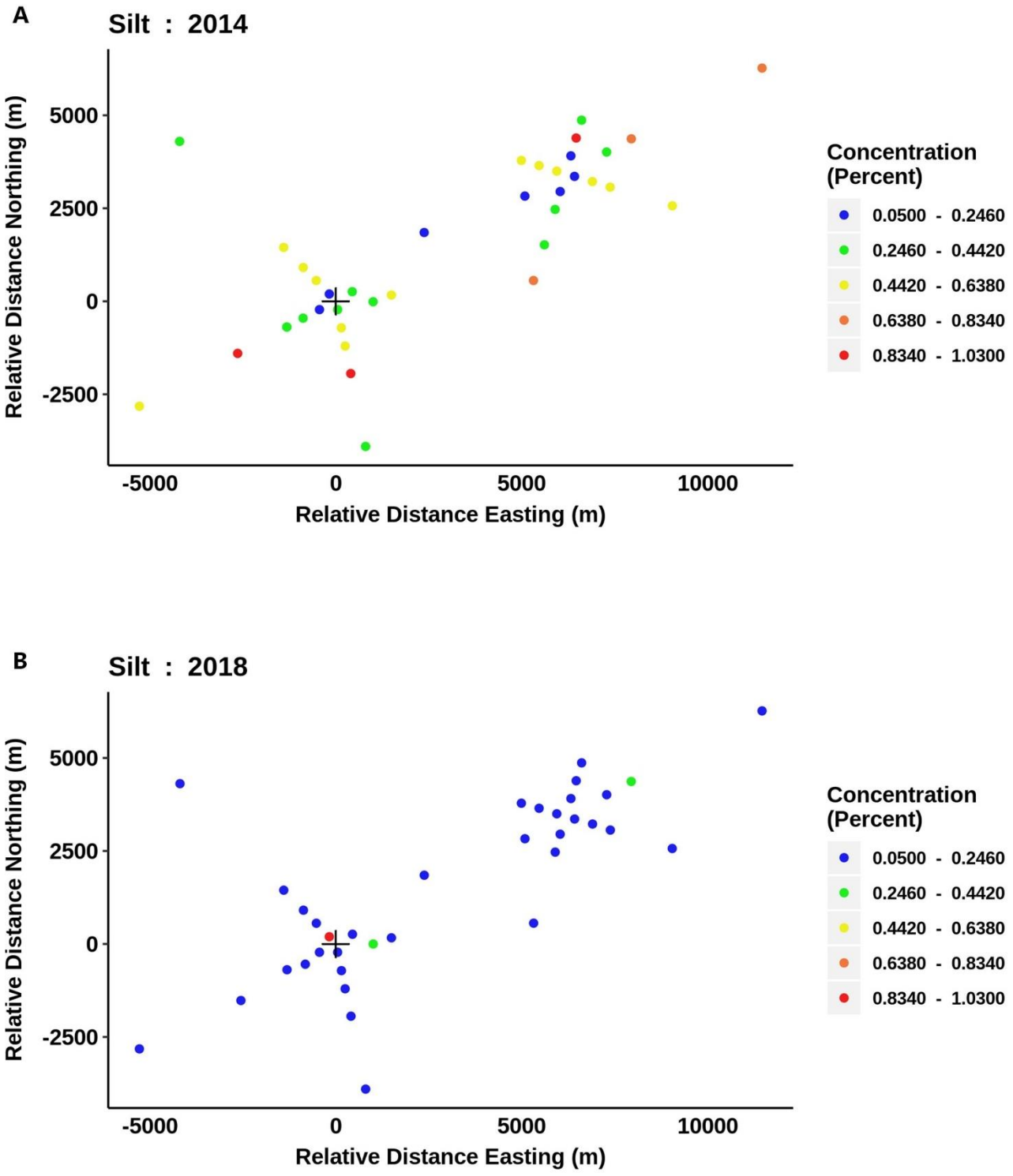

Figure 4-6 Spatial pattern of silt (percent composition) from 2014 (A) and 2018 (B surveyed around the platform (cross).

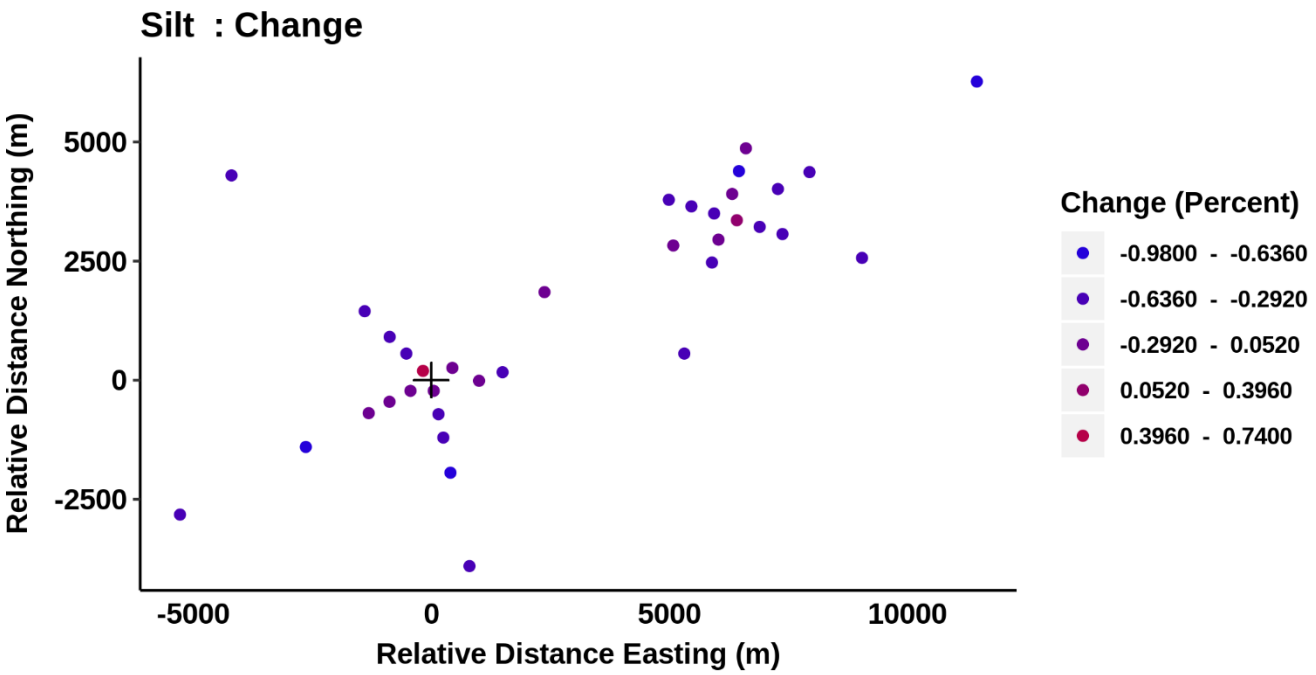

Figure 4-7 Spatial pattern of silt (percent composition) change between 2014 and 2018 levels surveyed around the platform (cross).

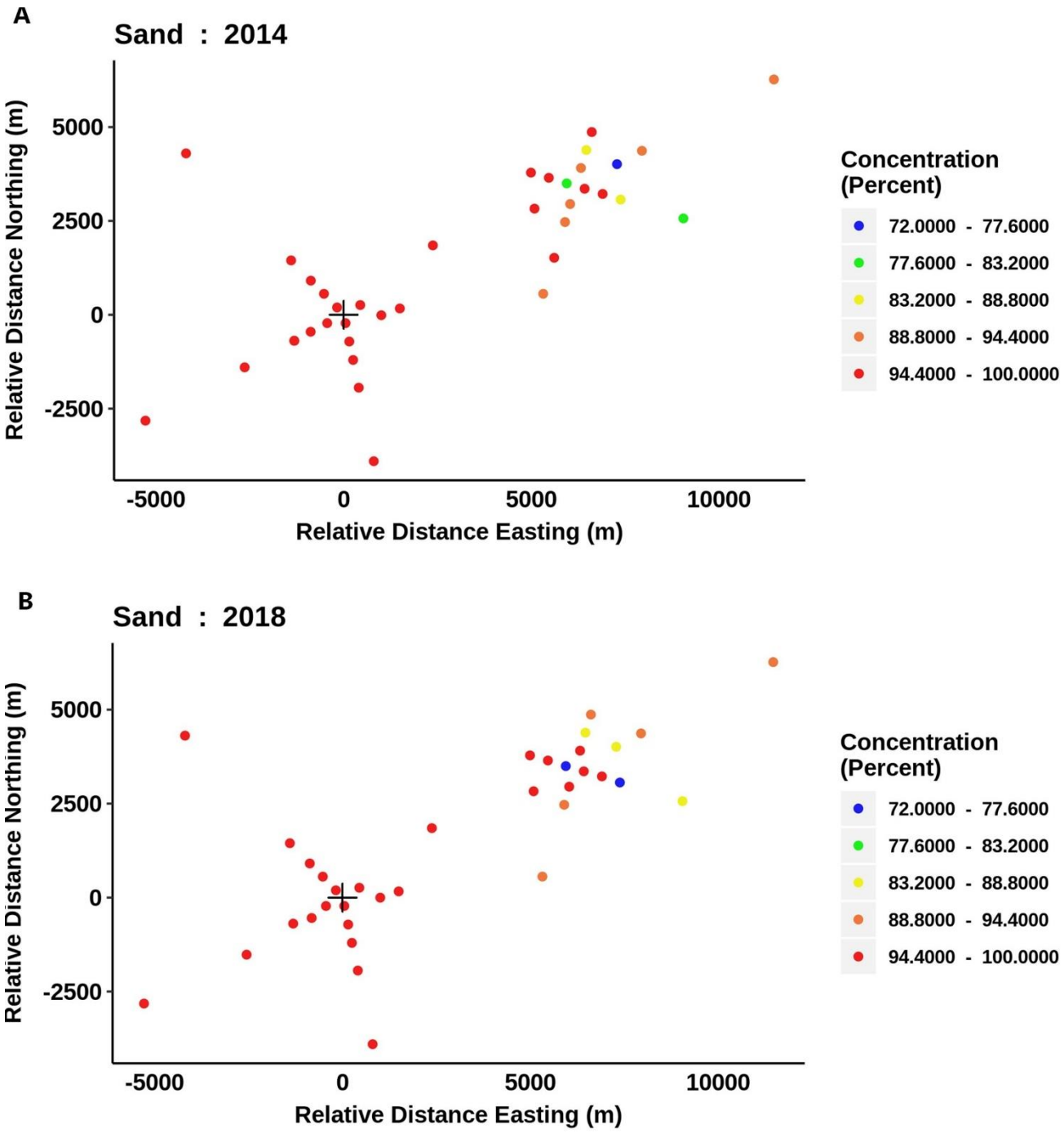

Figure 4-8 Spatial pattern of sand (percent composition) from 2014 (A) and 2018 (B) surveyed around platform (cross).

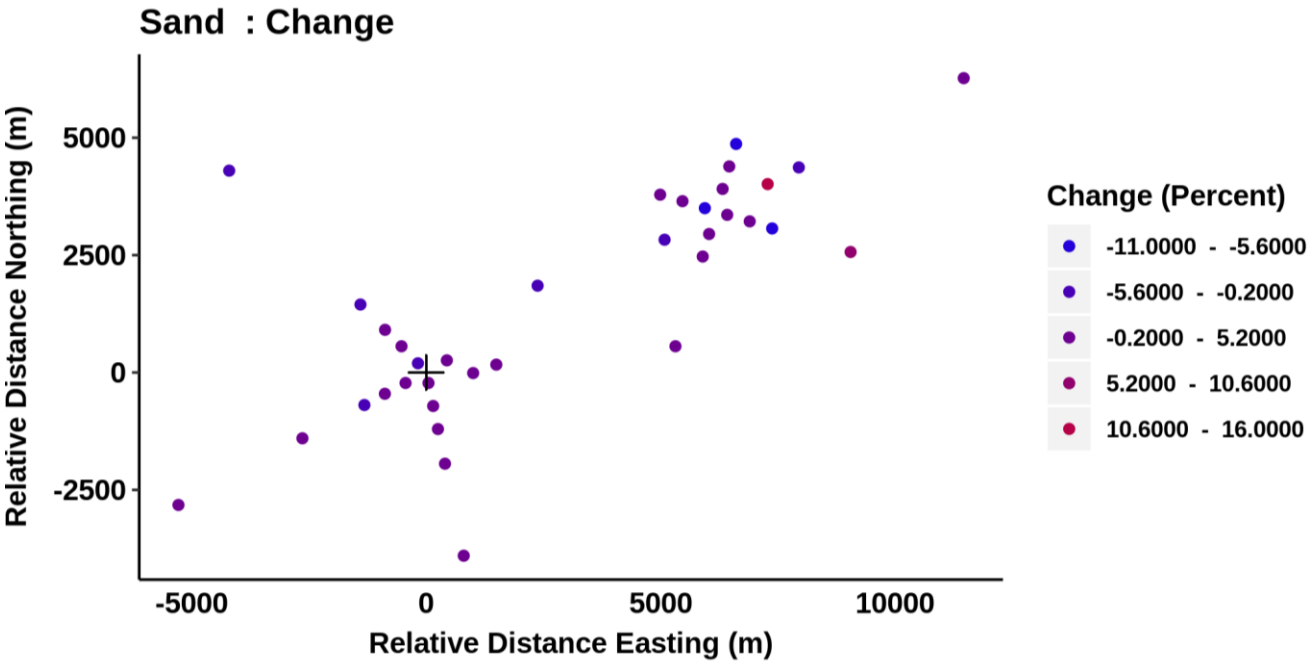

Figure 4-9 Spatial pattern of sand (percent composition) change between 2014 and 2018 levels surveyed around the platform (cross).

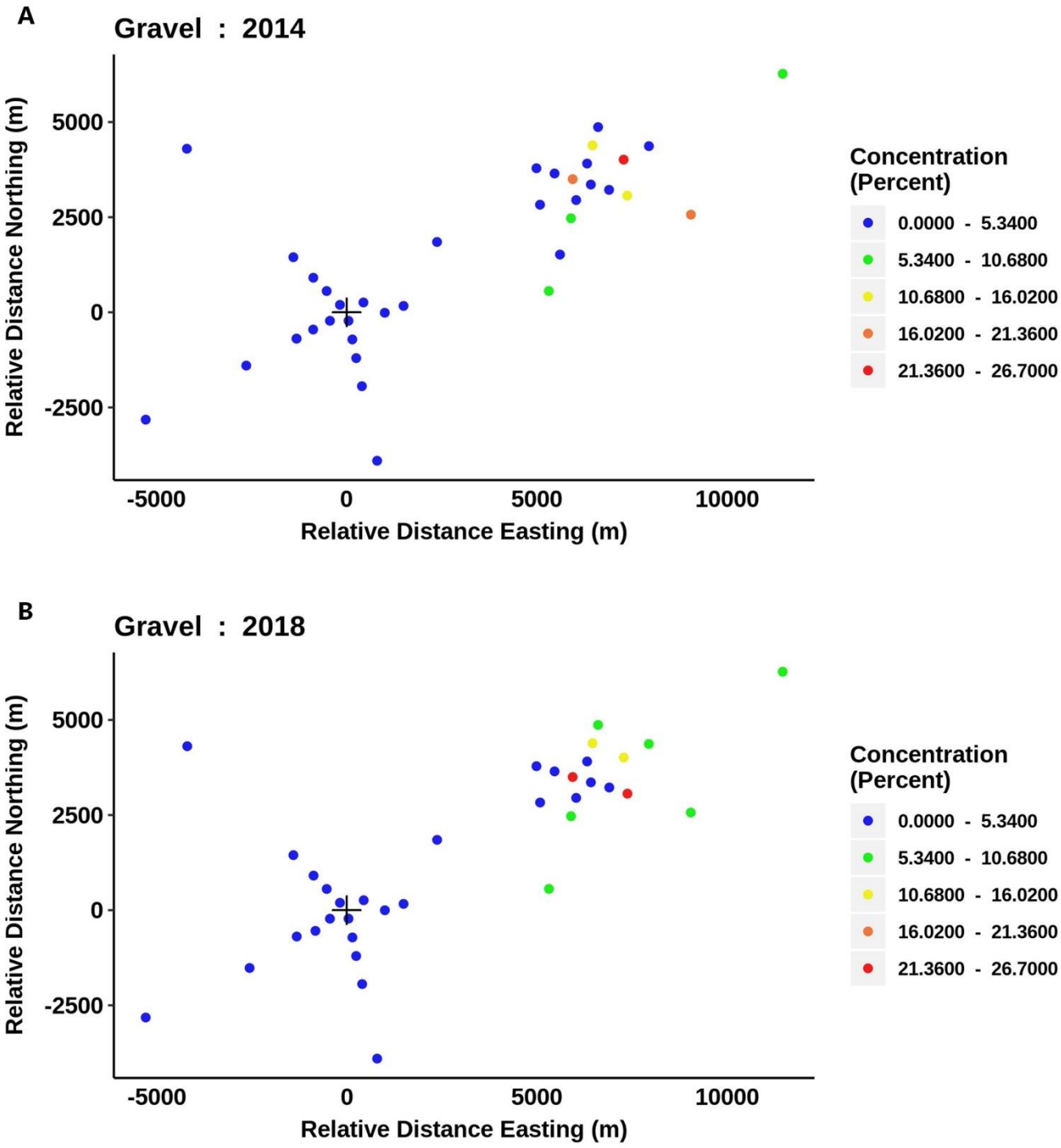

Figure 4-10 Spatial pattern of gravel (percent composition) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

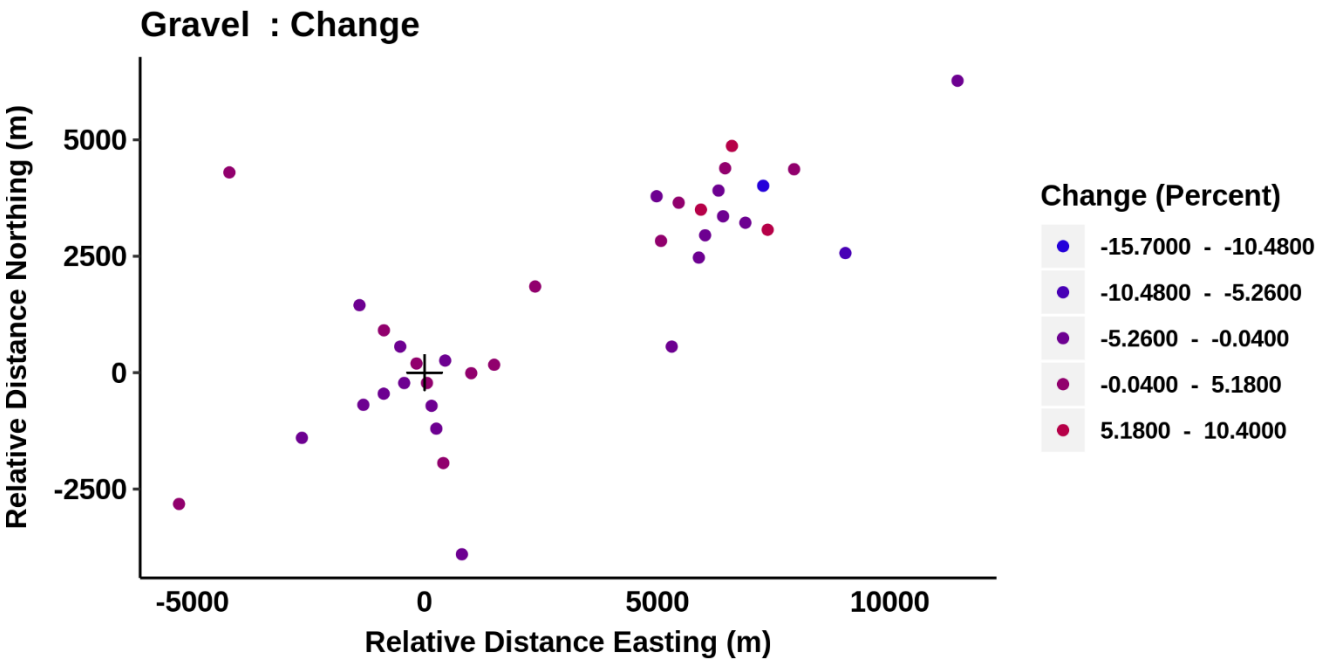

Figure 4-11 Spatial pattern of gravel (percent composition) change between 2014 and 2018 levels surveyed around the platform (cross).

Statistical Analysis

From Pearson correlation analyses, there were no significant positive correlations between the four particle sizes. To compare differences between year and distance bin (Field in table), two-way ANOVAs were conducted on each sediment fraction. Results are presented in Table 4-4 to Table 4-7. Graphical representations of sediment faction differences between sampling years are presented in Figure 4-12 to Figure 4-15.

There were statistically significant differences between years for both clay and silt ($p<0.001$). Median percent composition of clay increased over all distances between 2014 and 2018 (Figure 4-12) while there was a decrease in silt (Figure 4-13). The interaction term (Field x Year) was statistically significant for each both clay and silt ($p<0.05$) which may indicate a Project-related effect. Sand and gravel percent composition did not have a statistically significant difference between sampling years (Table 4-6, Table 4-7, Figure 4-14); however there was for Field ($p<0.001$). Gravel and sand composition was statistically different at the Far-field stations compared to Near- or Mid- (Tukey HSD $p<0.01$ and $p<0.05$ respectively). The median gravel percent composition in the Far-field decreased (Figure 4-15) while the composition of sand increased (Figure 4-14).

Table 4-4 Two-way ANOVA table for clay percent concentration (arcsine transformed)

Clay Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.000	0.000	0.175	0.840	
Year	1	0.017	0.017	67.948	<0.001	***
Field x Year	2	0.002	0.001	3.856	0.026	*
Residuals	66	0.016	0.000			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-5 Two-way ANOVA table for silt percent concentration (arcsine transformed).

Silt Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.000	0.000	0.336	0.716	
Year	1	0.023	0.023	91.262	<0.001	***
Field x Year	2	0.002	0.001	3.404	0.039	*
Residuals	66	0.017	0.00			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-6 Two-way ANOVA table for sand percent concentration (arcsine transformed).

Sand Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.231	0.116	7.974	<0.001	***
Year	1	0.002	0.002	0.151	0.699	
Field x Year	2	0.001	0.001	0.040	0.961	
Residuals	66	0.957	0.015			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-7 Two-way ANOVA table for gravel percent concentration (arcsine transformed).

Gravel Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.388	0.194	10.473	<0.001	***
Year	1	0.002	0.002	0.091	0.763	
Field x Year	2	0.000	0.000	0.008	0.992	
Residuals	66	1.222	0.019			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

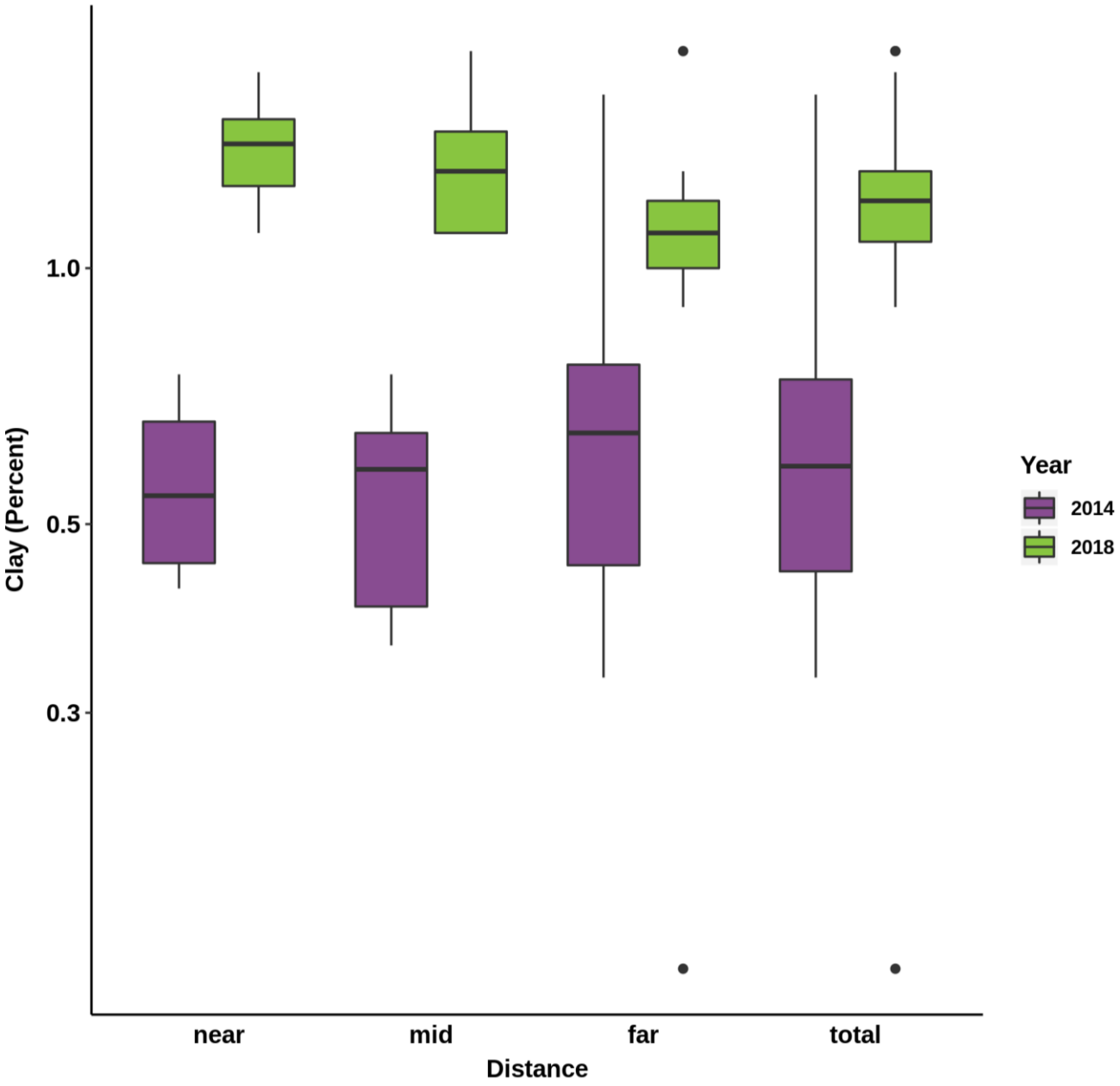

Figure 4-12 Boxplots of clay (percent composition) in sediment for three distances bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total <10,000 m) for years 2014 and 2018 around the platform. Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

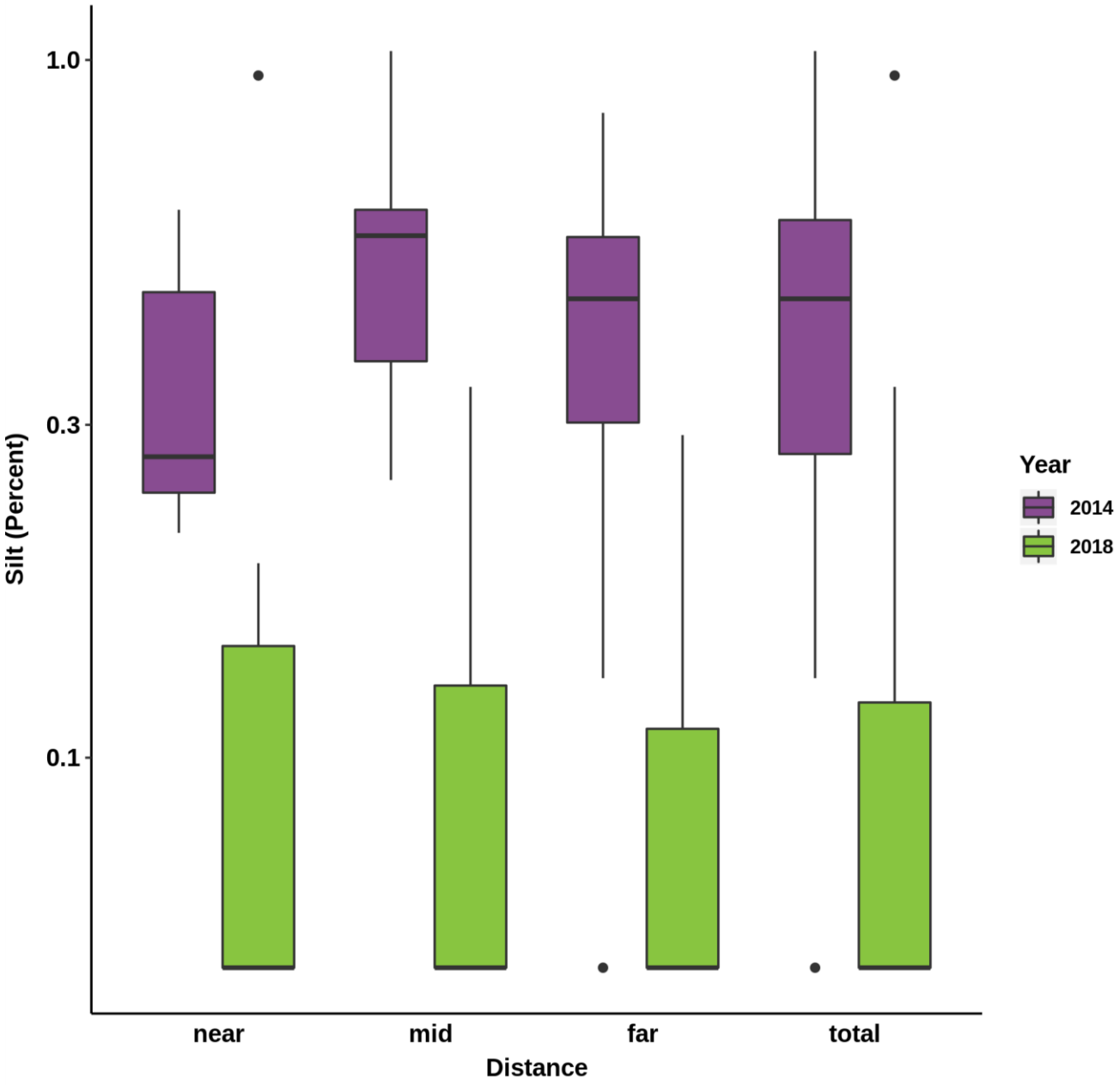

Figure 4-13 Boxplots of silt (percent composition) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total <10,000 m) for years 2014 and 2018 around the platform. Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

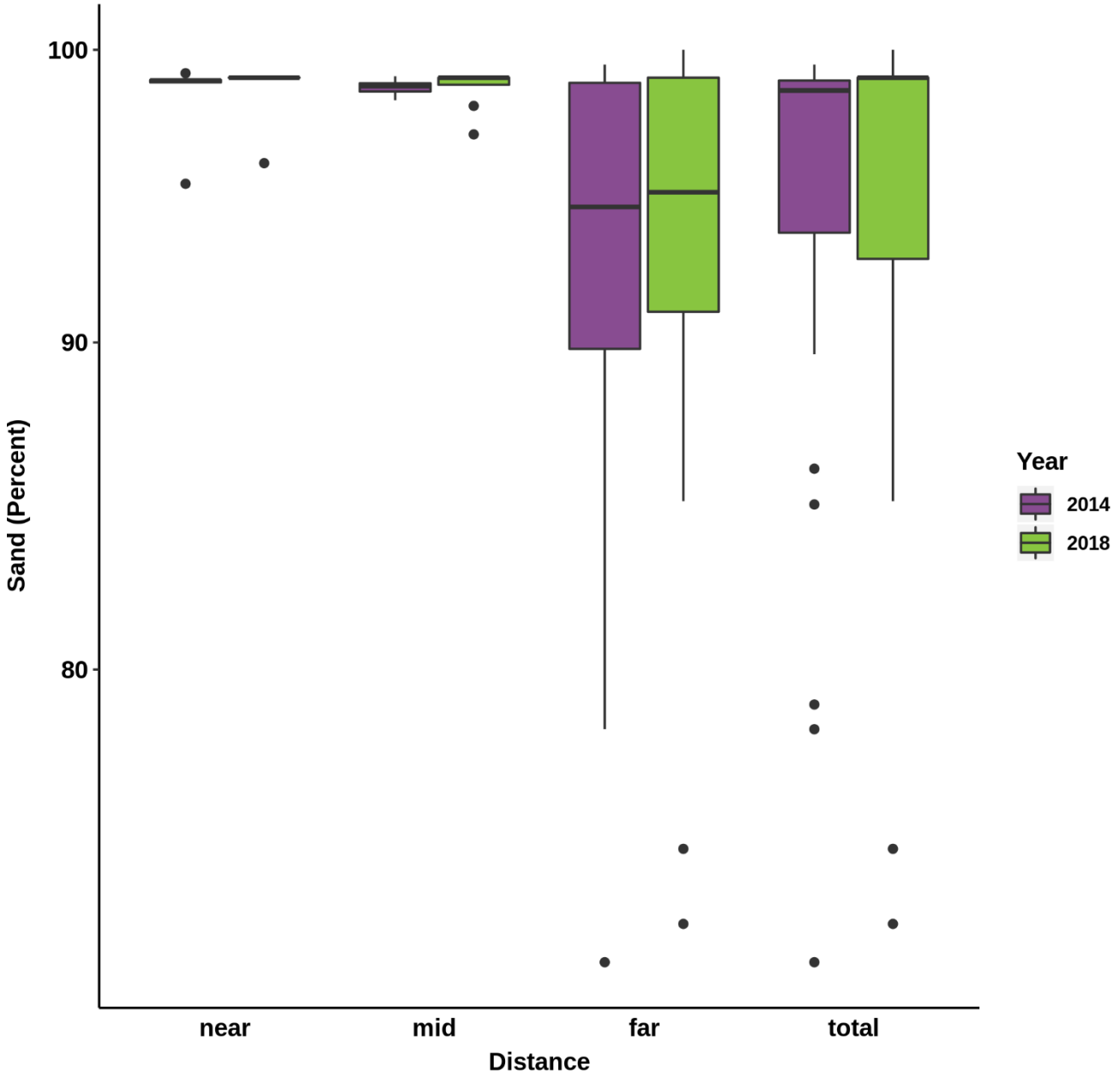

Figure 4-14 Boxplots of sand (percent composition) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total <10,000 m) for years 2014 and 2018 around the platform. Horizontal lines represent median percent compositions, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

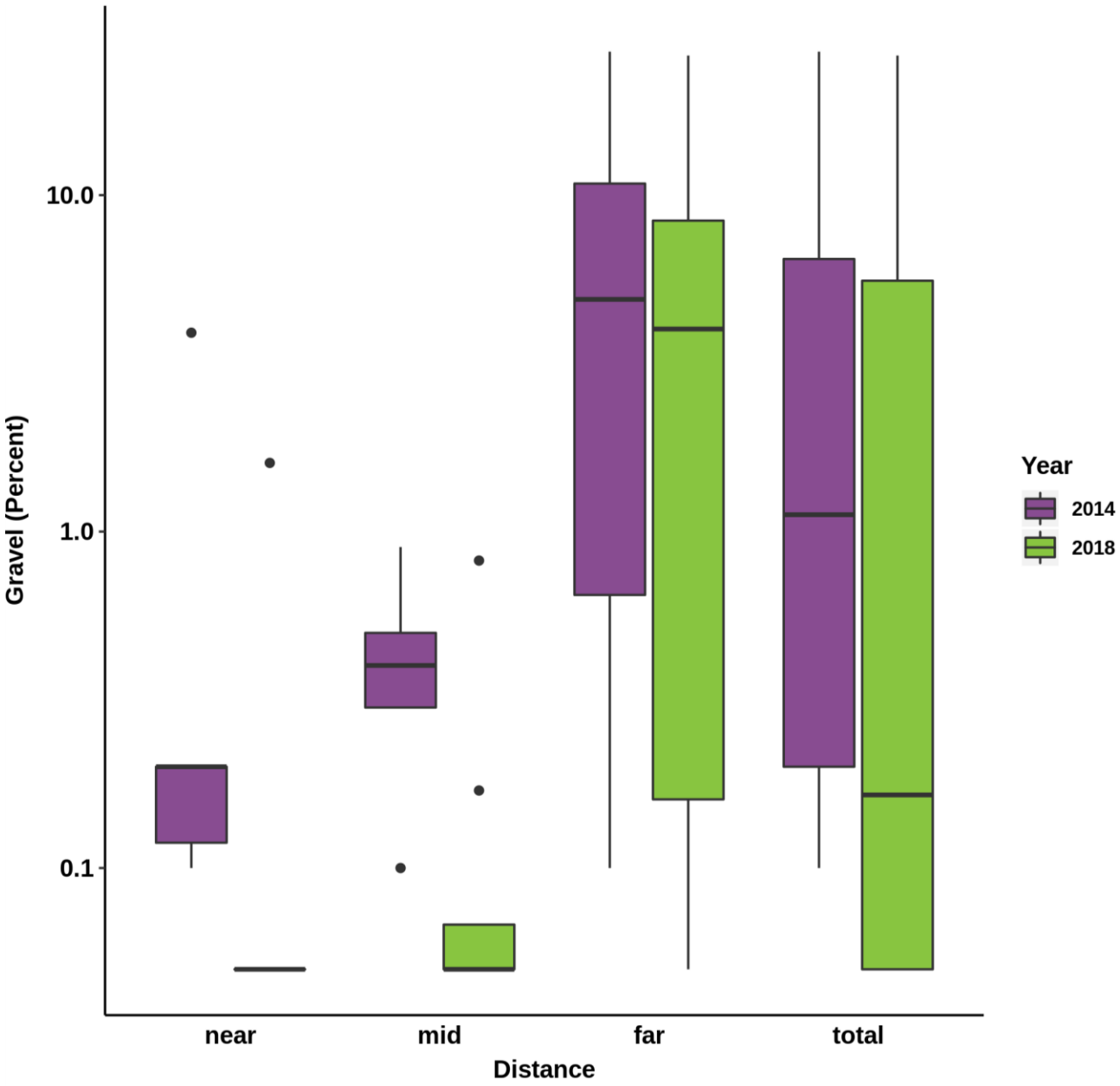

Figure 4-15 Boxplots of gravel (percent composition) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total <10,000 m) for years 2014 and 2018 around the platform. Horizontal lines represent median percent composition, boxes represent the Middle quartiles, and whiskers represent 1.5 times the interquartile range. Data beyond the whiskers are represented as individual dots.

4.3.1.1 Metals

The analytes barium, lead, iron, and manganese reported concentration levels at or above RDL in at least half of the samples tested and were therefore selected for further analysis. The 2D distribution maps and ANOVA analysis of the metal analytes are discussed in the following sections. Barium sulphate ($BaSO_4$) is one of the main components of drilling muds (both water and synthetic based) and has been used as a marker for drilling activities (Neff 2008; Bakhtyar and Gagnon 2012; Trefry et al. 2013; DeBlois et al. 2014b).

In 2014, barium concentrations ranged between 65 to 160.0 mg/kg. In 2018, these concentrations were largely the same except for samples taken at Site 8-250 (northwest of platform) which reported a concentration of 1,100 mg/kg (Figure 4-16,B). Barium concentration at Site 8-250 changed by 1,001 mg/kg from 2014 to 2018 (Figure 4-17).

In 2014, lead concentrations around the platform were between 1 to 2.2 mg/kg (Figure 4-18, A). These concentrations increased in 2018 to a range of1.8 to 3.6 mg/kg. Samples collected >6,000 m also increased in 2018, with levels reported between 0.9 to 2.7 mg/kg (Figure 4-18,B). Changes between years were observed throughout the samples (between -0.8 to 1.9 mg/kg) with no discernable pattern. Consistent with barium, the largest concentration increase occurred at Site 8-250 to the northwest of the platform (Figure 4-19).

Reported 2014 iron concentrations ranged between 77 and 1,700 mg/kg within the sampling area (Figure 4-20, A). Concentrations in the Near-field distance bin were between 77 to 1,050 mg/kg. The highest concentrations occurred at distances >2,000 m. In 2018, Near-field iron concentrations were reported between 1,050 and 1,575 mg/kg (Figure 4-21, B). Sites at distances >2,000 m reported concentrations between 1,050 to 2,100 mg/kg. Differences between 2014 and 2018 ranged between -600 to 790 mg/kg with the largest increases occurring at sites 8-250 (Near-field) and C-500 (Far-field). Sites to the south of the platform reported changes between 0 to 500 mg/kg.

Manganese concentrations ranged between 14 to 58 mg/kg for most of the sites collected in 2014 with the highest concentrations (58 mg/kg) reported for samples to the south of the platform at distances >3,000 m (Figure 4-22, A). A similar distributional pattern was observed in 2018 with concentrations of 3 to 34 mg/kg reported in most of the sampling area with the highest concentrations (68 mg/kg) reported in the southwestern sample region (Figure 4-22, B). Manganese concentrations changes between years ranged from -16 to 23 mg/kg (Figure 4-23). The largest increases occurred at Site 6-6000 to the south of the platform and at Site C-500 in the northeast (>6,000 m).

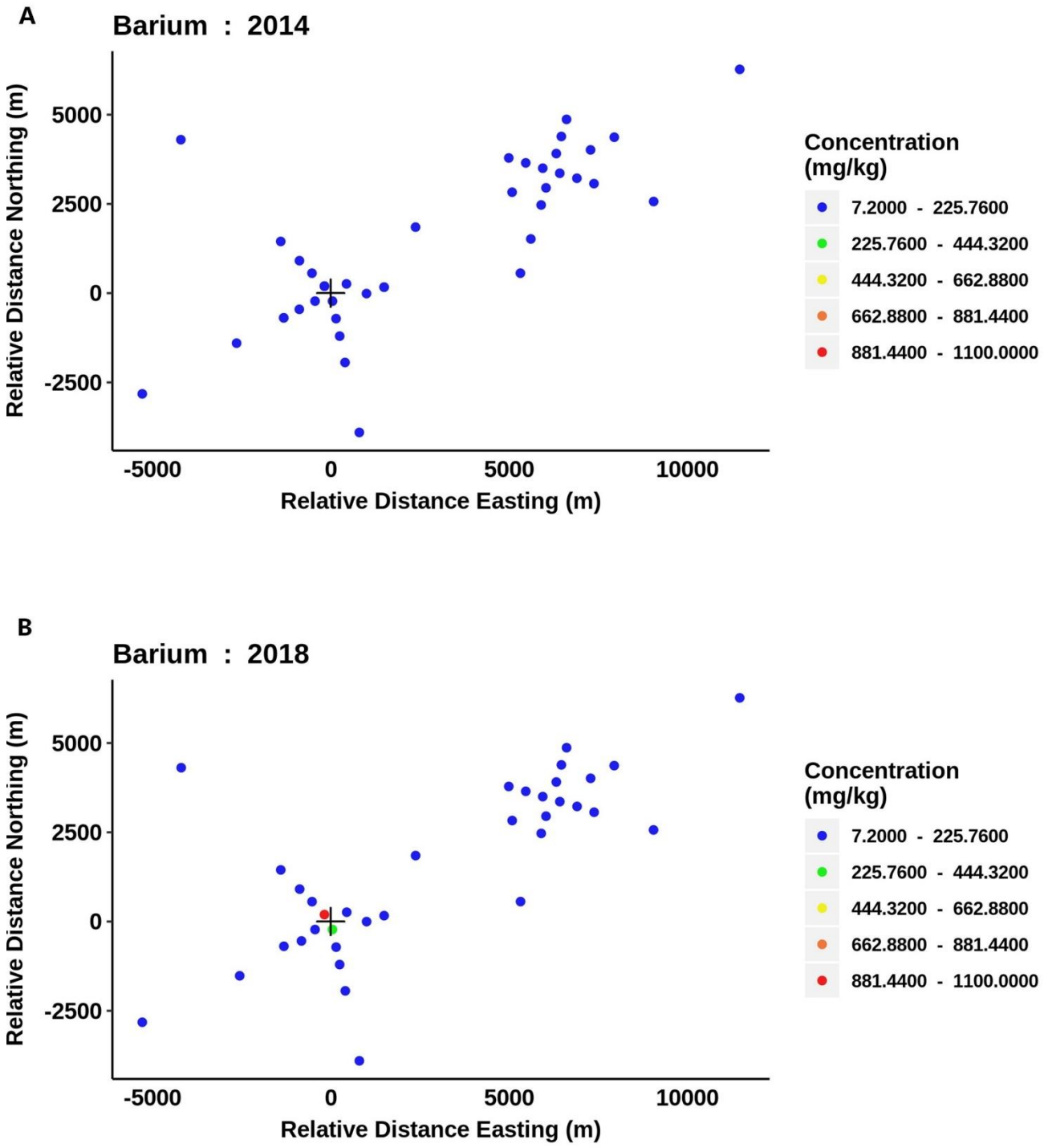

Figure 4-16 Spatial pattern of barium concentration (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

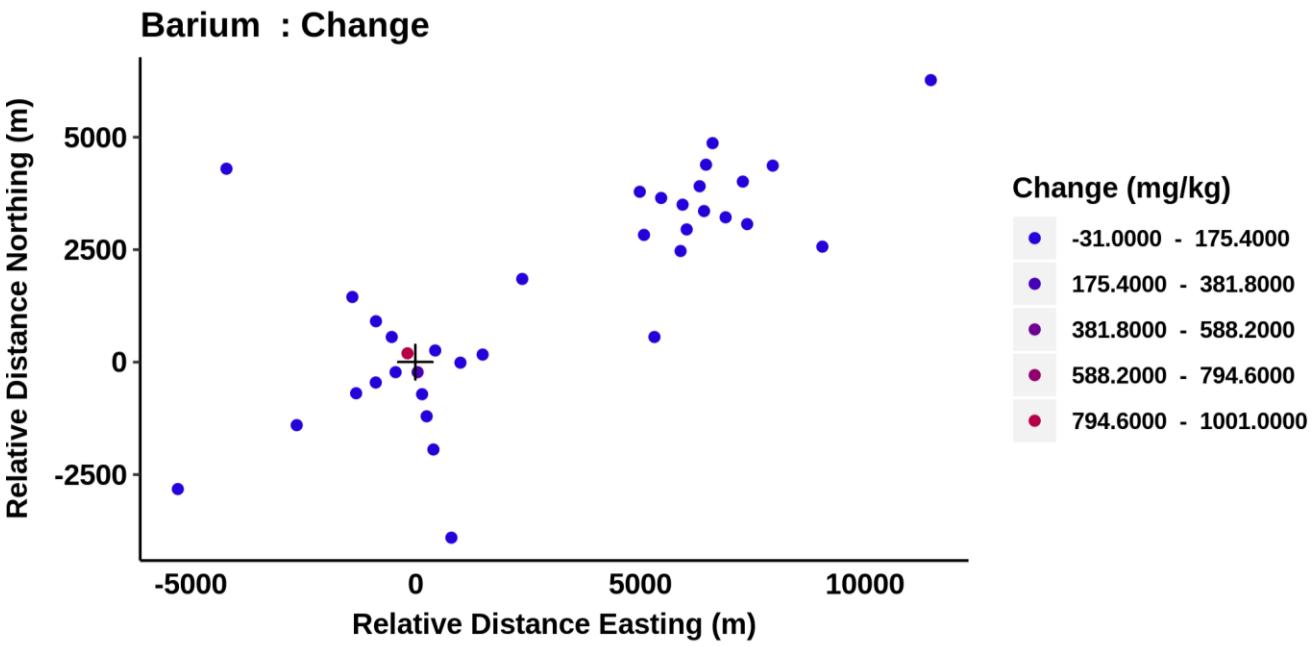

Figure 4-17 Spatial pattern of barium concentration change from 2014 to 2018 surveyed around the platform (cross).

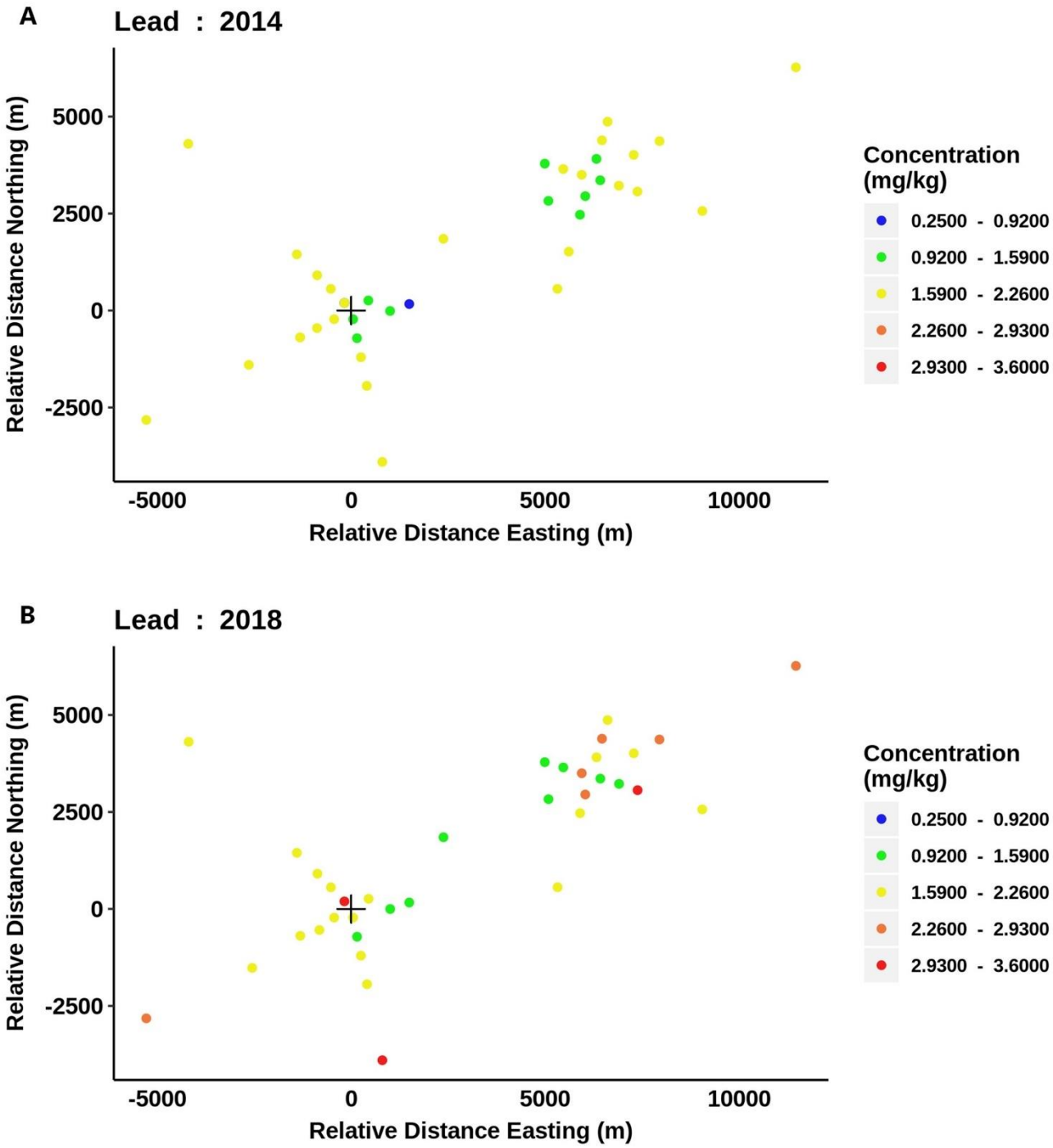

Figure 4-18 Spatial pattern of lead (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

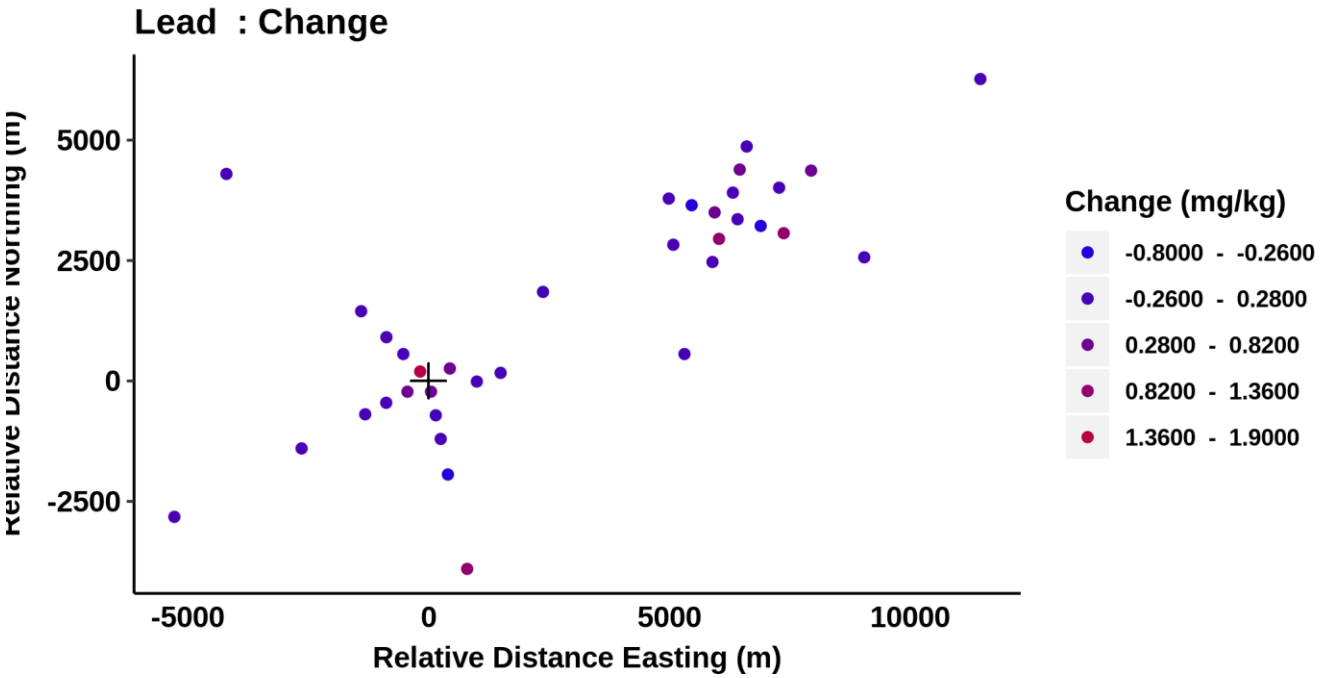

Figure 4-19 Spatial pattern of lead (mg/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

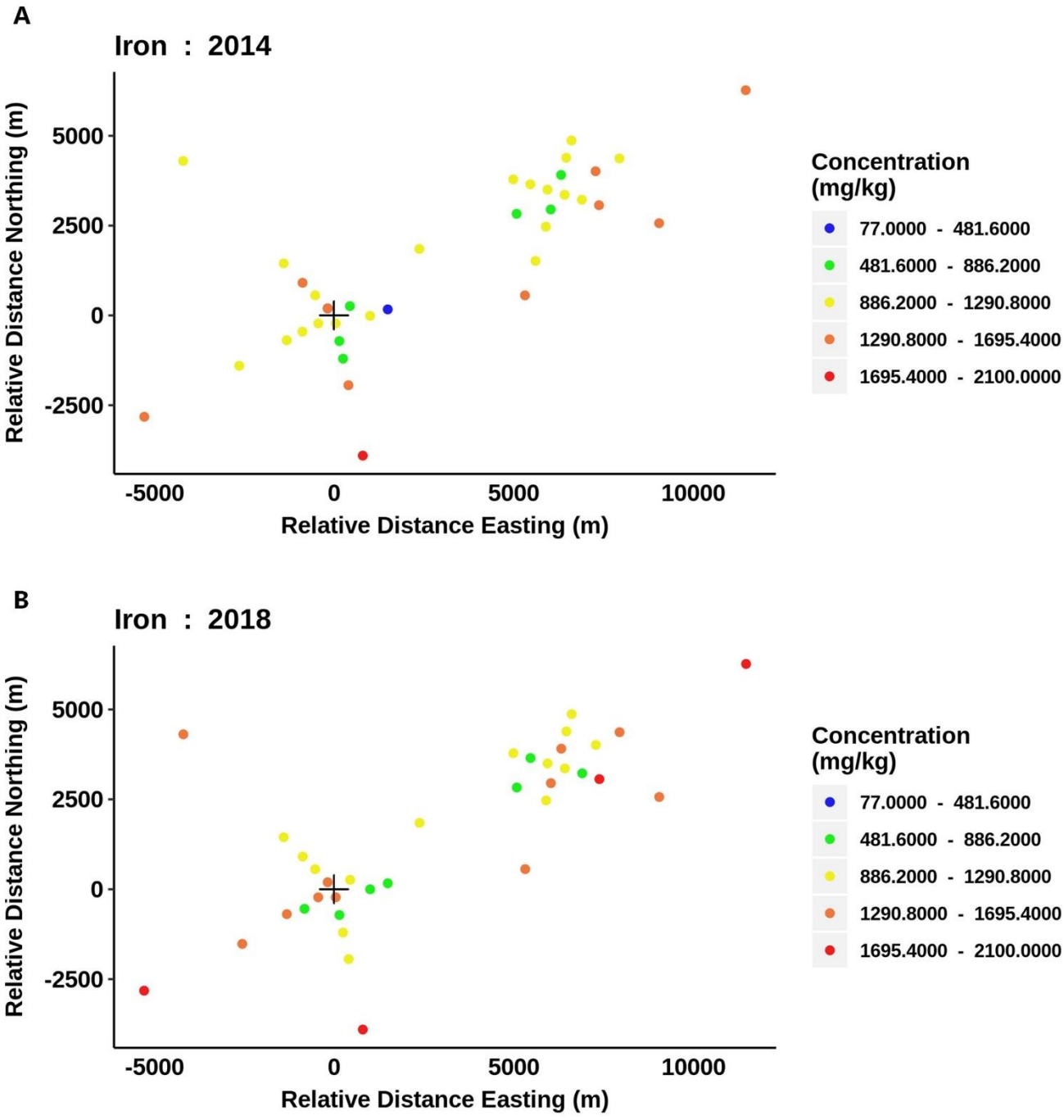

Figure 4-20 Spatial pattern of iron (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

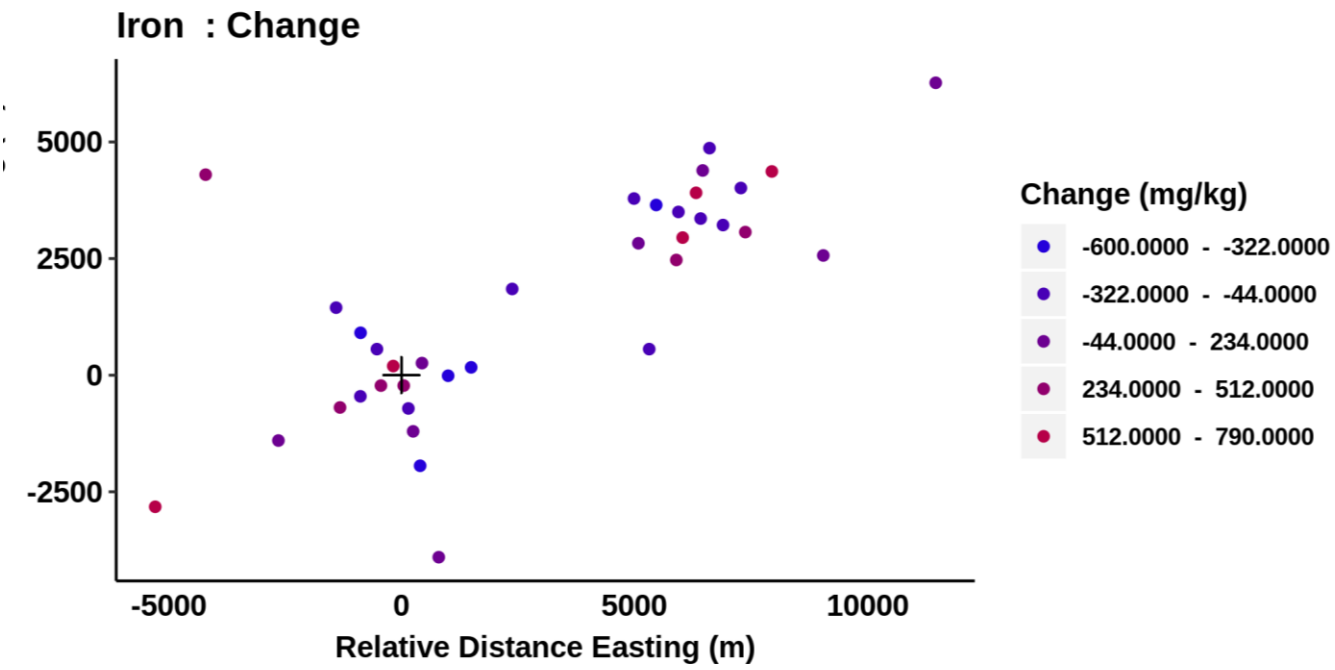

Figure 4-21 Spatial pattern of iron (mg/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

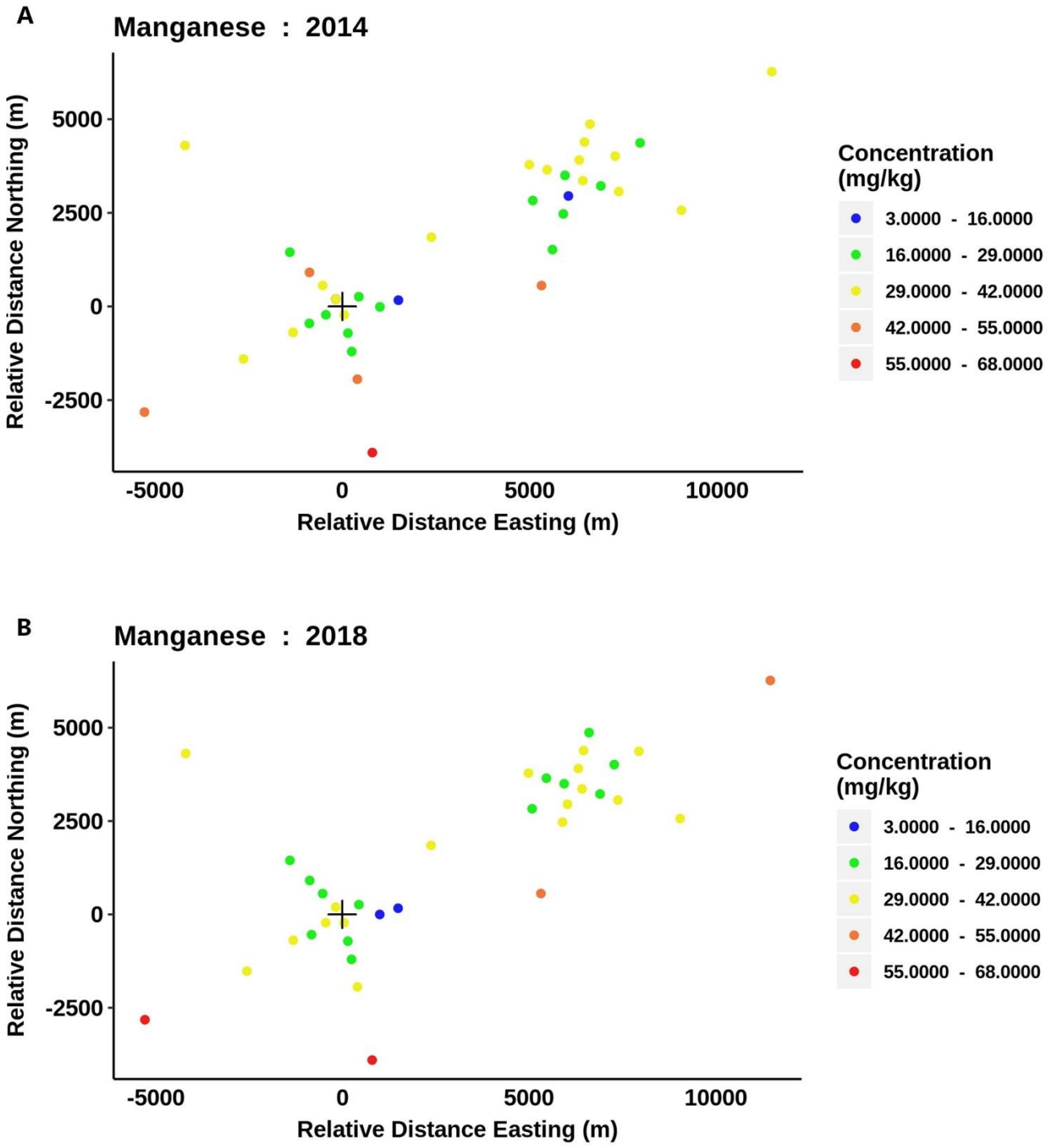

Figure 4-22 Spatial pattern of manganese (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

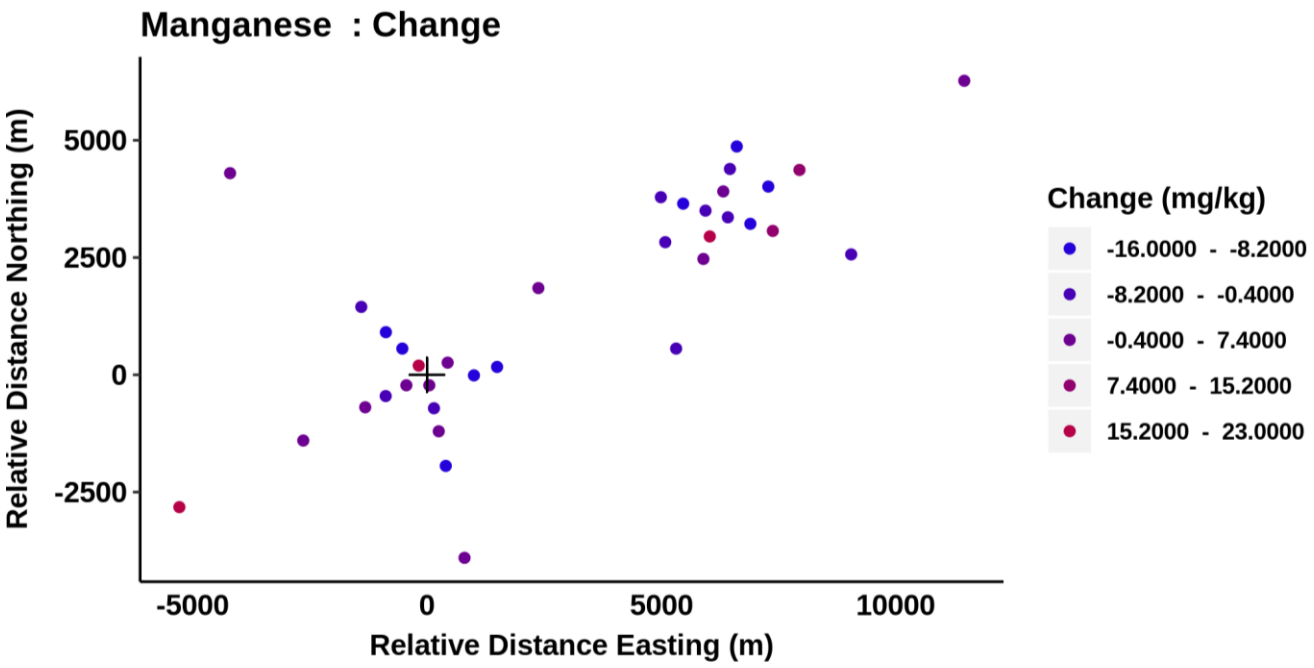

Figure 4-23 Spatial pattern of manganese (mg/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

Statistical Analysis

Pearson correlation analysis was conducted on screened-in analytes with sediment particle sizes (across all years and fields) (Table 4-8). Clay was a covariate with one analyte, total percent sulphur, and an ANCOVA was preformed. Two-way ANOVAs were conducted on the eight analytes and for any analysis that violated assumptions, an ANOVA was conducted.

Table 4-8 Summary of 2018 analytes with Hebron Platform sediment covariate types. Pearson correlations with an *r* above 0.5 are in bold.

Analyte	Covariate Sediment Type (*r* >0.5)			
	Clay	Silt	Sand	Gravel
Barium	0.349	0.164	-0.167	0.141
Lead	0.127	0.199	-0.343	0.337
Iron	-0.09	0.163	-0.237	0.254
Manganese	-0.225	0.164	-0.137	0.166
C10-C21 Hydrocarbons	0.287	0.095	0.215	-0.261
C21-C32 Hydrocarbons	0.448	-0.101	0.003	-0.012
Ammonia	0.110	0.156	0.063	-0.096
Total Percent Sulphur	**0.528***	-0.342	-0.145	0.156
Moisture	0.384	-0.300	0.238	-0.244
Redox Potential	-0.119	-0.054	0.321	-0.099
Organic Carbon (TOC)	0.418	0.014	-0.357	0.329

Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 '
*Indicates sediment type with the highest correlation and used as covariate within ANCOVA analyses.

Barium, lead, and iron were each positively correlated to at least one sediment type but these correlations were below the criteria (r<0.5) and an ANOVA was preformed. Barium concentrations were significantly different between years and fields (distance bins) (Table 4-9). The Field and Field x Year interaction term were statistically significant (p=0.005). A significant interaction term could indicate a Project-related effect. Median concentrations in the Near-field have increased relative to baseline level (Tukey HSD p<0.05; Figure 4-24). As noted from the 2D spatial graphs, Site 8-250 has seen an increase in barium levels and is the source of this change. This is an expected Project-related effect.

An ANOVA was conducted for lead, iron, and manganese (Table 4-10, Table 4-11, Table 4-12). There were no statistically significant results for lead. The factor Field (distance bin) was statistically significant for iron (p=0.036) and manganese (p=0.017). For both iron and manganese, the statistically significant differences were between the Near- and Far-fields (Tukey HSD p<0.1 and p<0.05 respectively). This is likely not a Project-related effect.

Table 4-9 Two-way ANOVA table for barium composition (log_{10} transformed).

Barium Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.199	0.100	4.800	0.011	*
Year	1	0.139	0.139	6.693	0.012	*
Field x Year	2	0.240	0.120	5.781	0.005	**
Residuals	66	1.370	0.021			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-10 Two-way ANOVA table for lead composition (log_{10} transformed).

Lead Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.008	0.004	0.387	0.680	
Year	1	0.024	0.024	2.442	0.123	
Field x Year	2	0.027	0.013	1.350	0.266	
Residuals	66	0.650	0.010			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-11 Two-way ANOVA table for iron composition (log_{10} transformed).

Iron Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.089	0.045	3.511	0.036	*
Year	1	0.001	0.001	0.095	0.759	
Field x Year	2	0.031	0.016	1.227	0.300	
Residuals	66	0.840	0.013			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-12 Two-way ANOVA table for manganese composition (log_{10} transformed).

Manganese Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.192	0.096	4.351	0.017	*
Year	1	0.011	0.011	0.509	0.478	
Field x Year	2	0.038	0.019	0.867	0.425	
Residuals	66	1.454	0.022			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

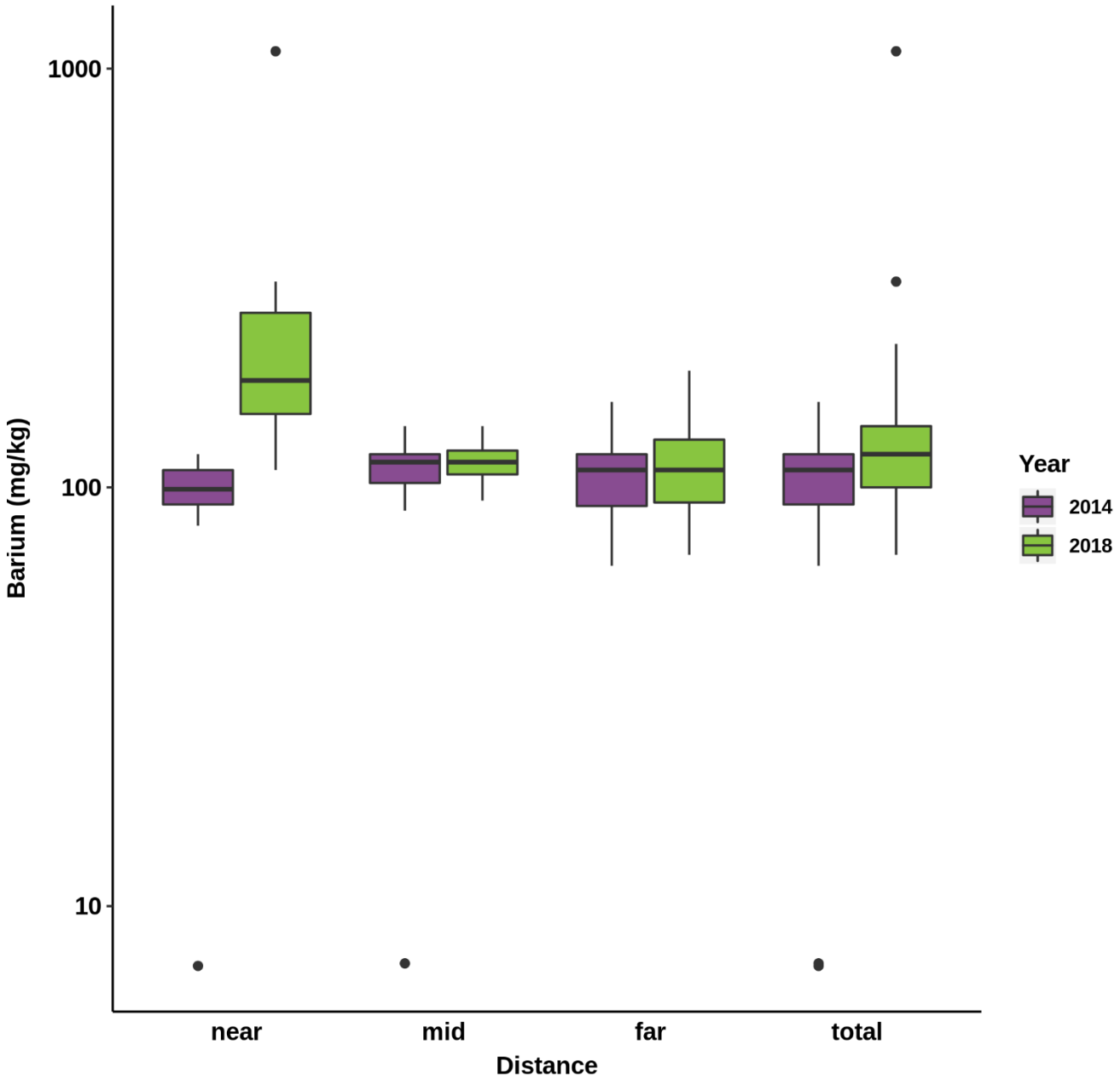

Figure 4-24 Boxplots of barium (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentration, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

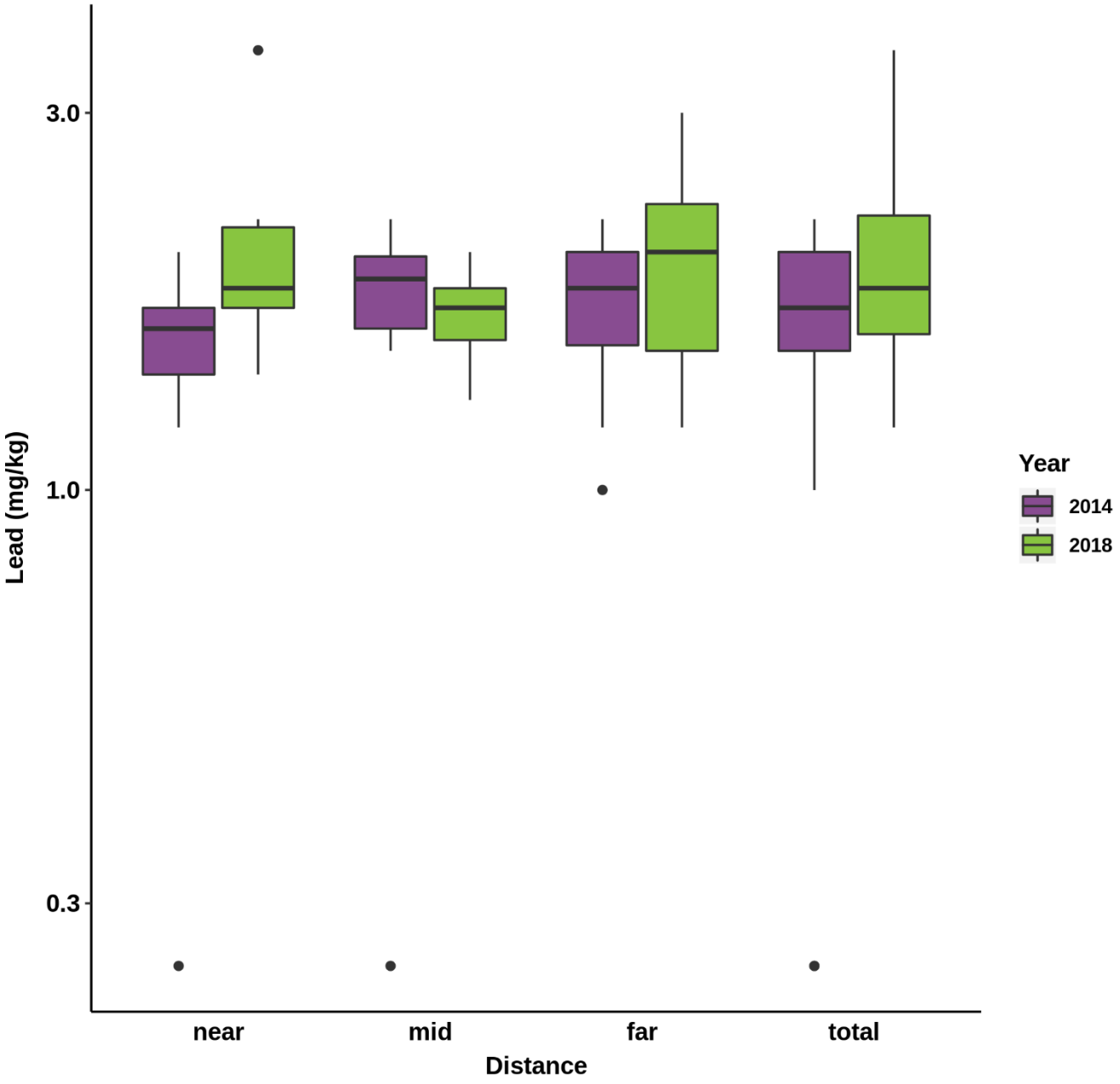

Figure 4-25 Boxplots of lead (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentration, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

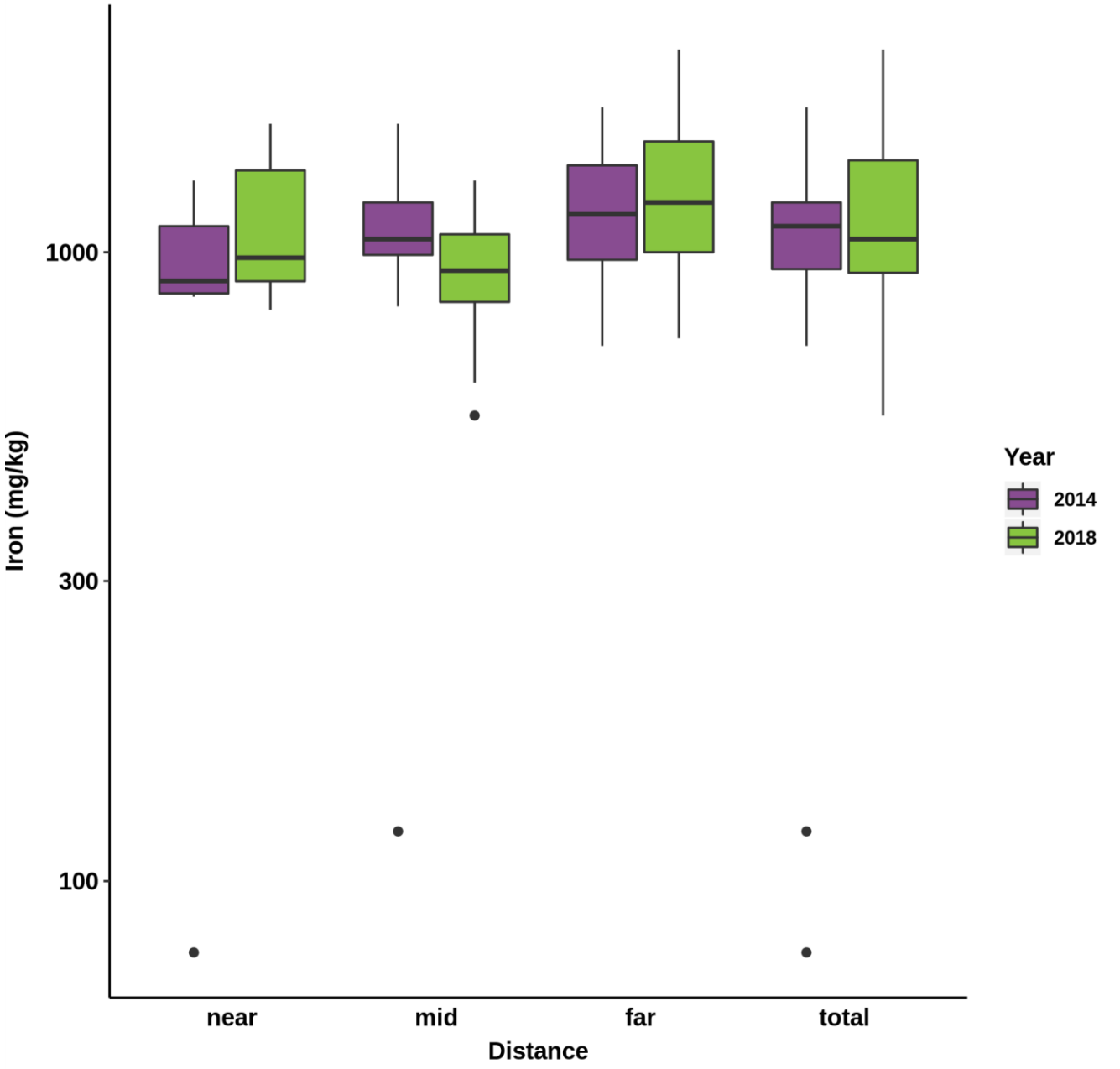

Figure 4-26 Boxplots of iron (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentration, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

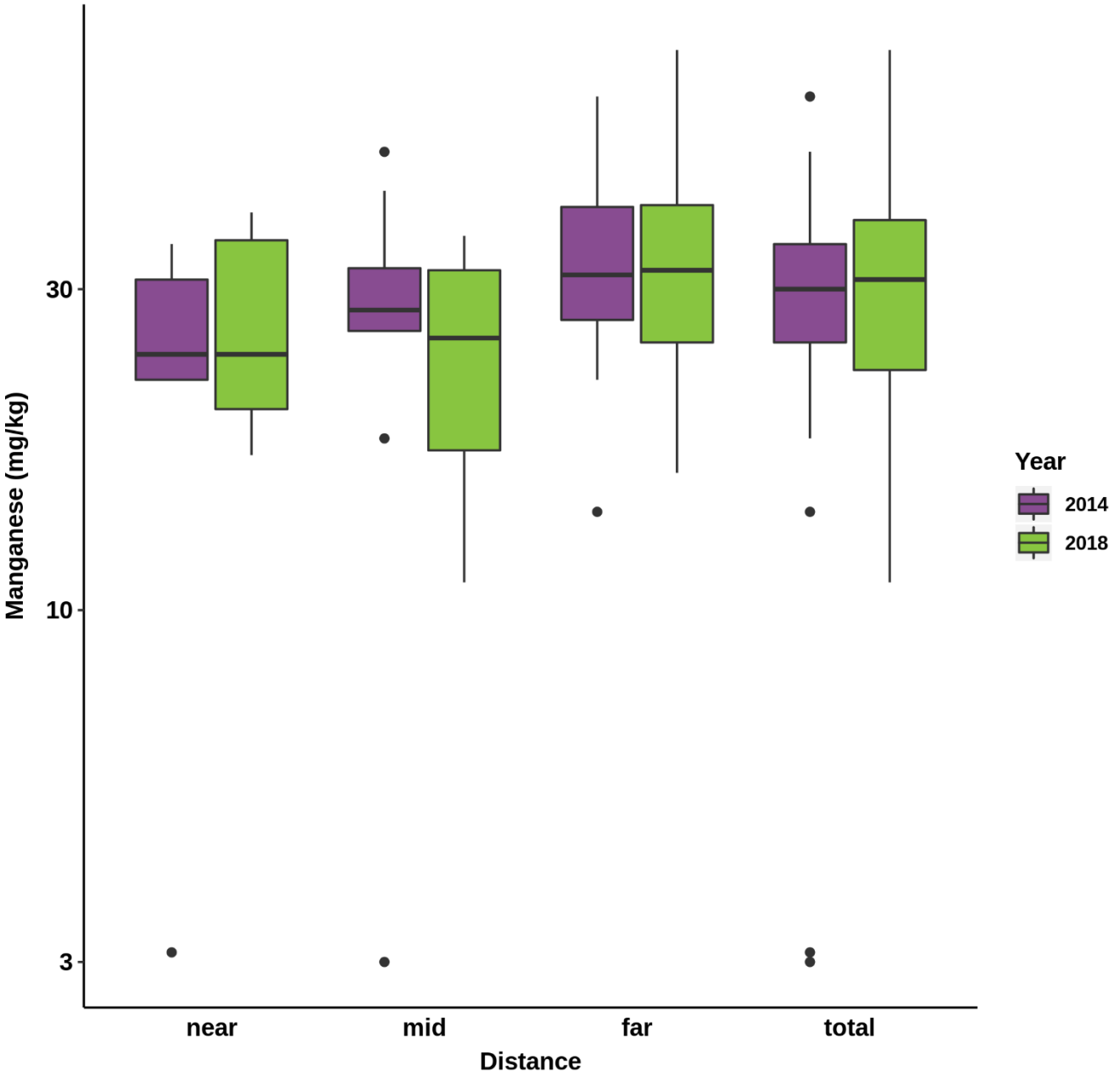

Figure 4-27 Boxplots of manganese (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentration, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

4.3.1.2 Hydrocarbons

Spatial distribution maps of fuel range (>C_{10}-C_{21}) and lube range (>C_{21}-C_{32}) hydrocarbons were generated for the sampling years 2014 and 2018. Hydrocarbons >C_{10}-C_{21} and >C_{21}-C_{32} concentrations increased slightly between 2014 and 2018.

Concentrations of >C_{10}-C_{21} reported in 2014 samples ranged from 0.0 to 0.125 mg/kg at all distances from the platform (Figure 4-28,A). This distribution pattern of concentrations was largely similar in 2018 except for Site 8-250 near the platform (<1,000 m) which had a concentration of 17.3 mg/kg (Figure 4-28, B). Concentrations in >C_{10}-C_{21} increased at Site 8-250 by 16.95 mg/kg and Site 4-250 by 4.57 mg/kg, other sites in the sampling area remained near 2014 levels (Figure 4-29).

Reported concentrations of >C_{21}-C_{32} in 2014 samples ranged from 0.125 to 1.7 mg/kg at all distances from the platform (Figure 4-30, A). The concentrations in 2018 increased at both Sites 8-250 and 4-250 as well as other sites towards the southwest (Figure 4-30, B). Changes between years included increases between 0.0 to 1.350 mg/kg with the largest increase at Site 8-250 (Figure 4-31). Increases were observed at the sites directly south of Site 8-250 and at sites to the northwest >6,000 m from the platform.

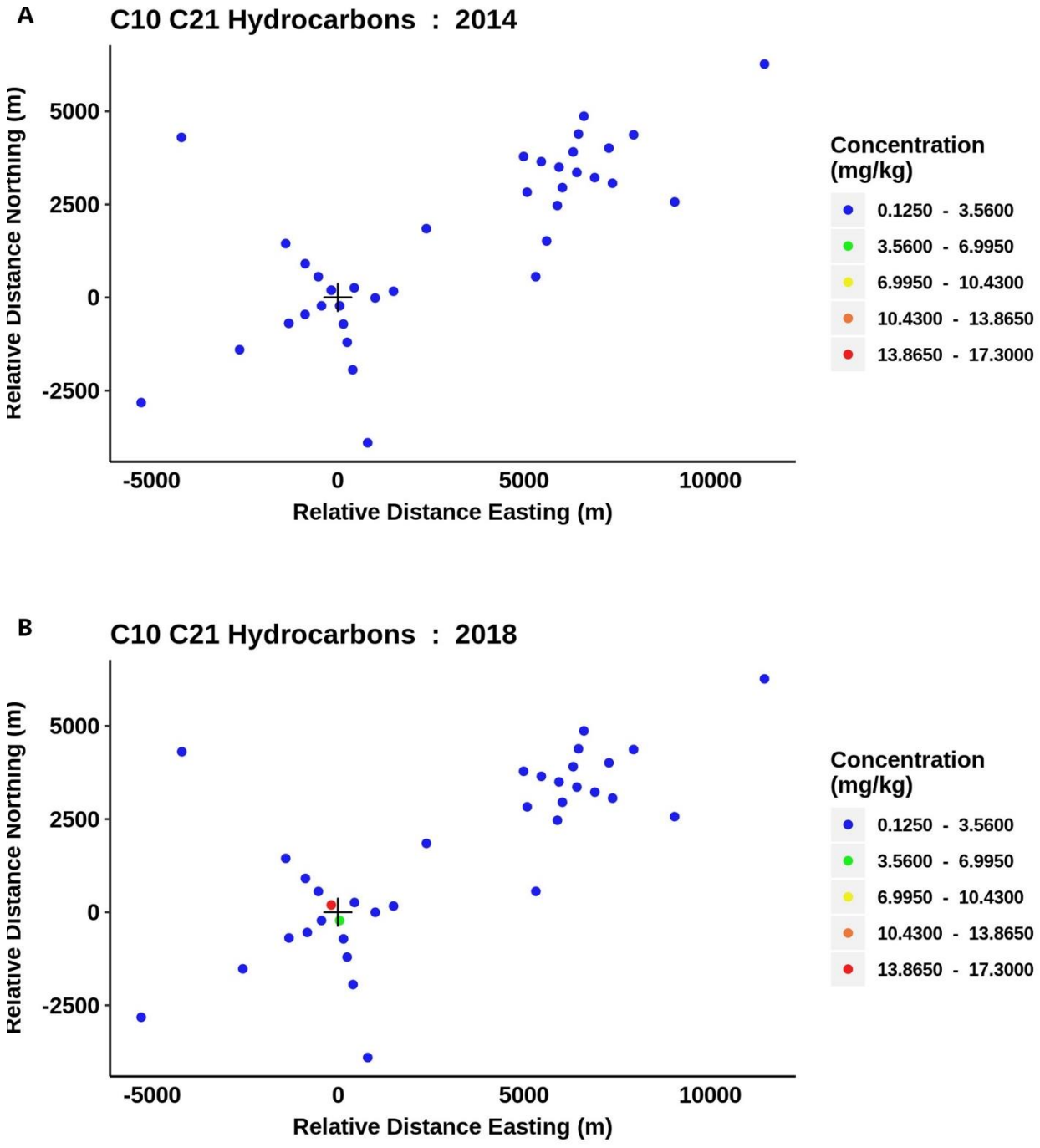

Figure 4-28 Spatial pattern of >C_{10}-C_{21} (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

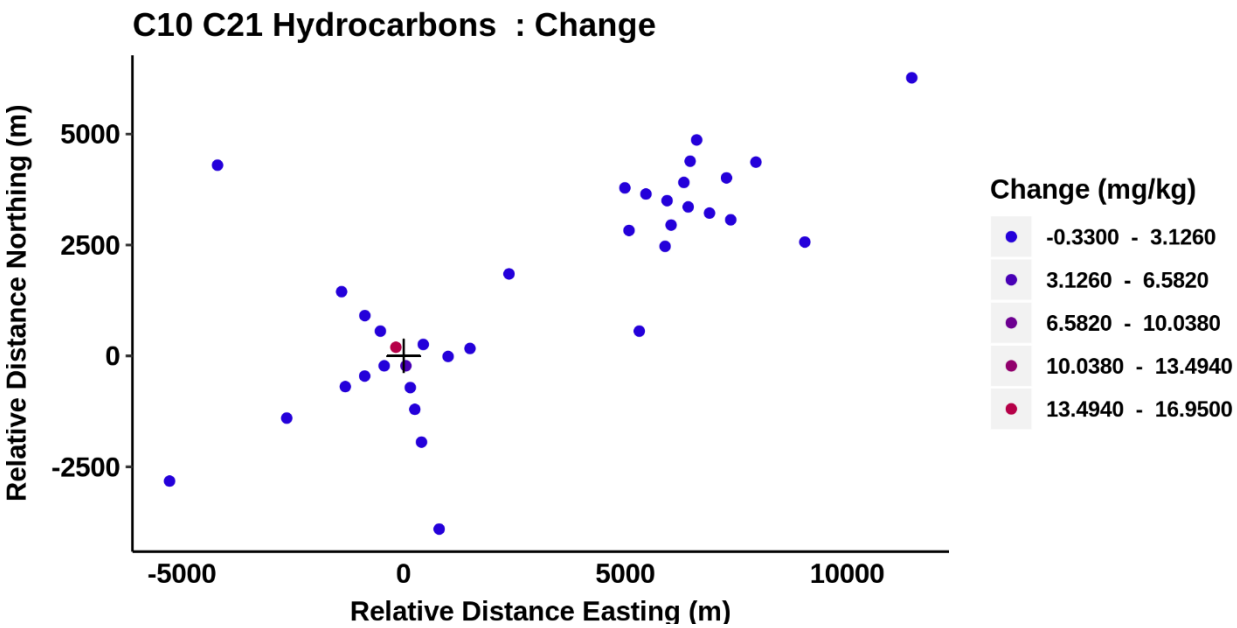

Figure 4-29 Spatial pattern of >C_{10}-C_{21} (mg/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

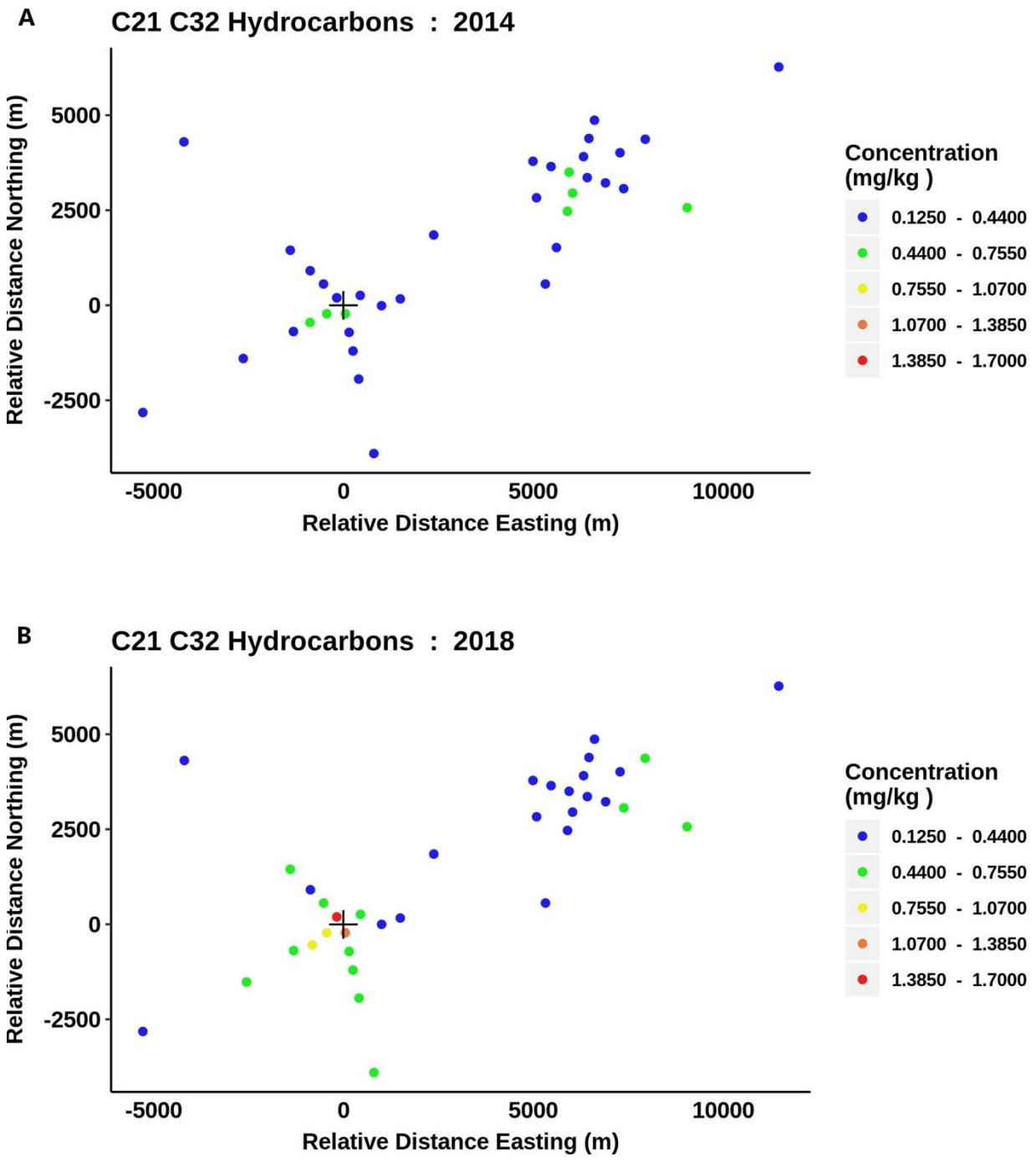

Figure 4-30 Spatial pattern of C_{21}-C_{32} (mg/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

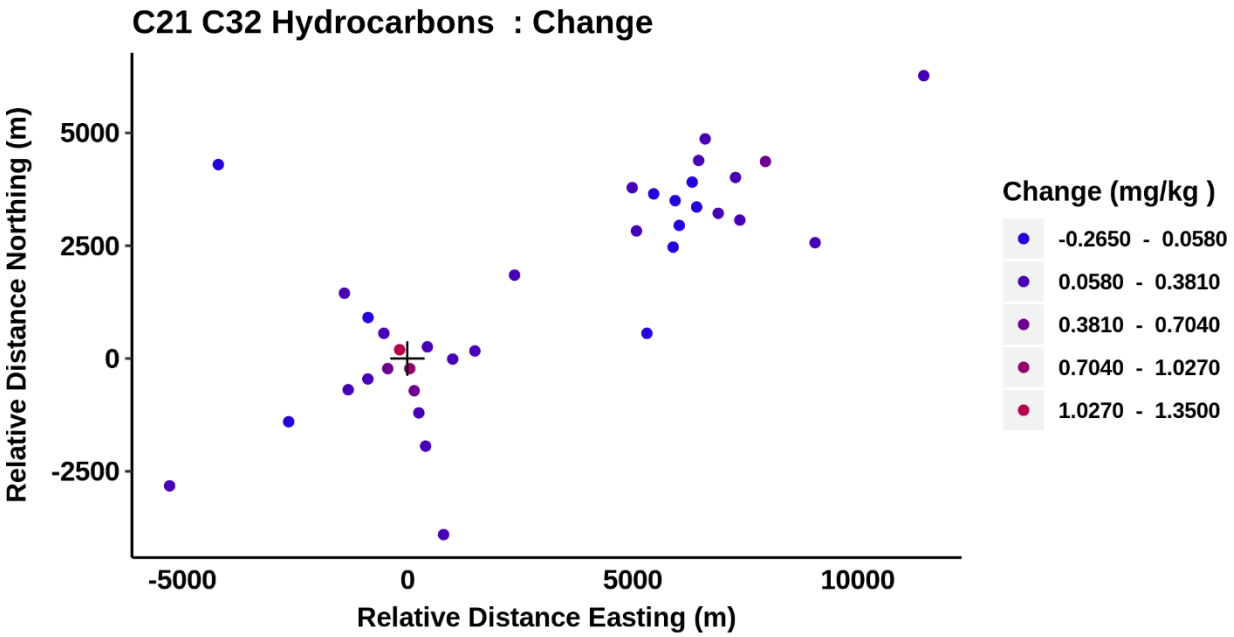

Figure 4-31 Spatial pattern of C_{21}-C_{32} (mg/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

Statistical Analysis

Neither hydrocarbon ranges were positively correlated (r>0.5) with any sediment analyte and ANOVAs were conducted (Table 4-13, Table 4-14).

Two-way ANOVA analyses for >C_{10}-C_{21} hydrocarbons indicate there was a statistically significant difference between Fields (p<0.001) and the Field x Year interaction term (p<0.001) (Table 4-13). A significant interaction term could indicate a Project-related effect. There was a statistically significant difference between the Near- and Mid-fields with the Far-field (Tukey HSD p<0.001). The median concentration of >C_{10}-C_{21} increased at Near-field and Mid-field distances in 2018 compared to 2014 (Figure 4-32). As shown in the 2D graphics, there is an increase in >C_{10}-C_{21} hydrocarbons concentrations at Site 8-250. This is an expected Project-related effect.

ANOVA analysis was deemed suitable for >C_{21}-C_{32} hydrocarbons (Table 4-14). The factor Field and Year were statistically significant (p=0.008 and p=0.003, respectively) (Table 4-14). There was a statistically significant difference between Near- and Far-field distance bins (Tukey HSD p<0.05). The median concentration of >C_{21}-C_{32} hydrocarbons has increased at all distances in 2018 compared to 2014 (Figure 4-33). The interaction term (Field x Year) was not statistically significant.

Table 4-13 Two-way ANOVA for >C_{10}-C_{21} concentrations (log_{10} transformed).

C_{10}-C_{21} Hydrocarbons Source (2014-2018)	**Degrees of freedom**	**Sum of squares**	**Mean of squares**	**F-value**	**p-value**	
Field	2	5.100	2.545	29.603	<0.001	***
Year	1	0.139	0.139	1.616	0.208	
Field x Year	2	2.671	1.336	15.508	<0.001	***
Residuals	66	5.685				
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-14 Two-way ANOVA for C_{21}-C_{32} concentrations (log_{10} transformed).

C_{21}-C_{32} Hydrocarbons Source (2014-2018)	**Degrees of freedom**	**Sum of squares**	**Mean of squares**	**F-value**	**p-value**	
Field	2	0.560	0.280	5.185	0.008	**
Year	1	0.530	0.53	9.810	0.003	**
Field x Year	2	0.171	0.086	1.585	0.213	
Residuals	66	3.565	0.054			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

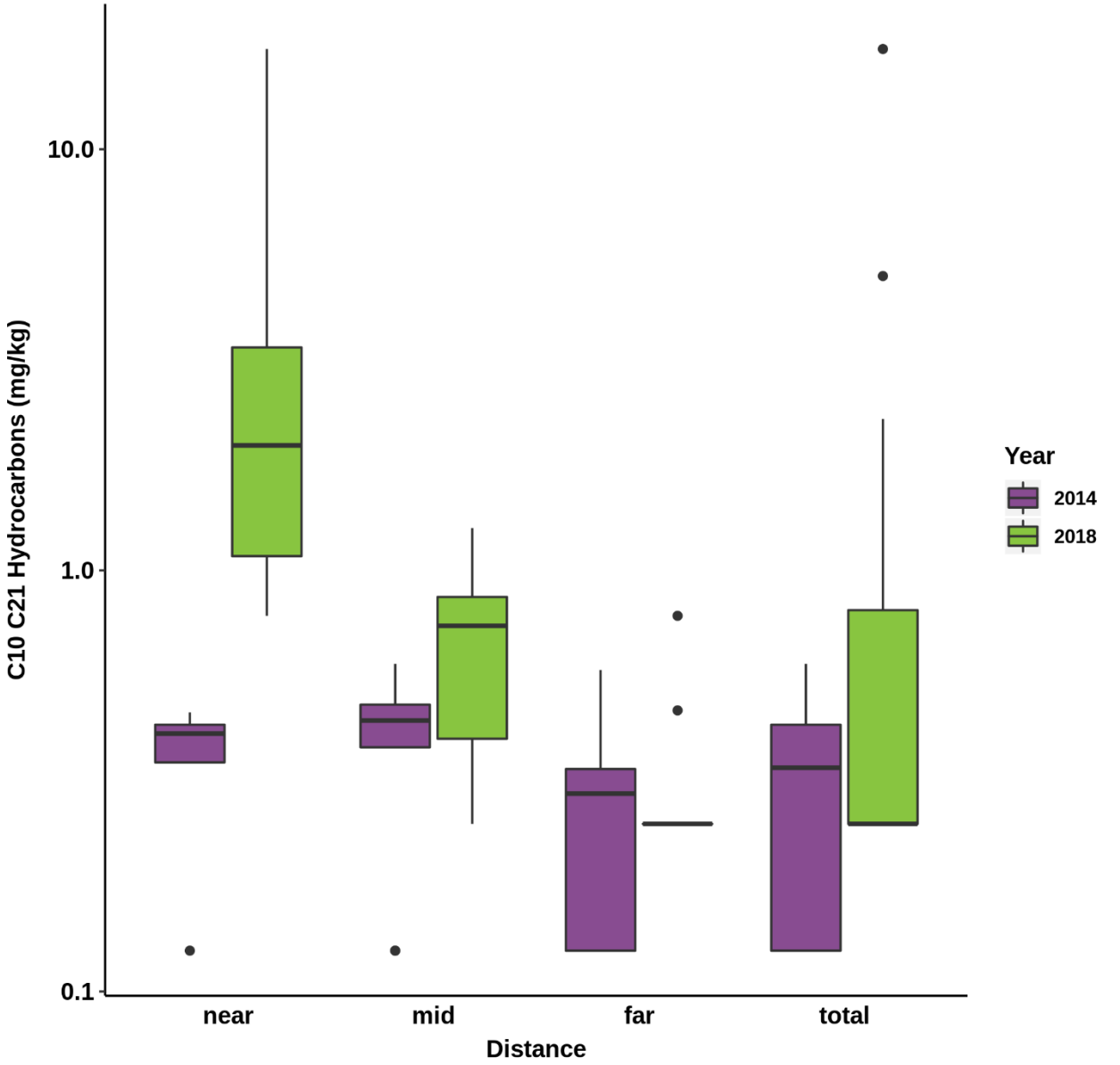

Figure 4-32 Boxplots of >C_{10}-C_{21} hydrocarbon concentrations (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentrations, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

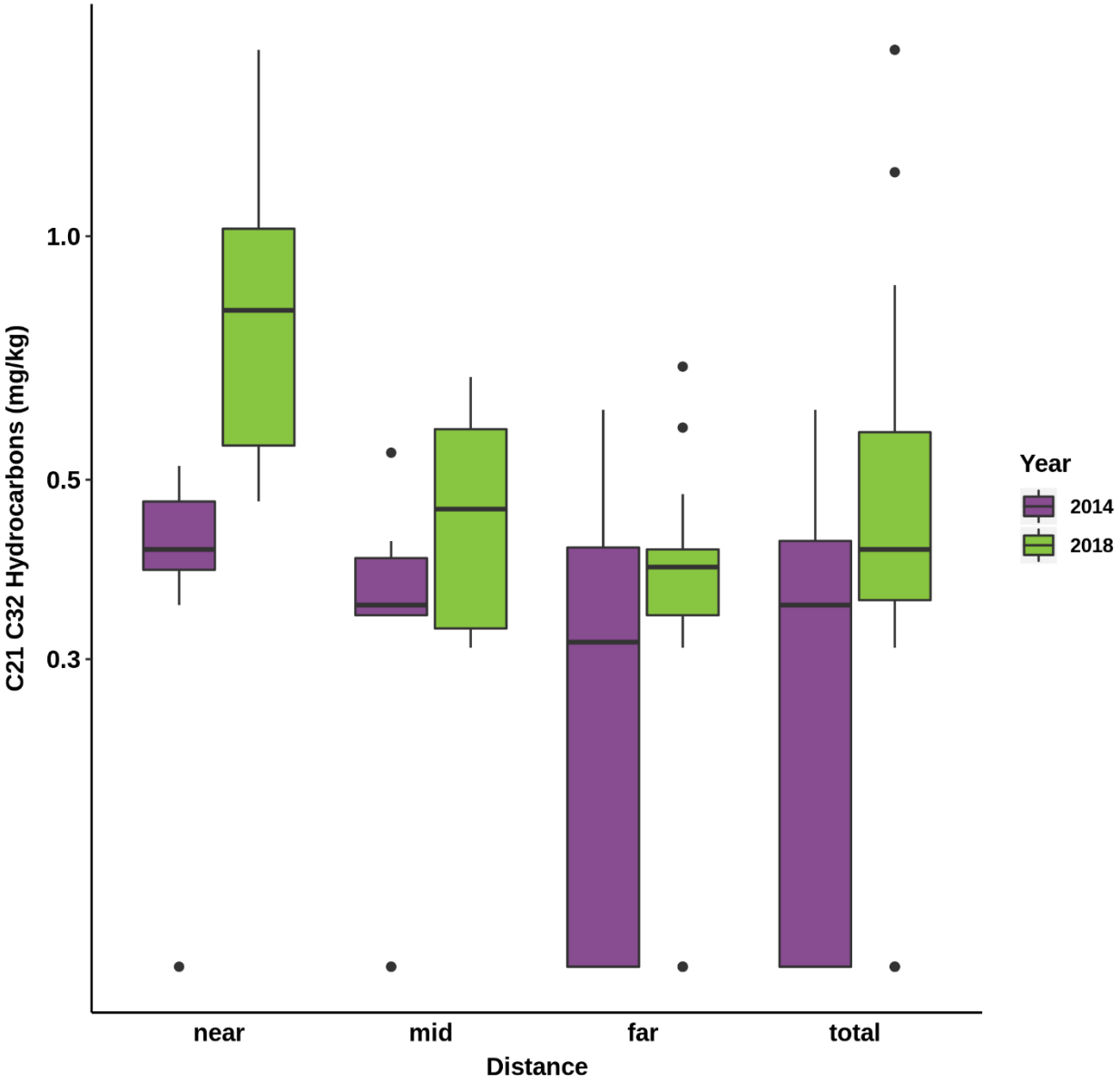

Figure 4-33 Boxplots of C_{21}-C_{32} hydrocarbon concentrations (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentrations, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

4.3.1.3 Other Analytes

Tests on sediment samples collected in 2018 had reported concentrations of ammonia ranging from 0.15 to 7.50 mg/kg near the platform. Samples collected towards the northwest and southwest of the platform had higher ammonia concentrations than other sample sites (Figure 4-34). At sites >6,000 m, only two sites (B-750 and B-1250) had reported relatively high concentrations of ammonia (7.50 to 15.00 mg/kg). Ammonia was not included in sediment analysis in 2014 (EMCP 2016a).

Total percent sulphur ranged from 0.0 to 0.02 mg/kg in 2014. Levels reported in 2018 ranged between to 0.0 and 0.04 mg/kg with one instance of 0.05 mg/kg at Site 8-250 (Figure 4-35). An increase in total percent sulphur was observed at most sites within the sample area (Figure 4-36). Site 8-250 adjacent to the platform reported and increase of 0.035 mg/kg. Most sites reported an increase between 0.0 to 0.030 mg/kg throughout the study area.

The distribution of moisture measurements in 2014 ranged between 9.5 to 19.0 percent with one site reporting between 0.0 to 0.5 percent (Figure 4-37, A). The spatial pattern was more homogenous in 2018 with percent moisture ranging from 9.5 to 19.0 percent (Figure 4-37,B). Samples within the study area reported percent increases ranging between 0 to 4.6 percent (Figure 4-38) with one instance of a change of 6 percent (Site C-500).

Redox potential was only reported for the 2018 sampling season. The redox potential was higher in samples collected northeast of the platform within 6,000 m (60 to120 mV, Figure 4-39). Other samples in the area ranged between 0 to 60 mV throughout the rest of the study area.

Total organic carbon (TOC) concentrations in 2014 ranged between 0.10 to 1.10 g/kg. Sample sites to the west of the platform ranged between 0.28 to 1.10 g/kg (Figure 4-40, A). This pattern was largely similar in 2018 (Figure 4-40, B). The largest change between years occurred at Site 8-250 (0.47 g/kg) with most other sites in the study area staying at 2014 levels (Figure 4-41). There was a slight decrease in reported TOC concentrations reported at sites 6-500, 4-750, and 4-2000.

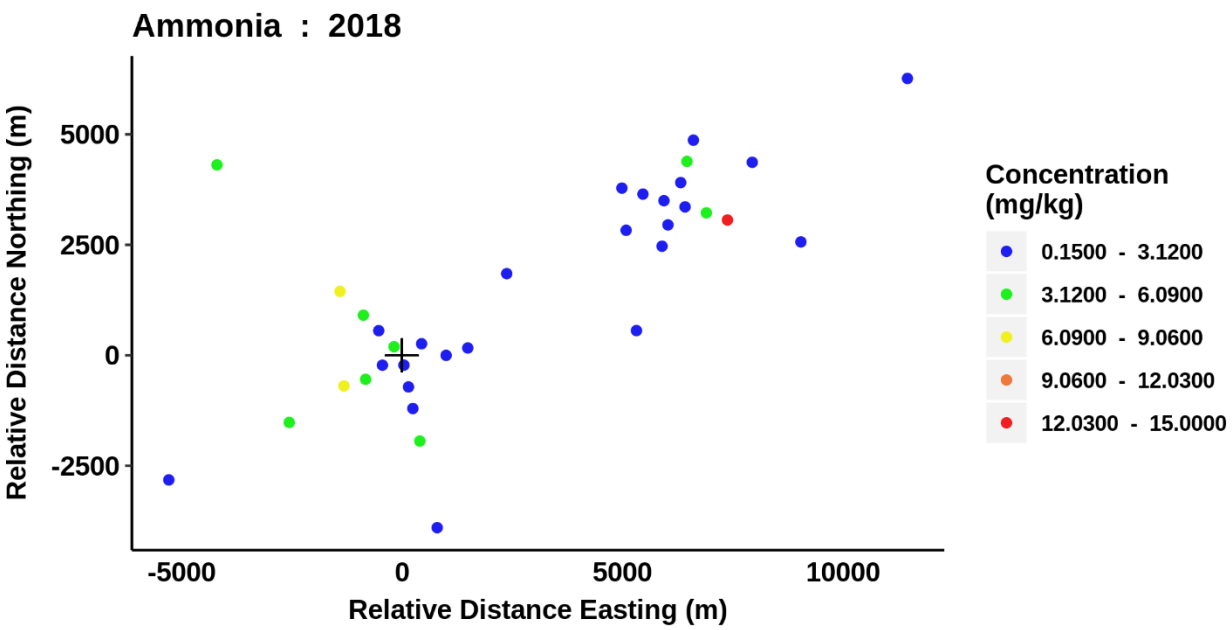

Figure 4-34 Spatial pattern of ammonia (mg/kg) from 2018 surveyed around the platform (cross).

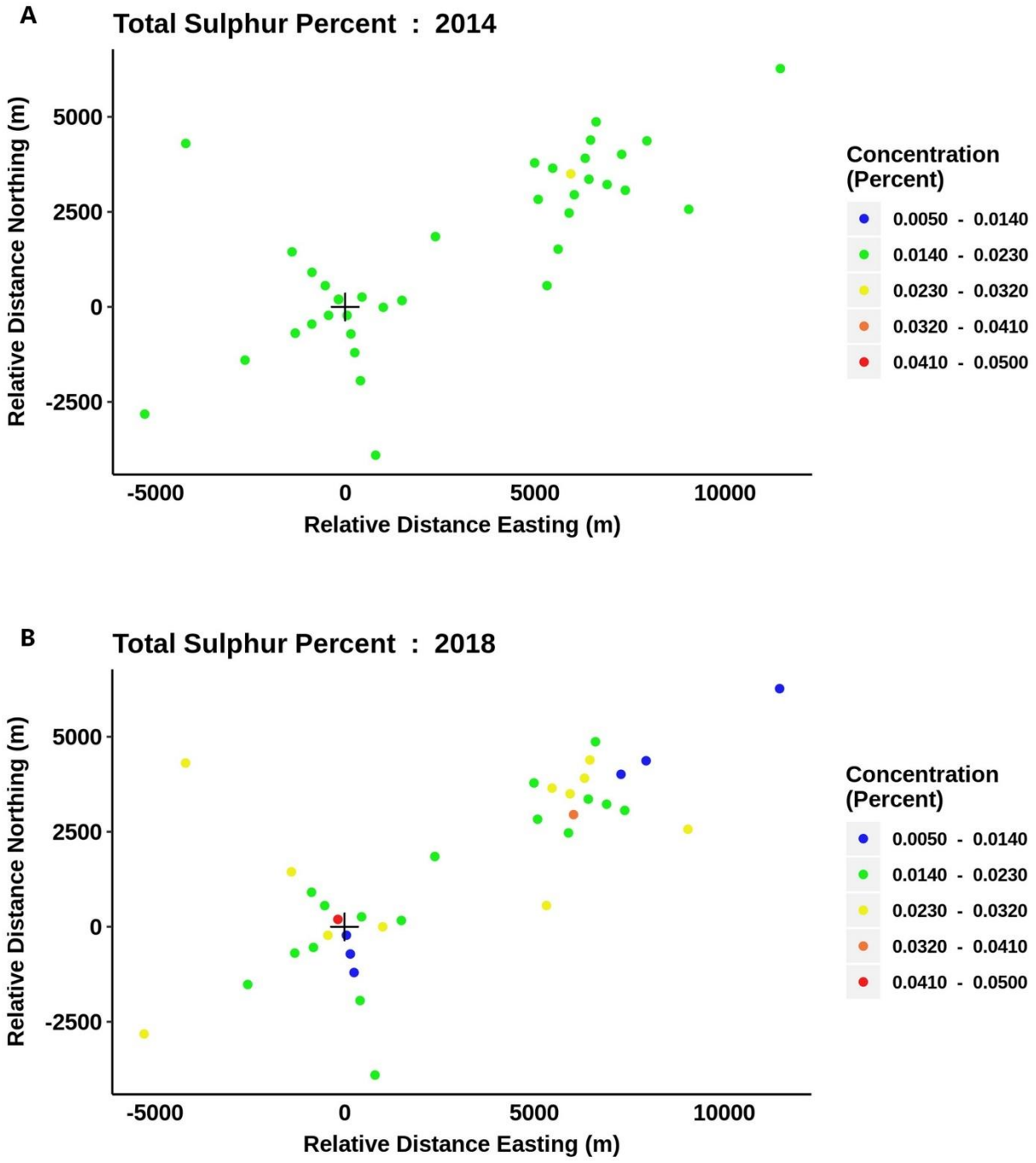

Figure 4-35 Spatial pattern of total sulphur percent from 2014 (A) and 2018 (B) surveyed around the platform (cross).

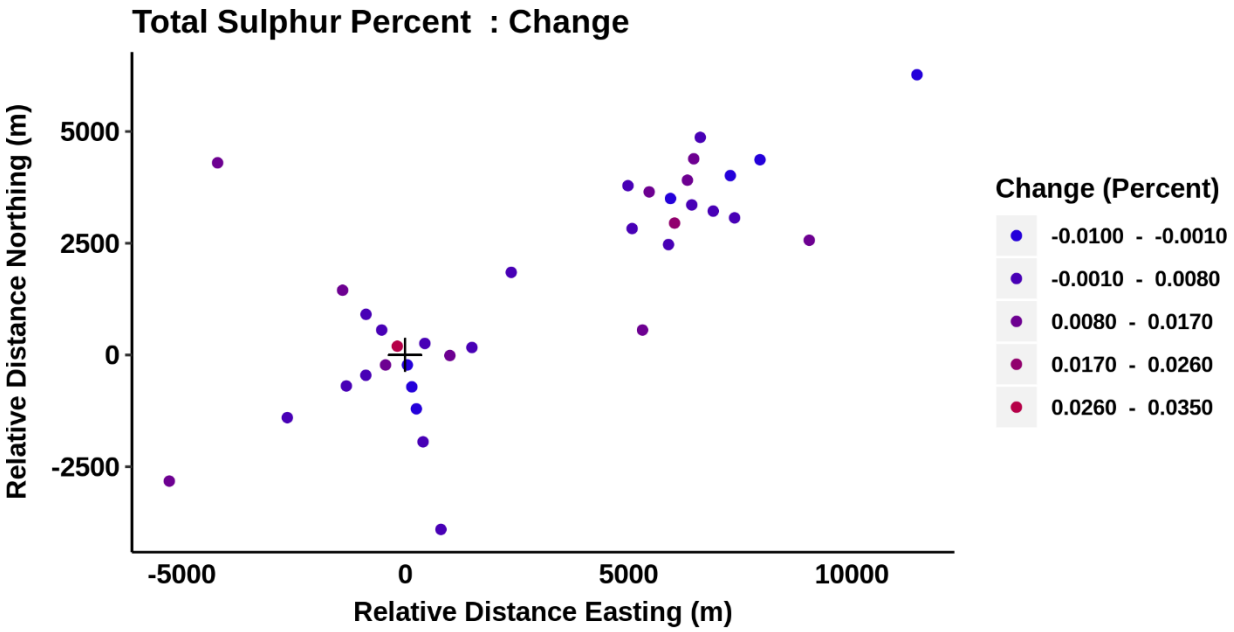

Figure 4-36 Spatial pattern of total sulphur percent change between 2014 and 2018 levels surveyed around the platform (cross).

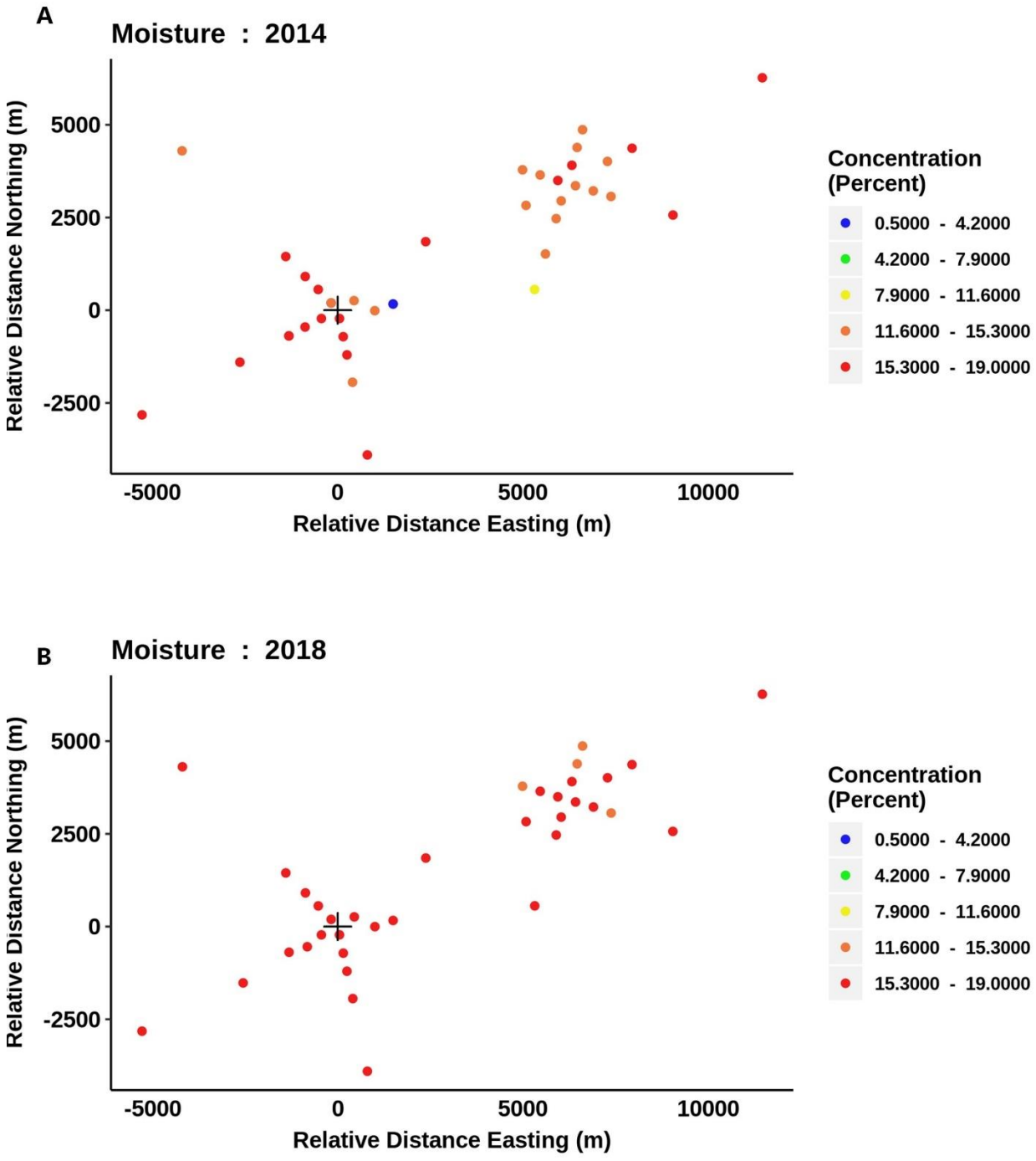

Figure 4-37 Spatial pattern of moisture (percent) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

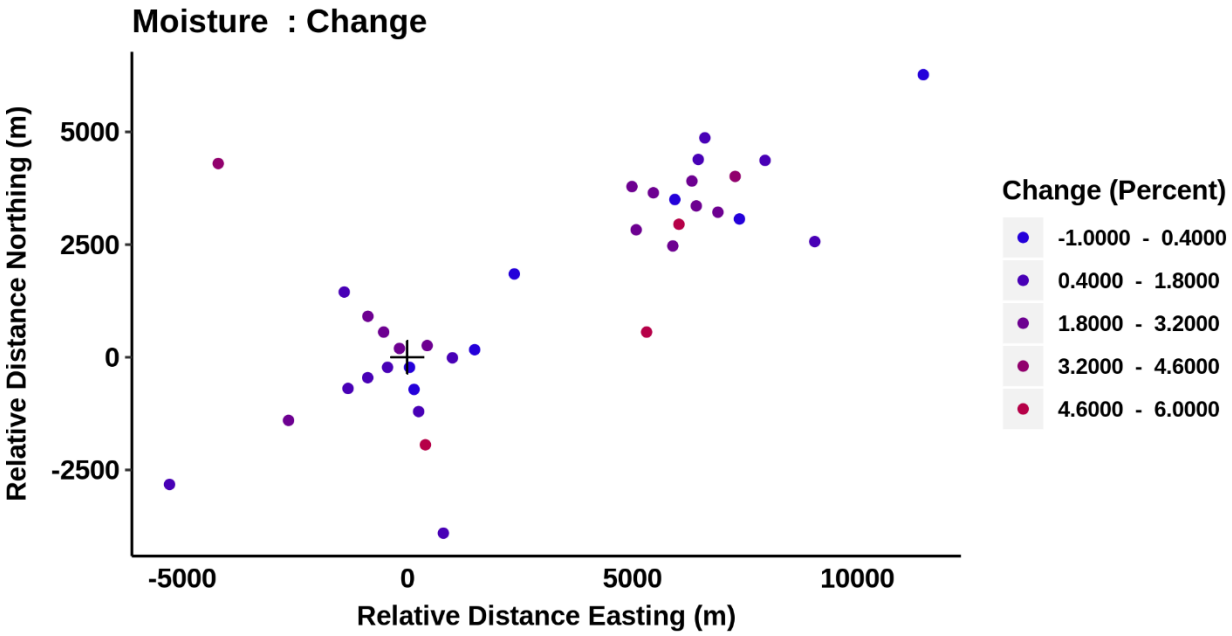

Figure 4-38 Spatial pattern of moisture (percent) change between 2014 and 2018 levels surveyed around the platform (cross).

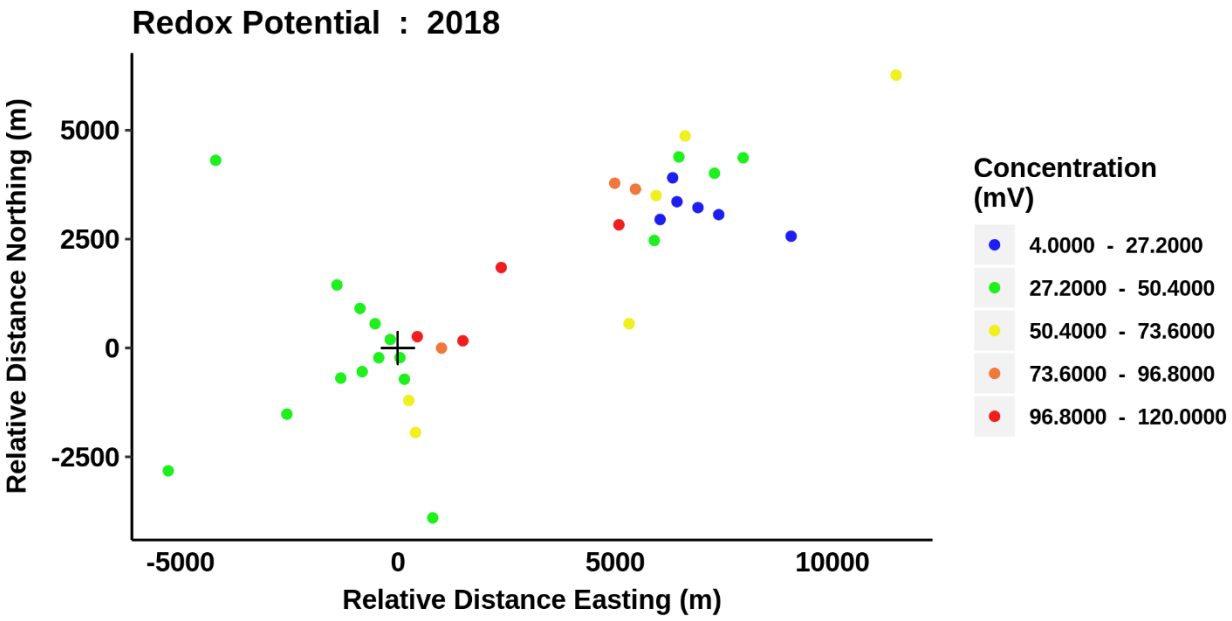

Figure 4-39 Spatial pattern of redox potential (mV) from 2018 surveyed around the platform (cross).

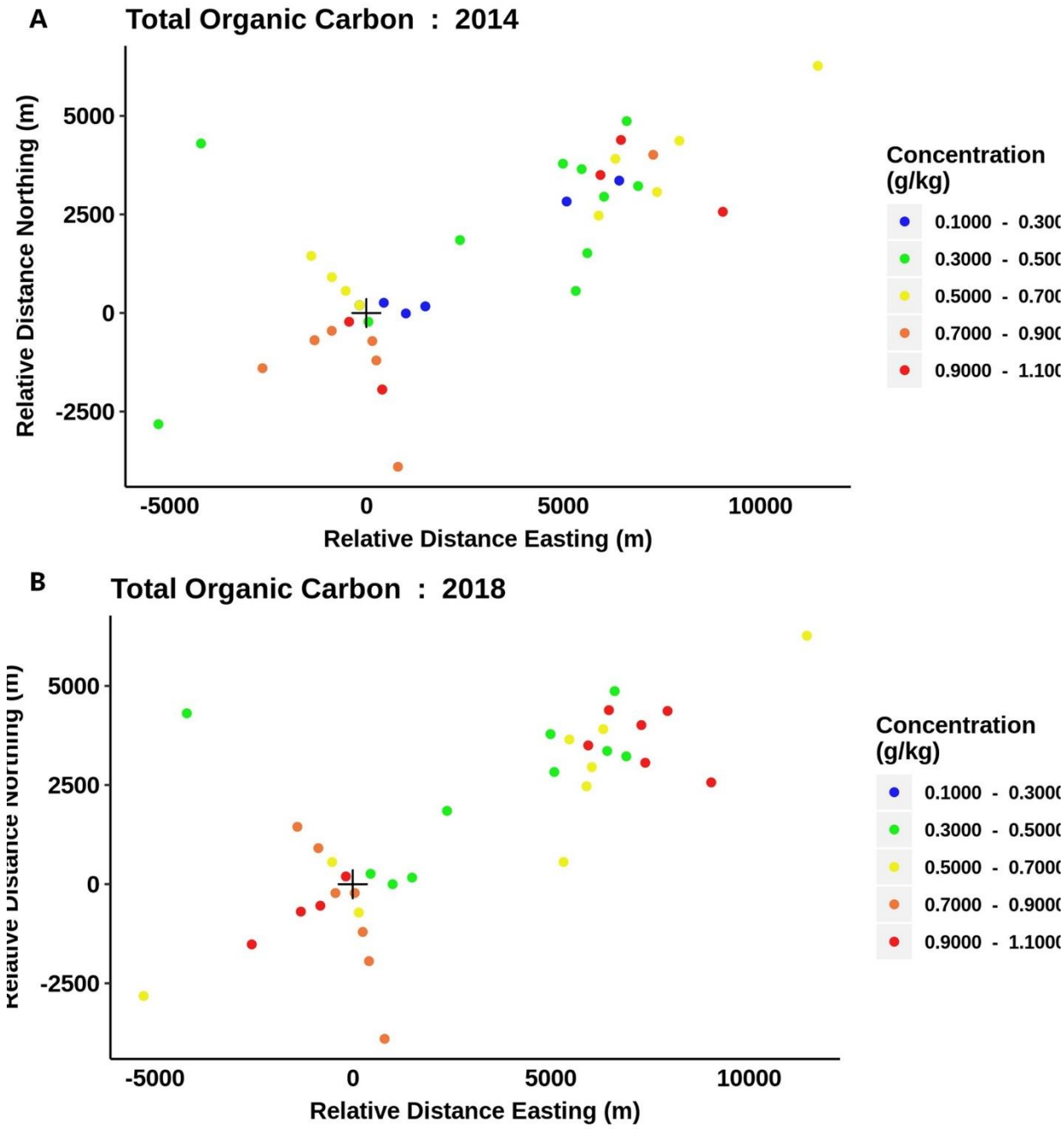

Figure 4-40 Spatial pattern of total organic carbon (g/kg) from 2014 (A) and 2018 (B) surveyed around the platform (cross).

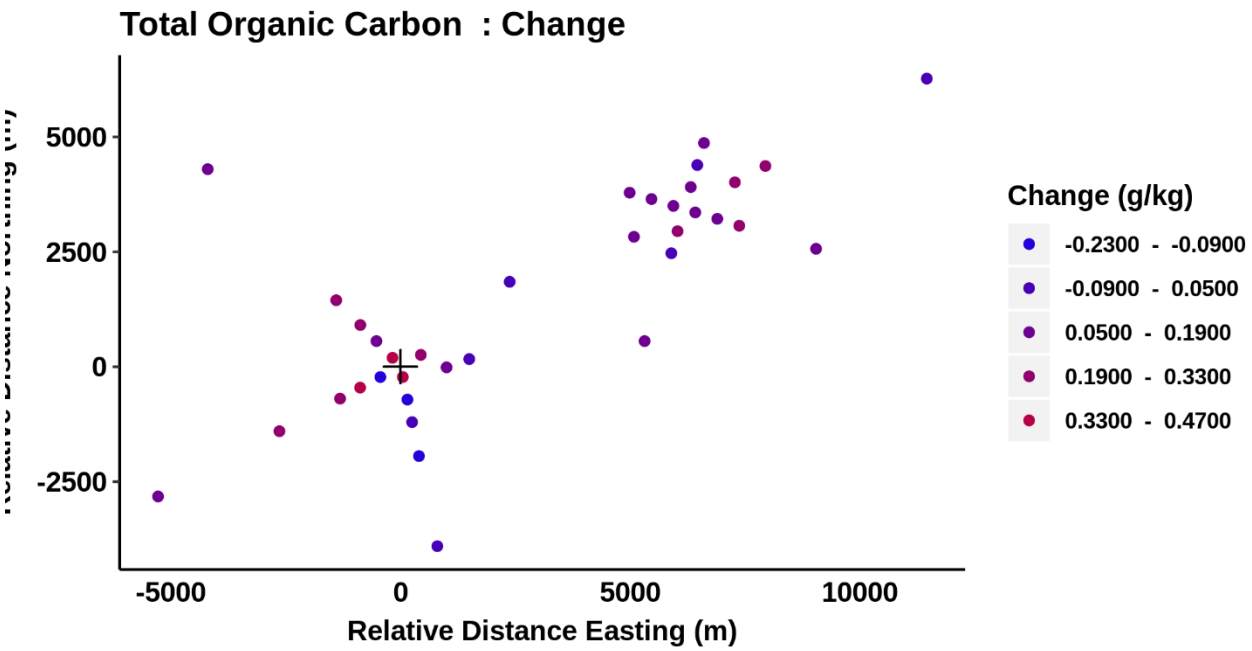

Figure 4-41 Spatial pattern of total organic carbon (g/kg) change between 2014 and 2018 levels surveyed around the platform (cross).

Statistical Analysis

Ammonia levels were measured in 2018 but baseline levels were not established in 2014. A one-way ANOVA was conducted to compare ammonia levels between fields (Table 4-15). There was a statistically significant difference between fields ($p=0.036$). The difference is between Mid- and Far-field stations (Tukey HSD, $p=0.033$). This will be monitored for changes in subsequent survey years.

Total sulphur (percent) was positively correlated to the clay sediment type and an ANCOVA was conducted. There was a statistically significant difference in total sulphur levels between years (Table 4-16). Levels of total percent sulphur increased throughout the sample area in 2018 from 2014 levels (Figure 4-42).

From Pearson correlation analysis, both moisture and total organic carbon (TOC) were not positively correlated with any sediment type ($r>0.5$). Year was statistically significant for both moisture and TOC ($p<0.001$ and $p=0.037$, respectively) (Table 4-17, Table 4-18). Median moisture concentrations increased between years across all fields (Figure 4-43). Boxplots of TOC concentrations indicate a median increase in Near- and Far-field sample sites (Figure 4-45).

Table 4-15 One-way ANOVA table for ammonia (log_{10} transformed)

Ammonia Source (2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	1.155	0.578	3.7	0.036	*
Residuals	33	5.152	0.156			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-16 Two-way ACNOVA table for total sulphur (log_{10} transformed).

Total Sulphur (percent) Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.0000	1.308e-06	0.218	0.805	
Year	1	0.0001	1.187e-04	19.834	<0.001	***
Field x Year	2	0.0000	9.530e-07	0.159	0.853	
Field x Clay	2	0.0000	1.29e-06	0.216	0.806	
Residuals	63	0.0003	5.99e-06			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-17 Two-way ANOVA table for moisture (log_{10} transformed).

Moisture Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.010	0.005	2.873	0.064	.
Year	1	0.038	0.038	21.842	<0.001	***
Field x Year	2	0.003	0.002	0.891	0.415	
Residuals	66	0.114	0.002			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

Table 4-18 Two-way ANOVA table for total organic carbon (log_{10} transformed).

Total Organic Carbon Source (2014-2018)	Degrees of freedom	Sum of squares	Mean of squares	F-value	p-value	
Field	2	0.045	0.022	0.737	0.483	
Year	1	0.138	0.138	4.533	0.037	*
Field x Year	2	0.011	0.005	0.178	0.838	
Residuals	66	2.007	0.030			
Notes: Significance codes: 0.001 '***', 0.01 '**', 0.05 '*', 0.1 '.', 1 ' '						

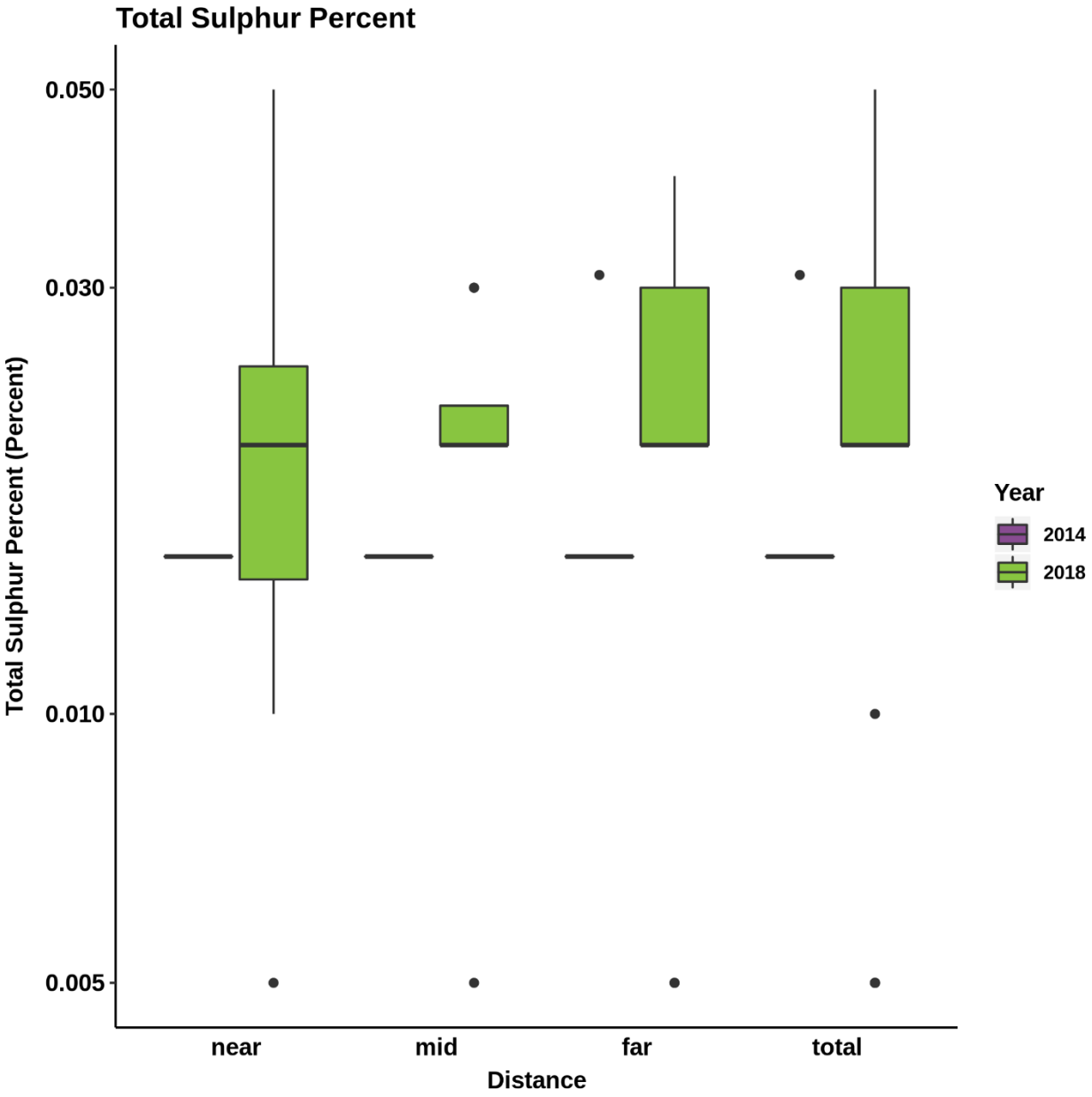

Figure 4-42 Boxplots of total sulphur percent (mg/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median percent, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

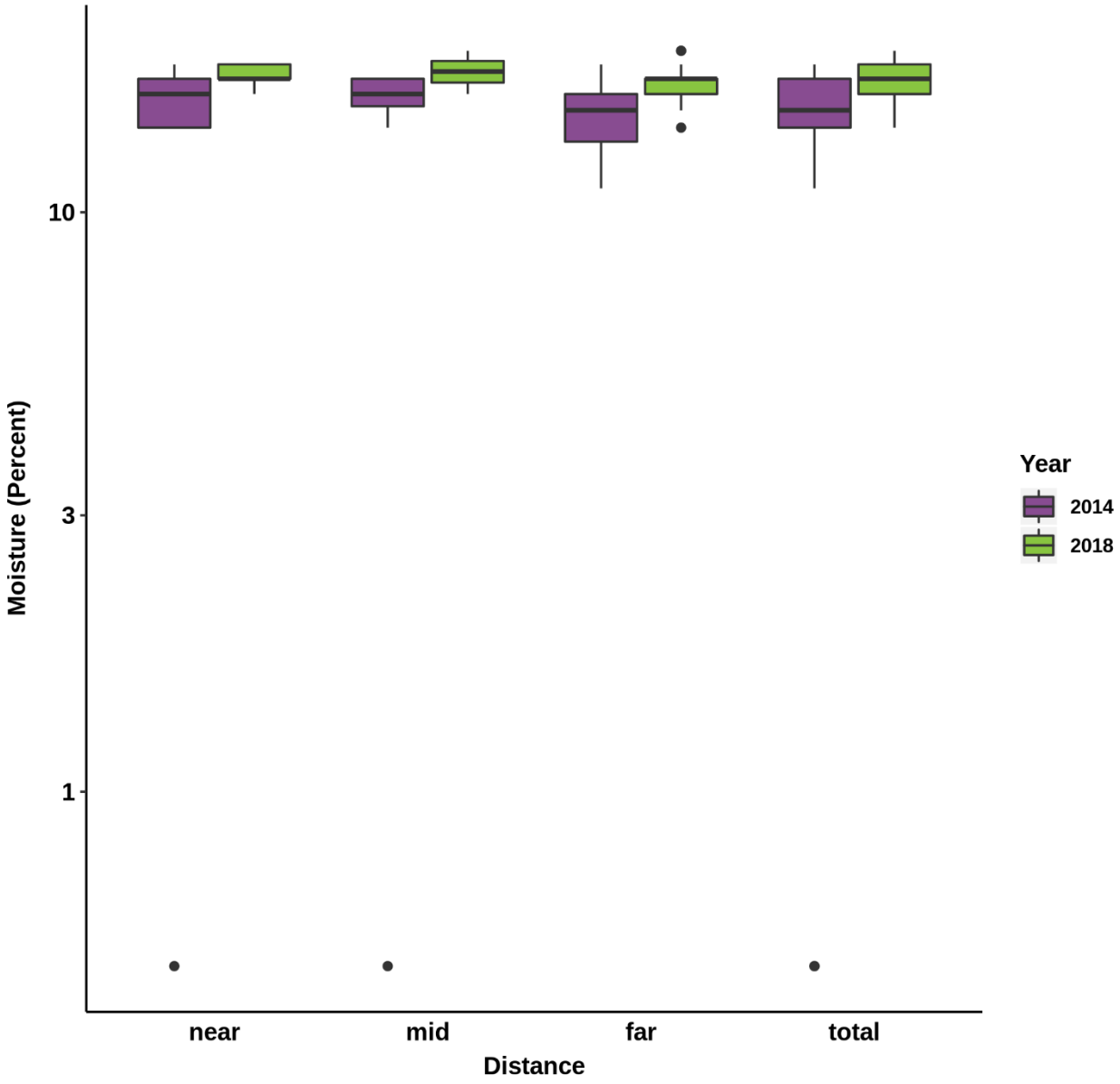

Figure 4-43 Boxplots of moisture (percent) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median percent, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

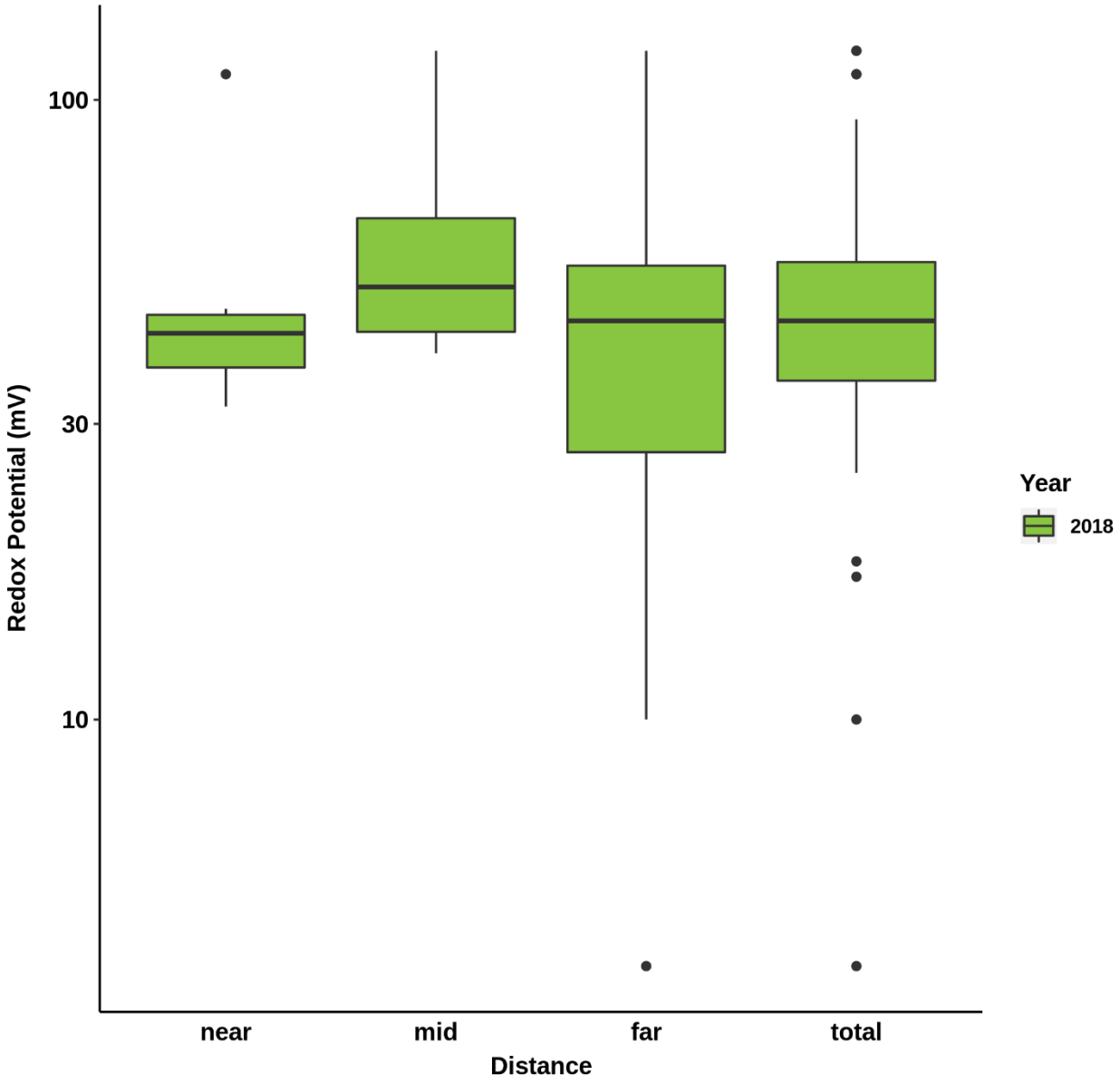

Figure 4-44 Boxplots of redox potential (mV) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for 2018 around the platform. Horizontal lines represent median potential, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

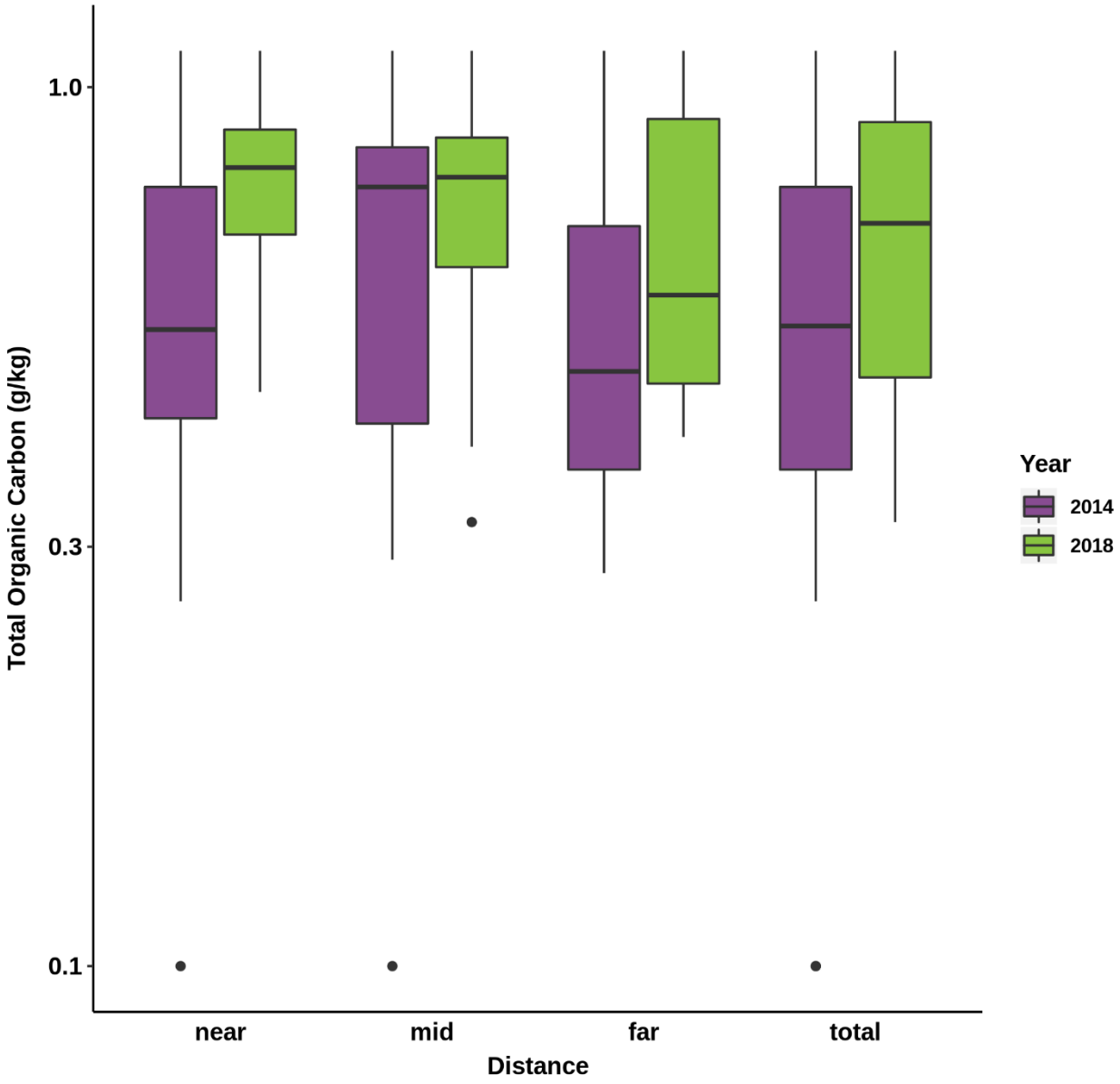

Figure 4-45 Boxplots of total organic carbon (g/kg) in sediment for three distance bins (Near ≤1,000 m, Mid=1,000-2,000 m, Far >2,000 m, and Total) for years 2014 and 2018 around the platform. Horizontal lines represent median concentrations, boxes represent the Middle quartiles, and whiskers represent 1.5 x the interquartile range. Data beyond the whiskers are represented as individual dots.

4.3.2 Toxicity

Screening criteria for toxicity testing included all sites within 500 m from Hebron Platform and any sample with a Petrotox (C_{10}-C_{21} hydrocarbon) level >150 mg/kg. Four stations were within 500 m from the platform and tested for toxicity (Table 4-19). The Petrotox levels at these sites were well below the threshold (Table 4-20). All other sites <3,000 m from the platform were also below Petrotox levels (>150 mg/kg >C_{10}-C_{21}) and not analyzed for toxicity. There were also no samples above Petrotox levels in 2014 (Stantec 2016).

Amphipod survival was greater than 98 percent in all four sites and results indicated the sediment is non-toxic. Based on these results, no further statistics were conducted. Samples collected and tested in 2014 were also non-toxic to amphipods (Stantec 2016).

As per recommendations from ECCC, pore water analysis was replaced with sediment ammonia, sulphides, and redox potential analyses. ECCC laboratories have implemented updated procedures to address discrepancies seen in pore water analyses for sediment toxicity and these updates have been implemented in the 2018 sampling program. In comparison to the control sample, levels of ammonia, sulphide, and redox potential were lower. These results are summarized in Table 4-20.

Table 4-19 Amphipod toxicity testing summary for four sediment samples (<500 m from the center of study area) for the 2018 sampling year.

Station ID	Amphipod Survival (percent)	Sample standard deviation	Significant difference from control	30% reduction from control	Interpretation
4-250	99	2.24	No	No	Non-toxic
6-500	100	0	No	No	Non-toxic
8-250	98	2.74	No	No	Non-toxic
FL-500	100	0	No	No	Non-toxic
Control*	100	0	NA	NA	NA

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

Table 4-20 Amphipod testing summary (2018) and sediment physiochemical analysis for ammonia, sulphides, and redox potential.

Station ID	% Mortality	Toxicity	Dry Sediment Ammonia (µg/g NH_3-N)	Dry Sediment Sulphides (µg/g S dry)	Wet Sediment Redox Potential (Eh)	Petrotox >C_{10}-C_{21} (mg/kg)
4-250	1	Non-toxic	0.51	<0.1	376	5
6-500	0	Non-toxic	0.18	<0.1	399	1.98
8-250	2	Non-toxic	0.15	<0.1	429	17.3
FL-500	0	Non-toxic	0.12	<0.1	352	1.27
Control*	0	Non-toxic	1.00	<0.1	420	NA

Notes: * Laboratory reference sediment was used as the control for comparison.
Petrotox threshold: 150 mg/kg

4.3.3 Benthic Community Structure

Benthic community structure was characterized for 2018 sediment samples and compared to 2014 results. Individuals were identified to the lowest possible taxonomic level however, analyses were conducted to the family level (Gray et al. 1990, Gomez Gesteira et al. 2003). Species and abundances observed in 2018 samples are reported in Volume II.

Overall benthic community structure parameter levels changed in 2018 from 2014 levels (Table 4-21). The highest community structure parameter values reported in 2014 occurred at sites in Far-field distance bins. In 2018, higher values were reported for sites in the Mid-field and Far-field distance bins (Table 4-21).

Total abundance levels in 2018 decreased from 2014 levels at 35 of the 36 sampling sites; there was, however, a single increase of abundance at site 6-3000. (Figure 4-46). In 2018, 162 taxa were identified totaling 9,745 individuals. This is a decrease from 2014 levels which reported 19,465 individuals from 182 taxa (from sites sampled in both 2014 and 2018). The overall mean was 33 species per site in 2018 which was close to the 2014 mean of 32 species per site however the mean abundance drops from 541 individuals per site in 2014 to 225 individuals per site in 2018 (Table 4-21). In 2014, Near-field stations number of taxa and total abundance ranged between 13 to 29 taxa and 126 to 442 (N) respectively (Table 4-21). In 2018, the number of taxa decreased at the Near-field sites (except for 6-500 which had a slight increase) and the range of total abundance decreased to between 74 to 175 (N) (Table 4-21).

In 2018, Site FL-1250 (Far-field) had the highest abundance (n=641) which, mostly comprised of the annelids in the class Clitellata. Site 4-750 (Near-field) had the lowest abundance of all 2018 samples (n=74) and one of the lowest abundances counts (n=126) in 2014.

In 2018, Site B-1250 (Far) had the highest number of: taxa observed (S=68), species richness (d=11.11), and diversity index scores (H'=3.468). In 2014, this site also had one of the highest values of number of taxa, abundance, evenness, and diversity index values. Site D-1250 (Far-field) had the lowest number of taxa (S=9) and lowest species richness (d=1.836) observed. In 2018, Sites B-750 and FL-1250 have the lowest Shannon-Wiener diversity index scores which indicates less species diversity and dominance of a few key taxa.

Taxa abundances differed from 2014 to 2018. The most abundant taxa reported in 2014 were annelids, nematodes, and arthropods. The top contributing classes of taxa were Polychaetes (30 percent), Oligochaetes (26 percent), and nematodes (16 percent). From 2018 samples, the most abundant taxa observed within the sampling area were annelids, arthropods, and molluscs. When examining the mean relative abundance of all 2018 samples, Polychaeta account for 35 percent, Clitellata 33 percent (annelid class), and Amphipoda 10 percent contribution. Clitellata were found in relative high abundance at B-750 (87 percent), FL-1250 (83 percent), and D-1250 (74 percent) compared to total abundance of all sites. In 2014, the most abundant taxa were annelids, nematodes, and arthropods. Two classes contributed to most of the annelid abundance in 2014; Oligochaetes (n=13976, includes Clitellata) and Polychaetes (specifically Spionidae and Syllidae).

Multivariate statistics on the 2018 benthic infauna family abundance per site and environmental variables (e. g. distance bins, and sediment physical and chemical) was conducted to discern patterns and to monitor change (Gray et al. 1990). To determine which sites were more similar to each other based on taxa present (family level), a cluster analysis (Bray-Curtis similarity) on square-root transformed abundance data was generated. This was graphically represented in a non-metric multidimensional scaling (nMDS)

plot with percent similarity thresholds from cluster analysis to delineate different groupings. To determine community assemblage similarities within distance bins, similarity percentage analysis (SIMPER) analyses were conducted.

Two groups were designated at the 40 percent similarity threshold in the cluster analysis with a 2D-stress of 0.12 (Figure 4-47, Figure 4-48, Figure 4-49). This 2D-stress value is a measure of goodness of fit (Clarke and Warwick 2001). The lower the stress value, the easier it is for the model based on the data to group samples together (stresses >0.3 are close to being arbitrary groupings). At the 60 percent similarity threshold, these groups are further differentiated into four main groups. Group A consists of sites at Far-field distances toward the northeast of the platform (Figure 4-48, Figure 4-49). Group B, C, D are differentiated at the 60 percent similarity threshold (Figure 4-47, Figure 4-48, Figure 4-49). Each group consisted of sites located in different distance bins however the separation is clearer when looking at direction from platform. Groups B and C consist mainly of sites located toward the northeast at all distance bins. Within group D, sites from the Near-field and Mid-field distance bins in the southeast, southwest, and northwest group together (Figure 4-49).

Results of the similarity analysis of abundance data for the distance bins are presented below. Sites in the Far-field distance bin have an average similarity of 47 percent. The top four taxa at sites within the Far-field distance bins contributed over 30 percent to the similarity (Syllidae=9.57 percent, Clitellata (indeterminate) =8.62 percent, Naididae=7.79 percent, and Spionidae =7.38 percent). Sites in the Mid-field distance bin had an average similarity of 70 percent. The top four taxa within this group contributed 36 percent to the overall similarity (Naididae = 12.53 percent, Cirratulidae=8.82 percent, Clitellata=8.30 percent, Pontoporeiidae=6.79 percent). Sites in the Near-field distance bins had an average of 68 percent similarity. The top four species in this bin accounted for 43 percent of the similarity (Naididae=16.95 percent, Clitellata (indeterminate) =9.75, Leptognathiidae=8.77, Cirratulidae=7.61).

From the DISTLM analysis, two variables accounted for 30 percent of the variability in the abundance data, sand and redox potential. Other important variables identified from the analysis include gravel, total organic carbon, and moisture.

Table 4-21 Benthic community structure parameters for 2014 and 2018 Hebron EEM sediment samples. Community structure parameters: number of taxa (S), total abundance (N), total biomass (g), Margalef's species richness (d), Pielou's evenness (J'), Shannon-Weiner diversity index (H').

Distance Bin	Sample Label	Number of taxa (S)		Total Abundance (N)		Total Biomass (g)		Species Richness (d)		Evenness (J')		Shannon-Weiner H'(loge)	
		2014	2018	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018
Near	4_250	25	25	442	168		44.83	9.07	4.68	0.73	0.66	2.34	2.11
Near	4_750	16	16	126	74		18.45	7.14	3.49	0.67	0.83	1.87	2.30
Near	6_1000	25	16	395	92		82.28	9.24	3.32	0.68	0.66	2.19	1.83
Near	6_500	23	28	366	158		16.98	8.58	5.33	0.70	0.77	2.20	2.55
Near	8_250	26	18	331	115		35.87	9.92	3.58	0.54	0.83*	1.77	2.40
Near	8_750	25	24	388	94		38.29	9.27	5.06	0.58	0.87	1.86	2.75

Distance Bin	Sample Label	Number of taxa (S)		Total Abundance (N)		Total Biomass (g)		Species Richness (d)		Evenness (J')		Shannon-Weiner H'(loge)	
		2014	2018	2014	2018	2014	2018	2014	2018	2014	2018	2014	2018
Near	FL_500	29	31	362	175		1.50	10.94	5.81	0.66	0.80	2.24	2.75
Near	FL_1000	13	29	214	141		74.99	5.15	5.66	0.51	0.77	1.31	2.60
Mid	4_1250	21	24	258	111		9.60	8.29	4.88	0.69	0.78	2.11	2.49
Mid	4_2000	21	25	291	138		13.52	8.12	4.87	0.66	0.83*	1.99	2.67
Mid	6_1500	33	29	455	146		114.49*	12.04	5.62	0.69	0.77	2.40	2.57
Mid	6_3000	13	22	93	175		30.32	6.10	4.07	0.60	0.77	1.54	2.37
Mid	8_1250	20	30	438	322		113.87*	7.19	5.02	0.54	0.73	1.62	2.47
Mid	8_2000	27	15	313	88		0.22	10.42	3.13	0.66	**0.87***	2.17	2.35
Mid	FL_1500	22	24	353	173		16.12	8.24	4.46	0.60	0.79	1.86	2.52
Far	FL_1250	24	28	814	**641***		52	7.9	4.18	0.35	0.31	1.11	1.04
Far	FL_3000	14	20	483	177		135.88*	4.84	3.67	0.43	0.74	1.13	2.23
Far	2_1250	54*	50*	792*	316		1.28	18.28*	8.51*	0.76*	0.81	3.01*	3.16*
Far	2_2000	60*	57*	1027*	540*		25.56	19.59*	8.90*	0.73*	0.80	2.98*	3.23*
Far	2_6000	54*	41	790	351*		12.49	18.29*	6.83	0.64	0.68	2.54	2.52
Far	4_4000	20	19	318	95		18.23	7.59	3.95	0.65	0.66	1.96	1.93
Far	6_6000	26	25	468	141		35.37	9.36	4.85	0.55	0.80	1.79	2.58
Far	8_6000	26	18	448	105		**139.09***	9.43	3.65	0.55	0.74	1.81	2.14
Far	A_1000	**61***	62*	685	476*		24.62	**21.16***	9.89*	0.81*	0.81	3.33*	3.34*
Far	A_1500	29	21	491	135		109.17*	10.41	4.08	0.51	0.59	1.72	1.80
Far	A_500	46	46	840*	280		104.70	15.39	7.99	0.68*	0.74	2.59*	2.83
Far	B_1250	55*	**68***	977*	417*		53.50	18.06*	**11.11***	**0.86***	0.82	**3.45***	**3.47***
Far	B_250	17	41	346	170		44.62	6.30	7.79	0.45	0.75	1.26	2.78
Far	B_3000	49	48*	**1131***	278		8.37	15.72	8.35*	0.53	0.84*	2.07	3.26*
Far	B_750	19	12	482	253		2.24	6.71	1.99	0.37	0.41	1.09	1.02
Far	C_1000	33	25	460	84		26.92	12.021	5.42	0.55	0.86*	1.91	2.76
Far	D_250	66	60	946	388		33.21	21.84	9.90	0.79	0.82	3.32	3.36
Far	D_750	45	56	709	323		23.6	15.44	9.52	0.63	0.80	2.39	3.21
Far	D_1250	19	9	574	78		89.45	6.52	1.84	0.38	0.64	1.11	1.41

Notes:
Numbers in bold indicate highest value and
"*" indicates one of the top 5 highest values.
2014 biomass counts were not available for direct comparison

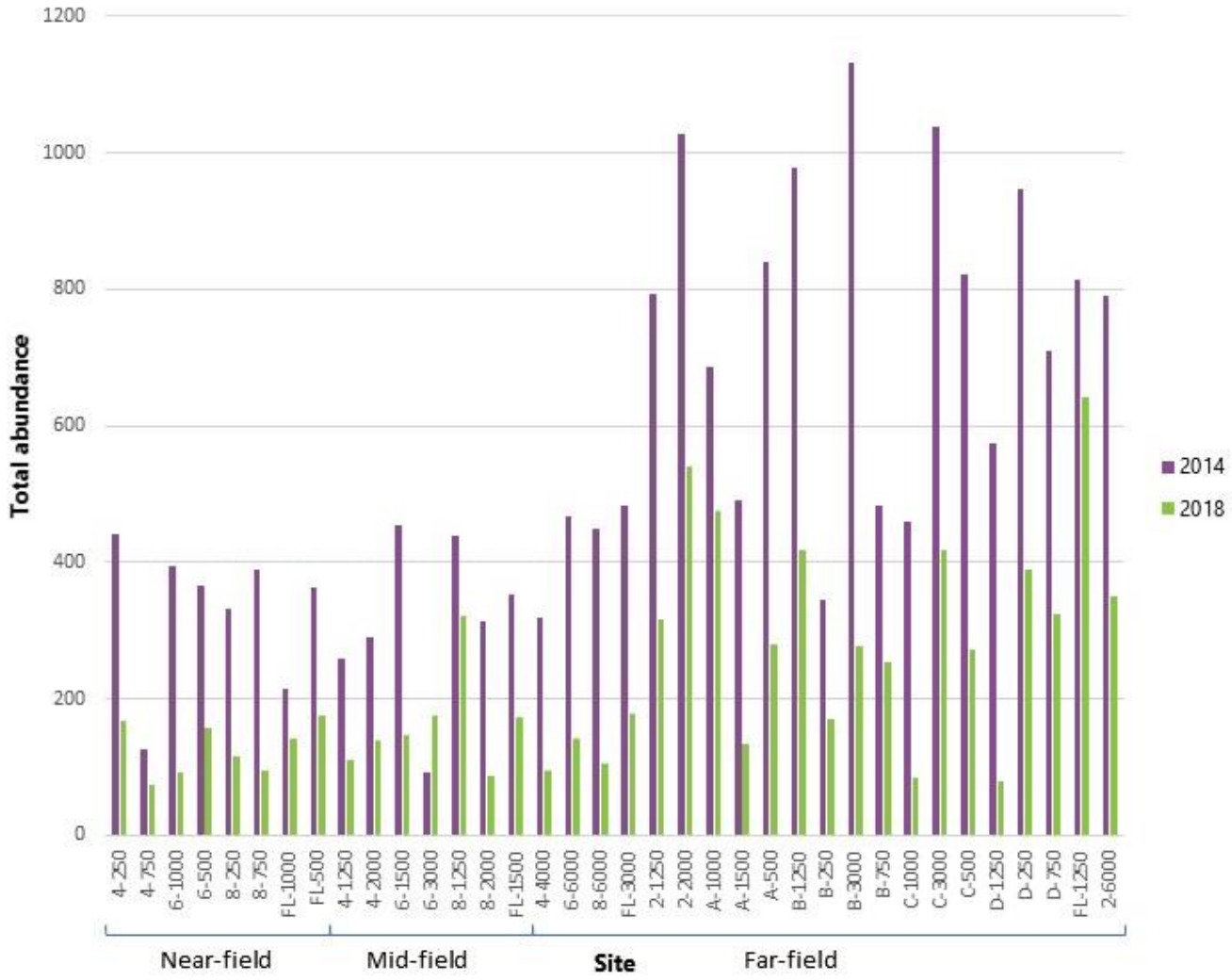

Figure 4-46 Total abundance of all taxa in order of distance category for all sites sampled in 2014 (purple) and 2018 (green).

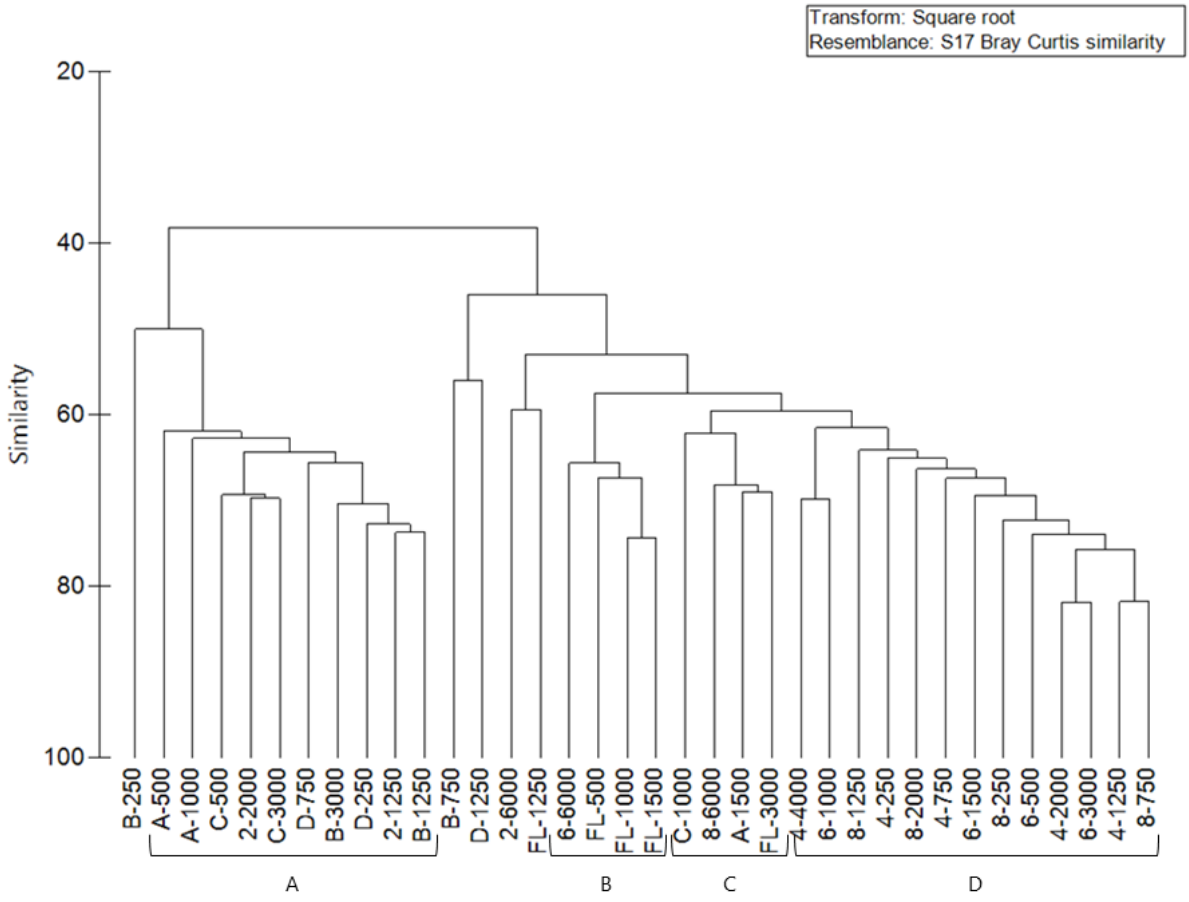

Figure 4-47 Hierarchical cluster similarity analysis on family groups per site. Groups are indicated at the 60 percent similarity threshold.

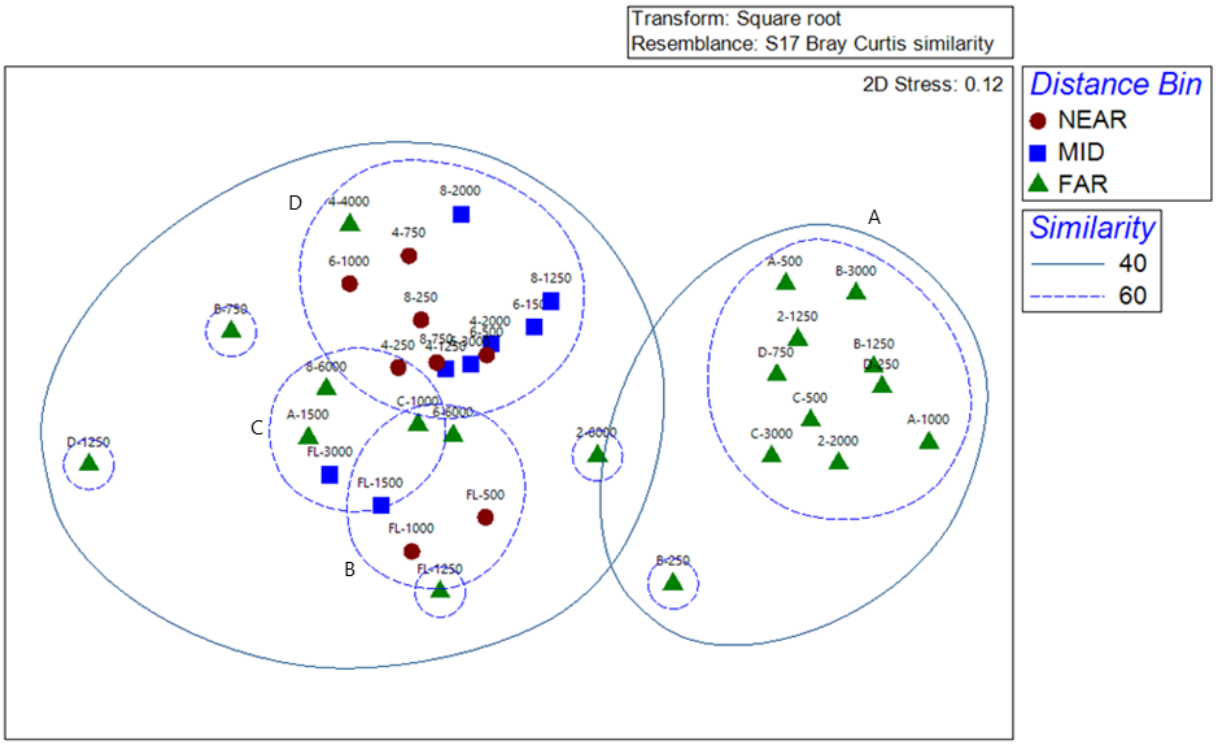

Figure 4-48 nMDS plot of site groupings based on family abundance by distance bin from platform. Solid lines represent 40 percent similarity within circle and dotted lines represent 60 percent similarity.

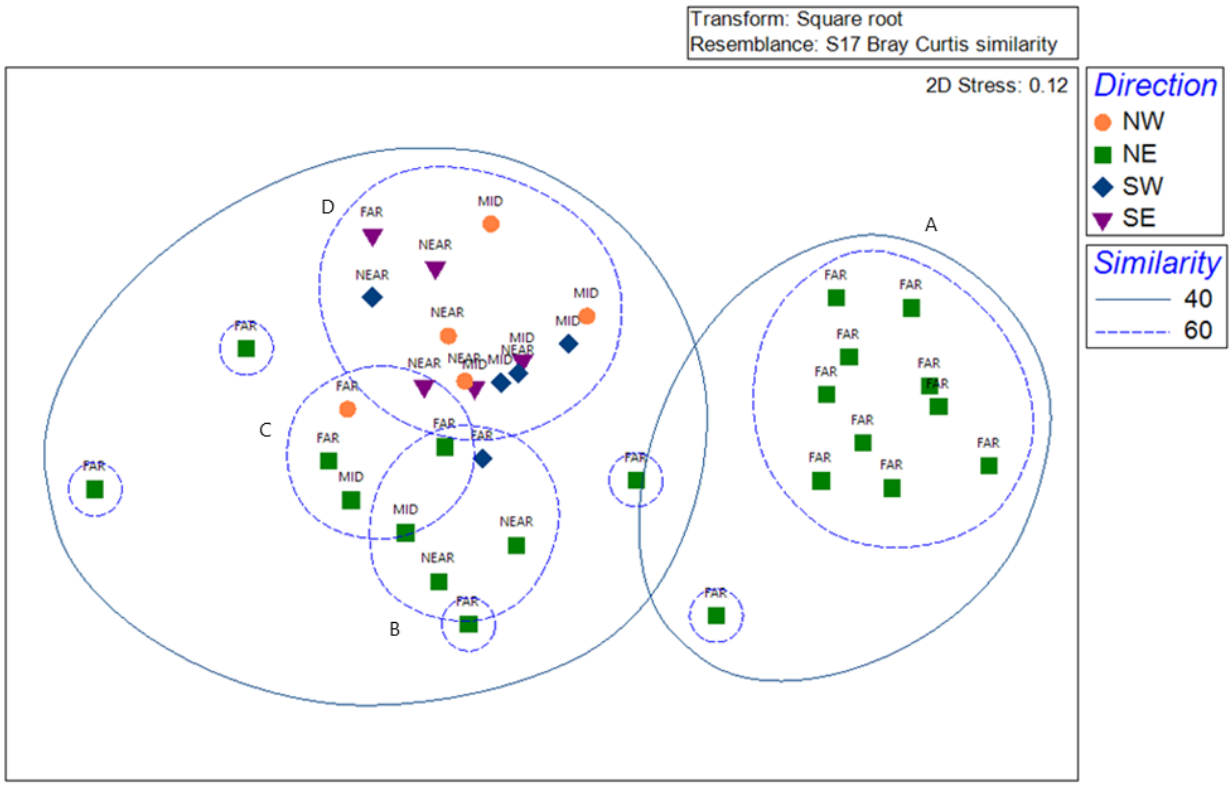

Figure 4-49 nMDS plot of site groupings based on family abundance by direction from platform. Solid lines represent 40 percent similarity within circle and dotted lines represent 60 percent similarity.

Table 4-22 Results for DISTLM stepwise analysis on Bray-Curtis similarity benthic infauna assemblage matrix.

Variable	SS (trace)	Pseudo-F	P-value	Proportion of the Explained Variation
Sulphide	1222.1	0.90356	0.467	2.59E-02
Total Sulphur	1082.6	0.79799	0.562	2.29E-02
Ammonia	1154.3	0.8521	0.496	2.44E-02
Total Organic Carbon	5569.2	4.5473	**0.003**	0.11797
Moisture	2084.2	1.5703	0.153	4.41E-02
Barium	1423.3	1.0569	0.333	3.01E-02
Cadmium	881.39	0.64684	0.791	1.87E-02
Iron	1729.3	1.2928	0.207	3.66E-02
Lead	3034.1	2.3351	0.051	6.43E-02
Manganese	1062.4	0.7827	0.545	2.25E-02
Zinc	885.82	0.65015	0.785	1.88E-02
Redox Potential	5103.3	4.1207	**0.005**	0.1081
Moisture (PSA)[1]	2238.5	1.6924	0.109	4.74E-02
Gravel	9916.1	9.0402	**0.001**	0.21004
Sand	9945.6	9.0743	**0.001**	0.21067
Silt	713.72	0.5219	0.875	1.51E-02
Clay	1381.9	1.0252	0.343	2.93E-02
>C10-C16 Hydrocarbons	1455.8	1.0818	0.344	3.08E-02
>C16-C21 Hydrocarbons	1465.9	1.0895	0.367	3.10E-02
>C21-C32 Hydrocarbons	2008.3	1.5106	0.141	4.25E-02
Moisture (PAH)[1]	3110.6	2.3982	**0.033**	6.59E-02

Notes:
Bold indicates significant at $p<0.05$ threshold.
[1]Sediment moisture associated with PSA or PAH analyses

4.4 Summary of Results

4.4.1 Physical and Chemical Characteristics

Analysis of physical and chemical analytes showed some differences between 2018 and 2014 samples. Clay was the only sediment fraction to increase in all distance bins between 2018 and 2014. These increases occurred at sites to the west and south of the platform. There was no change in sand or gravel percentage near the platform. Overall clay distribution patterns saw higher concentrations to the south and southwest of the platform and to the northeast at distances >6,000 m.

There was an increase in barium concentration for samples taken in the Near-field between 2014 and 2018. Lead concentrations also increased between sample years. There was no difference in concentration between years for iron or manganese. Hydrocarbons $>C_{10}$-C_{21} and $>C_{21}$-C_{32} concentrations were similar between 2014 and 2018, with the exception of certain near-field sites. Site 8-250 had increases of percent clay, percent silt, concentrations of barium, iron, lead, $>C_{10}$-C_{21}, $>C_{21}$-C_{32}, total sulphur, and total organic carbon. This is likely due to its location closest to the point of discharge.

4.4.2 Toxicity

All 2018 sediment samples passed Petrotox screening. Of the obligatory sediment samples tested (<500 m), all were determined to be non-toxic from amphipod survival assays.

4.4.3 Benthic Community Structure

Overall, there were fewer occurrences of organisms and taxon observed in 2018 than 2014. While overall abundance and taxa count decreased between years, the spatial distributions were similar between years. In 2014, Near- and Mid-field sites had an overall lower total abundance compared to the Far-field stations. In 2018, the number of taxa and total abundance was comparatively lower across all distance bins, however the highest levels were observed in the Far-field stations (similar to 2014). Cluster analysis shows a distinction between Far-field sites to the northeast of the platform and sites at Near-field and Mid-field distance bins towards the south and west. After examining the faunal and environmental data through multivariate analysis, clustering is influenced by percent total organic carbon, sand, gravel, moisture, and redox potential.

Taxa widely used as indicators of pollution effects (Spionidae and Clitellata) decreased between 2014 and 2018 samples. In both sampling years, sites farthest from the platform (>6,000 m) reported relatively high abundances of Spionidae polychaetes. Clitellata abundances decreased in 2018 from 2014 levels for all sites sampled. The most commonly used indicator of marine pollution world-wide, Capitellidae, were not abundant in 2014 or 2018 samples within the sampling area. Monitoring for changes in benthic community structure will continue in subsequent sampling years.

5 WATER COMPONENT

As outlined in the Hebron EEM Plan, water sampling will commence when the produced water is continuous (EMCP 2017). The Hebron produced water was not continuous in 2018. The water sampling hypothesis and planning will be discussed in subsequent Hebron EEM reports.

6 COMMERCIAL FISH COMPONENT

6.1 Methods

6.1.1 Field Collection

The 2018 commercial fish and fish health sampling program was conducted aboard the fisheries research vessel (*FRV*) *Nuliajuk* using a 1200 Campelen trawl towed within a 2 km radius of the Hebron Platform and associated Reference Area. The Reference Area is located 80 km NNE from the Hebron Platform (Figure 6-1) and is a shared Reference Area with the Hibernia and Hibernia Southern Extension (HSE) fish sampling programs. All sampling was conducted according to the requirements of the Experimental License issued by Fisheries and Oceans Canada (NL-4686-18) (see Volume II). All fish processing and sampling was performed by Wood personnel. The crew of the FRV *Nuliajuk* operated the trawl and aided in fish sorting of the trawl contents. Tows were 15 minutes in duration and the start and finish coordinates were recorded on bridge sheets. American plaice (*Hippoglossoides platessoides*) were immediately removed from the cod-end and placed in a large fish tub with flow-through sea water.

For each trawl, all species were identified, counted and recorded. American plaice greater than 30 cm and appearing free of trawl damage were retained for sampling. The fish length, weight (whole and gutted), sex, maturity, and liver and gonad weight were recorded. A blood sample was collected for blood cell count analyses. The liver, gills, stomach, and fillet tissues were preserved for histology, bioassays, body burden, and taint (taste) testing. Where available, livers and top fillets were sampled from additional fish to ensure sample volumes were sufficient for analyses. Sample handling and storage was completed as quickly as possible to maintain sample integrity; prepared samples were stored in appropriate facilities on-board the vessel. Furthermore, the deck of the vessel was cleaned with degreaser after each tow to mitigate against contamination between trawls/sites and ship sources.

Comparisons were made between the 2018 sampling program and the 2015 fish characterization sampling. However, since the fish characterization program informed the eventual EEM design, there are differences between the existing and pervious sampling methodology including minimum fish length and tissue chemistry compositing methodology. Areas initially sampled during the 2015 fish characterization study as potential Reference Areas for the Hebron EEM program were not resampled in 2018. The current Reference Area is shared with the Hibernia and Hibernia Southern Extension Program, therefore results from the 2015 HSE EEM Reference Area were used for across year comparisons in this chapter. Differences in data among sample years include variations in sample number and the use of composite samples (one lab sample consisting of several individual fish samples) (Table 6-1). Other methodologies used in 2015 were similar to the 2018 program (e.g., trawl length, fish sampling protocols, recorded measures) allowing comparison among years. Further details on the 2015 Reference Area commercial fish results are presented in Appendix A.

Table 6-1 Sampling design between the 2015 Fish Characterization Study and 2015 Hibernia Southern Extension EEM Methodology and the Hebron EEM Methodology.

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

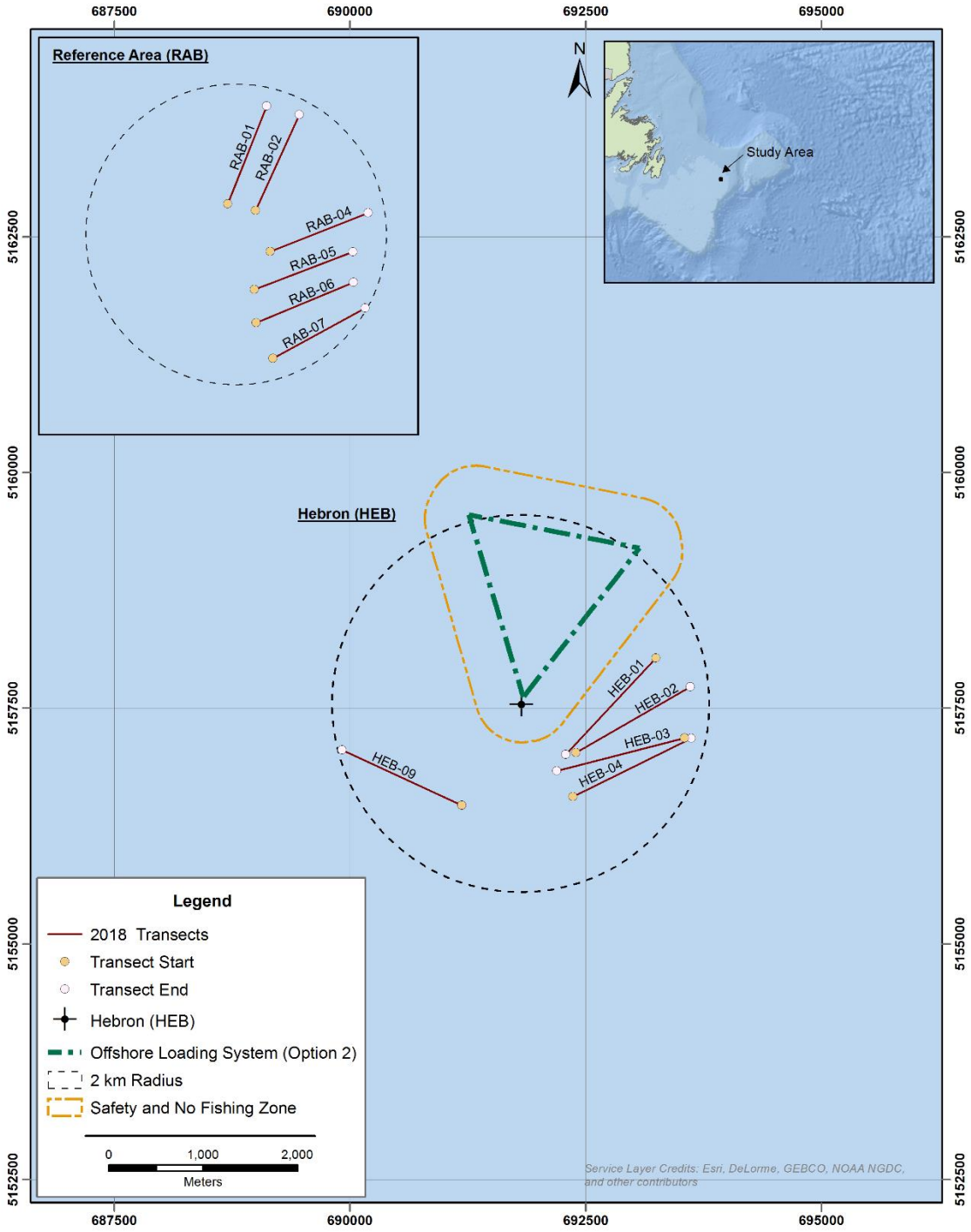

Figure 6-1 2018 Hebron EEM commercial fish sampling program trawl locations.

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 be made, dried and fixed in methanol.
2. Morphometrics (total length, and wet and gutted weight) were measured for each fish. Notes were made on the external condition of each fish and presence of any parasites or lesions for gross pathology (Goede and Barton 1990, Adams et al. 1993). The fish was then euthanized by severing the spinal cord.
3. The first gill arch was removed and stored in a Bio-tite container with 10% neutral buffered formalin for gill histology analysis.
4. The top fillet was removed for sensory evaluations and stored in a labelled Ziploc bag (-20°C freezer).
5. The internal tissues were examined for parasites, lesions and any abnormalities. The sex, maturity stage, gonad weight, liver weight, stomach contents, and other relevant information were recorded. Incidental observations of hydrocarbon odors 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 from the head and stored in a coin envelope for fish aging.
9. Samples were grouped together by area and trawl number.

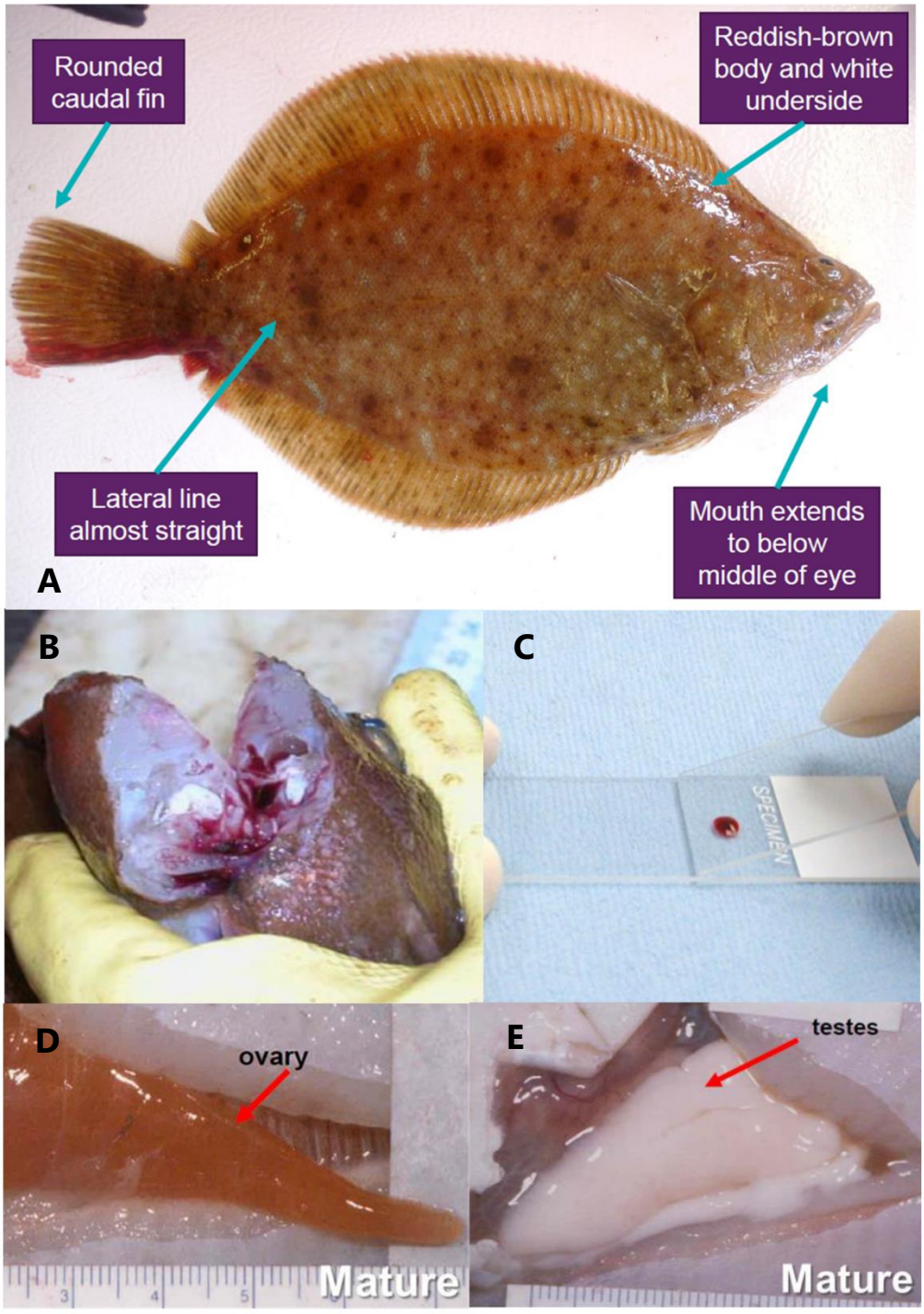

Figure 6-2 Examples of field sampling measures taken aboard the FRV *Nuliajuk*: A) American plaice with identifying characteristics, B) otoliths being extracted, C) creating a blood smear, D) mature female ovary, and E) mature male testes.

6.1.3 Laboratory and Statistical Analysis

6.1.3.1 Chemical Profiling

All fillet and composite samples were analysed for metals, fuel and lube range hydrocarbons (>C_{10}-C_{32}), and polycyclic aromatic hydrocarbons (PAHs) (EMCP 2017). Metals, hydrocarbons and PAHs were screened for reporting and further analysis if 50% or more of tested samples exceeded their reported detection limit (RDL) at one or more sites. One-way ANOVAs were used to compare between the Hebron Platform and Reference Area in 2018, and two-way ANOVAs were used to compare across both years (2015 and 2018) 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). Analytes listed in the design plan and additional tested analytes are listed in Table 6-2. To obtain meaningful descriptive statistics for samples with values below RDL, the value of the RDL was used for calculation so as not to present mean values below the detection limit as per the design plan (EMCP 2017). Half RDL was used for statistical analysis as a conservative value (EMCP 2017).

Table 6-2 Analytes tested in American plaice fillets and liver composites in 2018.

Metals in design Plan	Additional metals	Hydrocarbons	PAHs in design plan	Additional PAHs
• Arsenic • Barium • Cadmium • Chromium • Copper • Iron • Lead • Manganese • Mercury • Selenium • Zinc	• Aluminum • Antimony • Beryllium • Boron • Cobalt • Lithium • Molybdenum • Nickel • Silver • Strontium • Thallium • Tin • Uranium • Vanadium	• C_{10}-C_{21} [a] • C_{21}-C_{32}	• 1-Methylnaphthalene • 2-Methylnaphthalene • Acenaphthene • Acenaphthylene • Anthracene • Benzo(a)anthracene • Benzo(a)pyrene • Benzo(b)fluoranthene • Benzo(g,h,i)perylene • Benzo(j)fluoranthene • Benzo(k)fluoranthene • Chrysene • Dibenz(a,h)anthracene • Fluoranthene • Fluorene • Indeno(1,2,3-cd)pyrene • Naphthalene • Perylene • Phenanthrene • Pyrene	• Benzo(b/j)fluoranthene

Notes:
[a] Reported as >C_{10}-C_{16} and >C_{16}-C_{21} as per the latest Partnership in Risk-Based Corrective Action Implementation (PIRI) guidelines

6.1.3.2 Taste Testing

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 2018) 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.

Health Canada's maximum allowable limits are presented in Table 6-3. For arsenic, only total arsenic was measured but only inorganic is considered by Health Canada and as it is far more toxic than organic arsenic (Francesconi 2010). The United States Environmental Protection Agency (US EPA) published a report stating inorganic arsenic is roughly four percent of total arsenic present in wild fish populations (US EPA 1997). To be conservative for screening purposes, the inorganic arsenic was calculated as 10 percent (as opposed to four percent) of the total arsenic value. All fillets were deemed safe for human consumption.

Table 6-3 Screening of potential contaminants present in fish fillets against Health Canada maximum allowable limits in fish protein.

Contaminant	Health Canada Maximum Limit
Arsenic (inorganic)	3.5 ppm (mg/kg)[1]
Lead	0.5 ppm (mg/kg)
Mercury	0.5 mg/kg

Notes:
[1] As only total arsenic was measured, the value screened was calculated as 10% of the total arsenic concentration (i.e. 35 mg/kg total organic)

Chemical analysis of American plaice tissues that are sampled for the EEM program may not necessarily detect an overall difference in sensory perception of the sampled tissues. Therefore, sensory evaluations are performed using two qualitative assays; the triangle test and the Hedonic Scaling test (EMCP 2017).

The triangle test is used to qualitatively assess American plaice fillet samples for any disparities in sensory perception between samples derived from fish collected from the Hebron Platform versus the Reference Area (EMCP 2017). 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 are 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.

6.1.3.3 Fish Health Program

The Hebron fish health survey was conducted to qualitatively assess American plaice collected adjacent to the Hebron Platform and the Reference Area (Figure 6-1). Tissues were subsampled and used as health indicators as indicated in Section 5.3 of the Design Plan (EMCP 2017). As American plaice are sexually dimorphic, each sex was analyzed separately to account for growth differences and maturation rates (Swain and Morgan 2001). Raw data for measures reported in this section are found in Volume II.

6.1.3.3.1 Biological Characteristics

Sexual maturity stage was assessed for males and females according to standard Fisheries and Oceans Canada (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.

6.1.3.3.2 Gross Pathology

Gross pathology of specimens was documented using a fish autopsy-based condition assessment adapted from Goede and Barton (1990) for field codes and Adams et al. (1993) for assignment of a health assessment index value (Volume II). Three health assessment indexes 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 effects). Assessments of the fish thymus were not conducted as it may have interfered with otolith extraction. Fish were examined individually in the onboard vessel laboratory by biologists and any macroscopic indications of disease, abnormalities, or lesions were noted for each specimen. Only qualitative assessments of gross pathology were conducted in 2015, therefore, cross-year comparisons are not available. For 2018, 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.

6.1.3.3.3 Haematology

Haematological changes are strongly related to fish health in response to environmental changes (Corrêa et al. 2016) 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, lymphocytes, and thrombocytes in 200 cell counts were done by the Cold-Ocean Deep-Sea Research Facility (CDRF) at Memorial University of Newfoundland (MUN) (EMCP 2017). Results from the Reference Area in 2015 were not available. Comparisons between the Hebron Platform and the Reference Area in 2018 were done using one-way ANOVAs, and comparisons across years and sites (with data only at the Hebron Platform in 2015, as samples from the Reference Area were discarded) used two-way ANOVAs.

6.1.3.3.4 Mixed Function Oxygenases

Mixed function oxygenases (MFOs), fish liver detoxification enzymes, are a family of membrane-bound enzymes that facilitate the transformation of aromatic and lipophilic compounds into more water-soluble ones for excretion (Hodson et al. 1991, van der Oost et al. 2003). Measurement of MFO activity is used as a monitoring tool to indicate the presence of chemical contamination in fish (Hodson et al. 1991, van der Oost et al. 2003). To quantify MFO, the fluorometric activity of one of the most important bio-transforming enzymes in this group, ethoxyresorufin-O-deethylase (EROD), is measured via spectrophotometry (Hodson et al. 1991, Brooks et al. 2015; EMCP 2017). Basal EROD activity and response to exposure of a contaminant can vary between genders and sexual maturity may have the greatest influence on this response in certain species of fish (Kirby et al. 1999, Mathieu et al. 2011). One-way ANOVAs were used to compare between sites in 2018, and two-way ANOVAs to compare across years and sites.

6.1.3.3.5 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 are conducted. Briefly, fish tissue samples were preserved in formalin, embedded in wax, sectioned into thin (6 µm) slices and mounted on slides according to standard histological methods (EMCP 2017). The histological parameters examined included the presence of different lesions defined according to standard methods (Khan and Kiceniuk 1984, Khan 1990, 1995, Khan et al. 1994). Gill and liver samples were processed for histopathology comparisons by the CDRF using haematoxylin and eosin, which stains nuclei purple-blue and cytoplasm red-pink, respectively. Gill samples were assessed by the CDRF and liver samples were assessed by Dr. Rasul Khan. Fisher's t-test was used to compare each liver histology in 2018, while one-way ANOVAs were used to compare gill histologies. Cross-year comparisons were done using multivariate analysis of variance (MANOVA) incorporating each histopathology factor that was detected in fish, with two-way ANOVAs used to compare each factor in the MANOVA to verify which are driving any significant differences found.

6.2 Results

6.2.1 Field Collection

There were five trawls conducted at the Hebron Platform and six conducted at the Reference Area in 2018 (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 6-4. The most common catch at both sites was sand lance (*Ammodytes dubius*; n=1,360 and 2,665 at the Hebron Platform and Reference Area, respectively), followed by American plaice (*Hippoglossoides platessoides*; n=396 and 246, respectively) and yellowtail flounder (*Pleuronectes ferruginea*; n=16 and 272, respectively) (Table 6-4). Non-fish species were observed at low densities, with northern shrimp (*Pandalus borealis*; n=5 and 0, respectively) being the most common. The number of American plaice retained for processing from each tow is given in Table 6-5, and the start and end coordinates for each tow is given in Table 6-6.

Length-frequency distributions were created using 70 American plaice collected from each survey location in 2018 (Figure 6-5). Male and female American plaice retained from both sites were comparable in size (Figure 6-5). Overall, the greater proportion of larger fish were collected at the Hebron Platform for both males and females, though the largest fish collected was a female at the Reference Area (Figure 6-5).

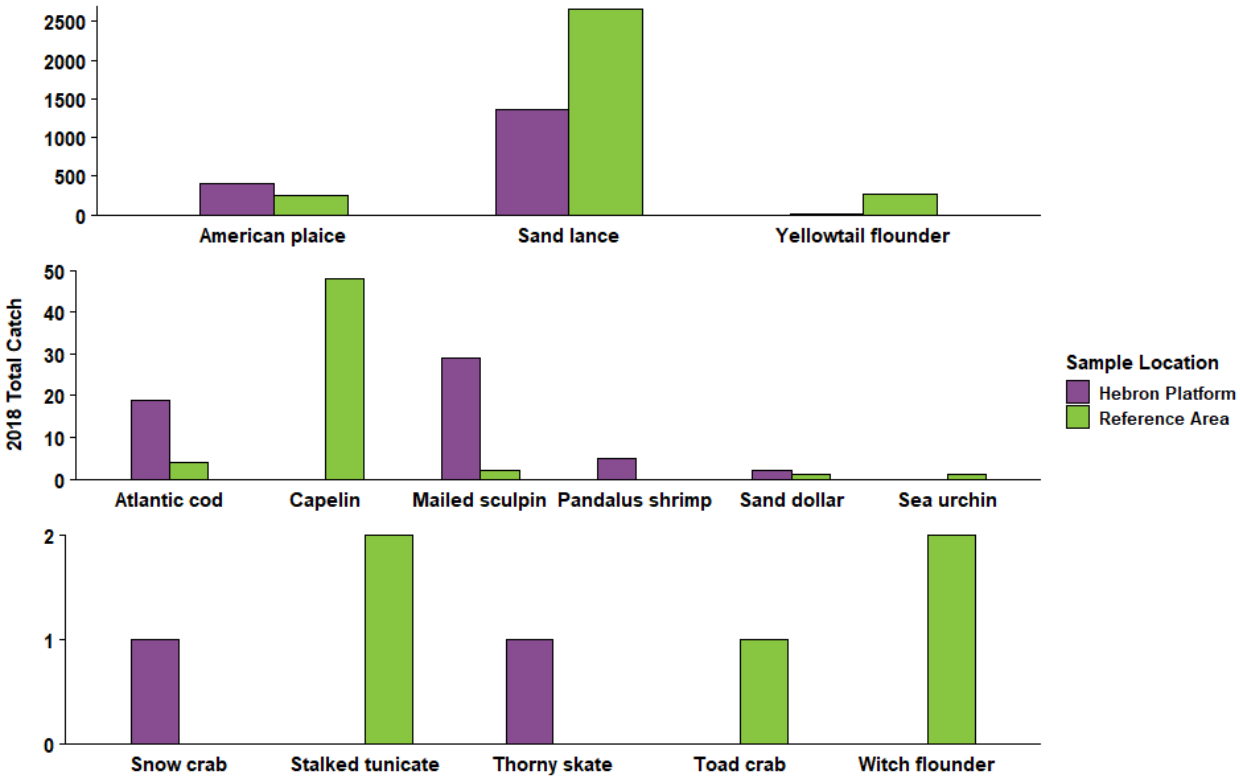

Figure 6-3 Total catch at Hebron Platform and Reference Area during the 2018 EEM.

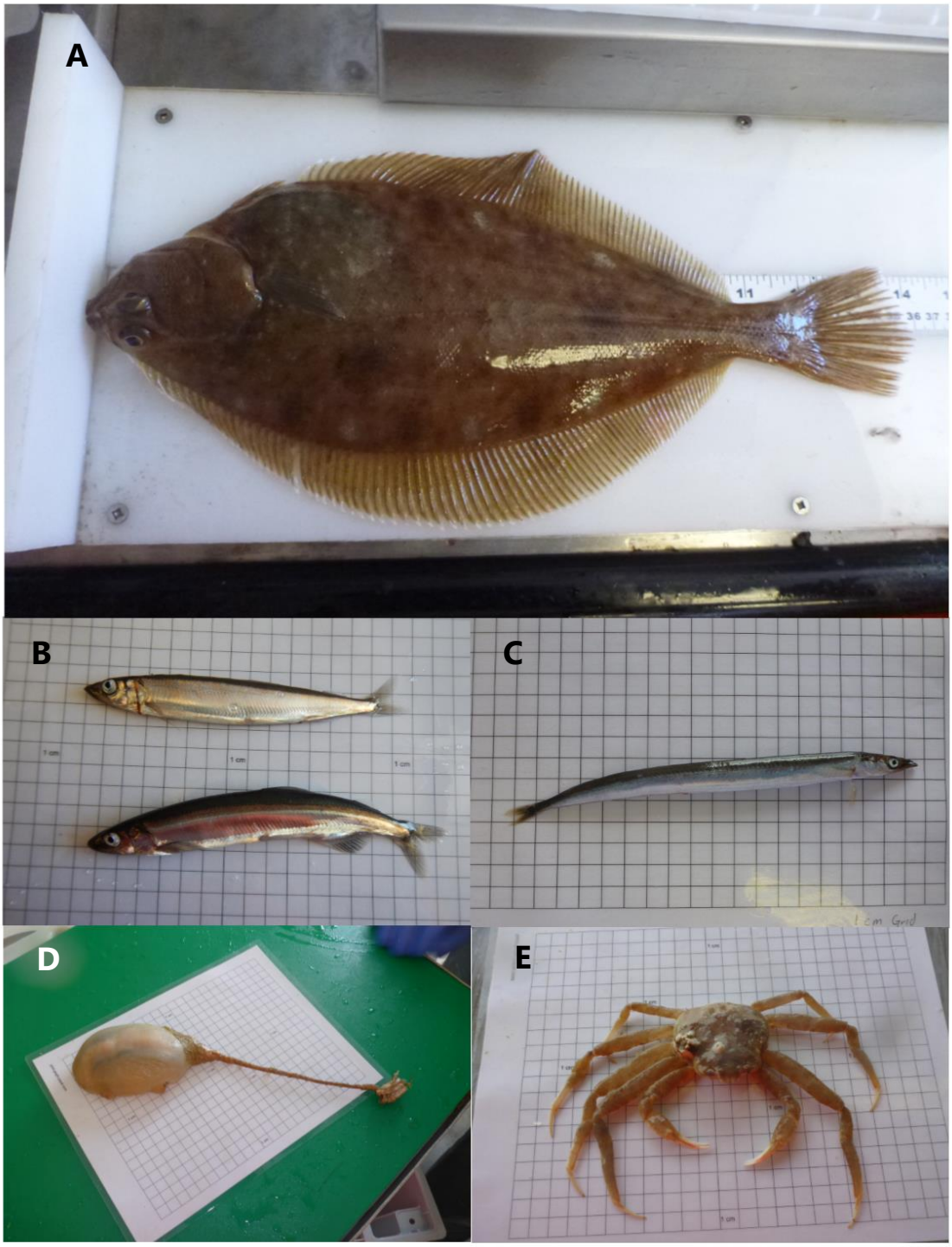

Figure 6-4 Representative catch species from the 2018 Hebron EEM program: A) American plaice, B) capelin, C) sand lance, D) stalked tunicate, and E) snow crab. See Table 7.1 for scientific names.

Table 6-4 Total catch per species and catch per unit effort (number per trawl) around the Hebron Platform and Reference Area, 2018.

Faunal Group	Species Name	Scientific Name	Hebron Platform		Reference Area	
			Total Catch	CPUE (n=5)	Total Catch	CPUE (n=6)
Fish	American plaice	*Hippoglossoides platessoides*	396	79.20	246	41.00
Fish	Atlantic cod	*Gadus morhua*	19	3.80	4	0.67
Fish	Capelin	*Mallotus villosus*	0	0	48	8.00
Fish	Mailed sculpin	*Triglops* sp.	29	5.80	2	0.33
Fish	Sand lance	*Ammodytes dubius*	1360	272.00	2665	444.00
Fish	Thorny Skate	*Amblyraja radiata*	1	0.20	0	0
Fish	Witch flounder	*Glyptocephalus cynoglossus*	0	0	2	0.33
Fish	Yellowtail flounder	*Pleuronectes ferruginea*	16	3.20	272	45.30
Ascidian	Stalked tunicate	*Boltenia ovifera*	0	0	2	0.33
Crustacean	Northern shrimp	*Pandalus borealis*	5	1.00	0	0
Crustacean	Snow crab	*Chionoecetes opilio*	1	0.20	0	0
Crustacean	Toad crab	*Hyas araneus*	0	0	1	0.17
Echinoderm	Green sea urchin	*Strongylocentrotus droebachiensis*	0	0	1	0.17
Echinoderm	Sand dollar	*Echinarachnius parma*	2	0.40	1	0.17

Table 6-5 Tows completed, and American plaice retained, for sampling and summary of samples taken for analysis.

Sampling area	Tow number	American plaice captured	Liver samples collected	Fillet samples collected	Sensory analyses samples collected (g)
Hebron Platform	HEB-01	15	15	15	1,455
	HEB-02	15	15	15	1,472
	HEB-03	15	15	15	1,455
	HEB-04	15	15	15	1,403
	HEB-09	10	10	10	1,031
	Total	**70**	**70**	**70**	**6,816**
Reference Area	RAB-01	14	14	14	835
	RAB-02	15	15	15	1,086
	RAB-04	13	13	13	898
	RAB-05	4	4	4	490
	RAB-06	9	9	9	604
	RAB-07	15	15	15	1,548
	Total	**70**	**70**	**70**	**5,461**

Table 6-6 Start and end coordinates for each trawl for the Hebron Platform Commercial Fish Sampling Program (UTM Coordinates, NAD83, Zone 22), 2018.

Trawl ID	Depth (m)	Station Type	Start		End	
			Easting	Northing	Easting	Northing
HEB-01	93	Hebron Platform	693243.55	5158031.05	692287.36	5157008.45
HEB-02	93	Hebron Platform	692397.45	5157027.77	693610.52	5157726.68
HEB-03	92	Hebron Platform	693548.57	5157183.44	692193.22	5156832.68
HEB-04	93	Hebron Platform	692364.96	5156561.86	693620.44	5157181.36
HEB-09	94	Hebron Platform	691186.53	5156467.26	689915.76	5157054.75
RAB-01	82	Hebron Reference Area	634869.71	5216244.60	635388.97	5217544.74
RAB-02	82	Hebron Reference Area	635241.96	5216157.80	635823.06	5217431.50
RAB-04	80	Hebron Reference Area	635436.49	5215611.89	636739.62	5216123.61
RAB-05	78	Hebron Reference Area	635226.84	5215106.18	636534.82	5215605.37
RAB-06	76	Hebron Reference Area	635250.06	5214662.20	636542.82	5215199.58
RAB-07	77	Hebron Reference Area	635471.31	5214177.70	636701.12	5214857.71

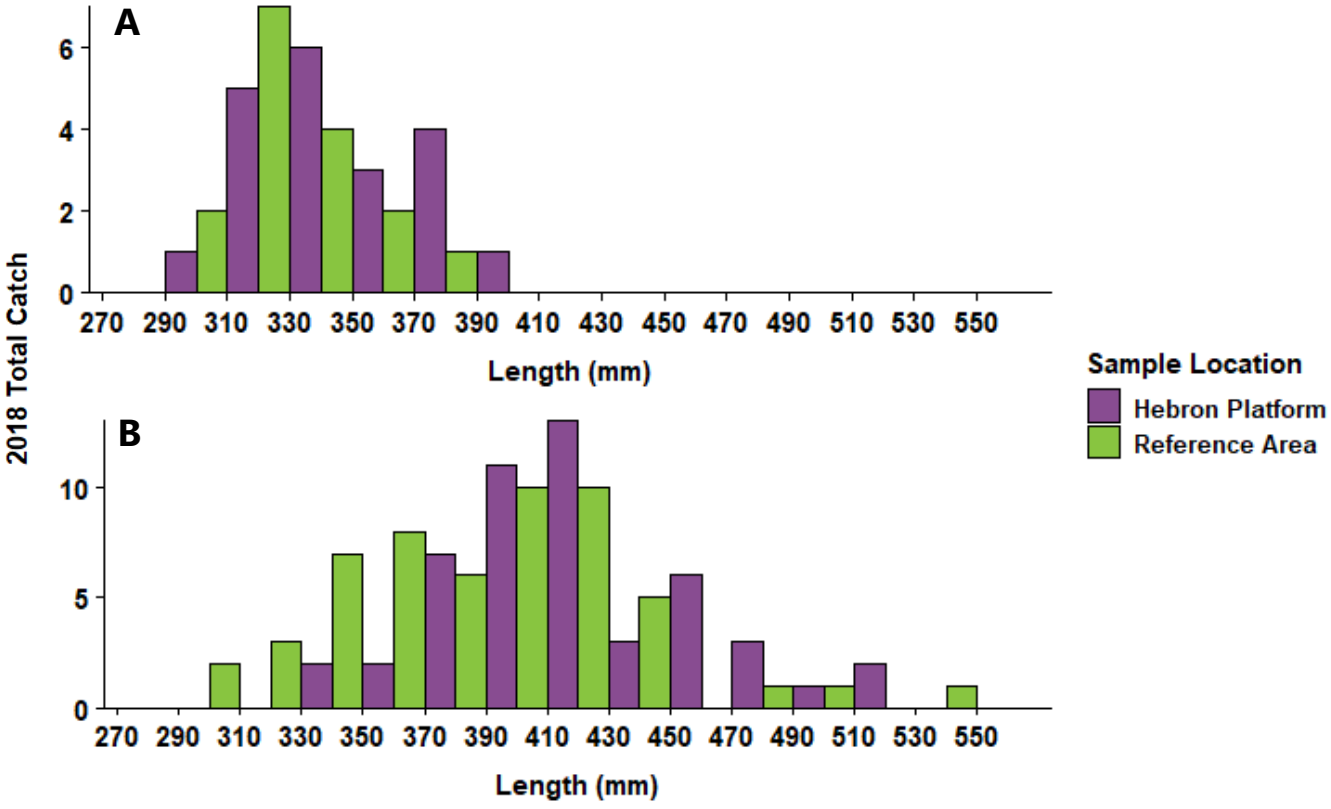

Figure 6-5 Length-frequency of male (A) and female (B) American plaice collected from the Hebron Platform and Reference Area in 2018.

6.2.1.1 Across-year Comparison

Two-way ANOVA comparison of CPUE results from 2015 and 2018 across both the Hebron Platform and Reference Area for all species showed no significant difference for either site or year (Table 6-7). Though the average CPUE is higher in 2018, the standard deviation is much higher as well at both sites (Table 6-7). CPUE for American plaice across years is shown in Figure 6-6, with Hebron Platform in 2018 being significantly higher than all other sites (p=<0.01 for all Tukey HSD comparisons).

Table 6-7 Two-way ANOVAs of average CPUE of all species collected from Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Site	1	958	957.9	0.1327	0.718
Year	1	7679	7678.7	1.0640	0.309
Site*Year	1	86	85.9	0.0119	0.914
Residuals	36	259803	7216.7		
Notes: Bolded p-value denotes a significant result (α=0.05)					

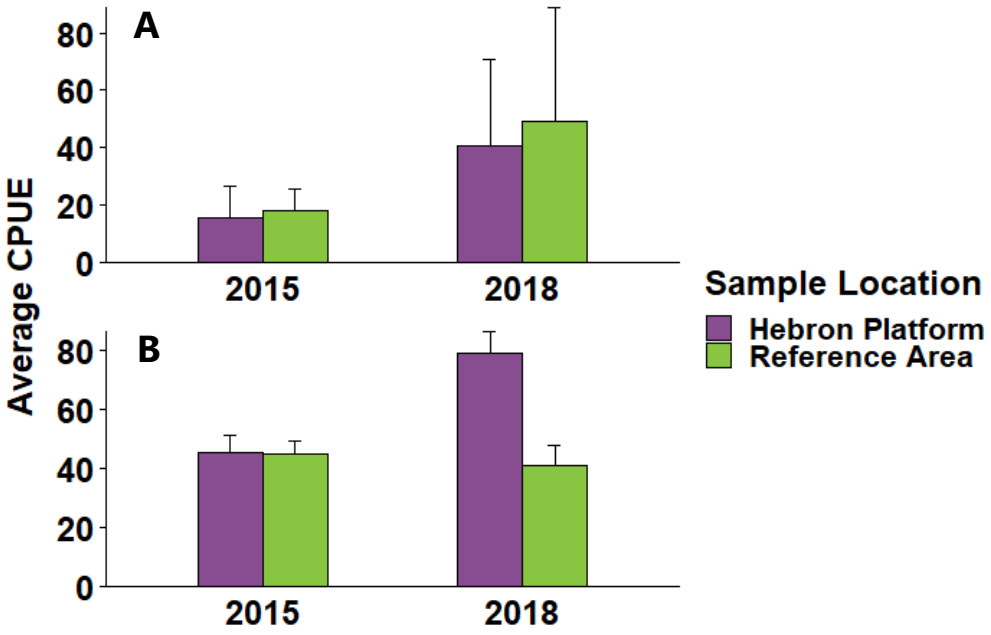

Figure 6-6 CPUE of A) all species, and B) American plaice collected from the Hebron Platform and Reference Area in 2015 and 2018.

6.2.2 Chemical Profiles of American Plaice Tissue

Five sets of composite tissue and liver samples were collected from American plaice from each of the two areas (Hebron Platform and Reference Area). Tissue and liver samples were composites of at least 10 individual fish per sample, and composites were used to ensure sufficient portions for tests. Analytes listed in the design plan and additional tested analytes are listed in Table 6-2. All tested analyte data is included in Volume II of this report and a summary of the body burden chemistry analytes that were detected (>RDL) at the Hebron Platform and Reference Area within fillets and liver composites is presented in Table 6-8 and Table 6-9.

For fillet tissue samples, both the Platform and Reference Area contained arsenic, mercury, and zinc above the detection limit in all five samples (Table 6-8). 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 among any sampled fillets (Table 6-8). One-way ANOVAs found no significant difference between the Hebron Platform and Reference Area for arsenic ($p=0.80$), mercury ($p=0.70$), or zinc ($p=0.28$) (Table 6-8).

For the liver composites, both the Platform and Reference Area samples contained arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc above the RDL in all five samples (Table 6-9). Two samples from the Reference Area contained silver above RDL (1.3 mg/kg and 0.16 mg/kg), and one sample from both the Platform and Reference Area contained vanadium above RDL (1.3 mg/kg and 0.54 mg/kg, respectively). Though no hydrocarbons from the $>C_{10}$-C_{16} range were detected, all samples contained those in the $>C_{16}$-C_{21} and $>C_{21}$-C_{32} ranges (Table 6-9). For PAHs, acenaphthylene was above RDL for all samples, while fluorene was above RDL for two of five samples at the Platform (though two other samples had RDLs above 0.2 mg/kg due to matrix/co-extractive interference) and all five samples at the Reference Area (Table 6-9).

Two-way ANOVAs found no significant difference between the Hebron Platform and Reference Area for arsenic, copper, iron, manganese, mercury, selenium, or zinc (Table 6-9). Cadmium was found to differ between the two sites ($p=0.032$) and was higher at the Reference Area (Table 6-9). Hydrocarbons in both the $>C_{16}$-C_{21} and $>C_{21}$-C_{32} ranges did not differ between sites ($p=0.249$ and 0.947, respectively; Table 6-9). The two PAHs consistently detected above their RDLs (acenaphthylene and fluorene) did not differ between sites ($p=0.794$ and 0.089, respectively; Table 6-9).

Table 6-8 Summary statistics of 2018 Hebron Platform and Reference Area fillet body burden data (mg/kg).

Parameter	RDL (mg/kg)	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	No. ≥ RDL	Mean	St. Dev	Median	Min	Max	p-value
Hebron Platform Fillet composites (n=5)								Reference Area Fillet composites (n=5)						
Metals								**Metals**						
Arsenic	0.50	5	3.4	0.47	3.8	2.6	3.8	5	3.5	0.71	3.8	2.6	4.2	0.799
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Iron	15	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Mercury	0.01	5	0.10	0.01	0.08	0.05	0.09	5	0.10	0.03	0.07	0.06	0.12	0.697
Selenium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Zinc	1.5	5	3.8	0.16	3.9	3.6	4.0	5	3.6	0.30	3.5	3.4	4.1	0.279
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 6-9 Summary statistics of 2018 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=5)**						**Reference Area Fillet (n=5)**						
Arsenic	0.50	5	5.3	1.19	4.9	4.0	6.7	5	6.3	0.62	6.3	5.6	7.3	0.127
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Cadmium	0.050	5	0.90	0.05	0.93	0.85	0.99	5	1.00	0.07	1.00	0.95	1.10	**0.032**
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Copper	0.50	5	4.6	1.03	4.9	2.9	5.6	5	6.6	1.78	5.8	5.0	8.9	0.066
Iron	15	5	61.2	20.99	60	39	95	5	70	18.19	65	50	99	0.499
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL	-
Manganese	0.50	5	0.90	0.04	0.92	0.84	0.96	5	0.90	0.06	0.89	0.83	1.00	0.821
Mercury	0.01	5	0.04	0.01	0.04	0.03	0.06	5	0.04	0.02	0.04	0.02	0.09	0.987
Selenium	0.50	5	2.48	0.23	2.5	2.2	2.7	5	2.52	0.38	2.6	1.9	2.9	0.844
Zinc	1.5	5	33.20	1.79	32	32	36	5	34.40	2.70	36	31	37	0.432
Hydrocarbons								**Hydrocarbons**						
>C_{10}-C_{16}	15	None detected, all samples <RDL						None detected, all samples <RDL						-
>C_{16}-C_{21}	15	5	35.60	14.69	30	19	57	5	51.00	23.48	40	29	89	0.249
>C_{21}-C_{32}	15	5	78.40	17.56	74	55	100	5	79.00	8.15	80	70	91	0.947
PAHs [a, b, c]								**PAHs**						
Acenaphthylene	0.050	5	0.069	0.007	0.069	0.061	0.078	5	0.071	0.013	0.068	0.057	0.091	0.794
Fluorene	0.050 [a]	2	0.122	0.077	0.076	<RDL	0.210	5	0.106	0.014	0.100	0.088	0.120	0.089

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

[a] Several PAHs had elevated RDLs due to matrix/co-extractive interference: 2-Methylnaphthalene, Fluoranthene, and Fluorene.

[b] RDL for Benzo(b/j)fluoranthene is 0.10 mg/kg

[c] The following requested PAHs were below their RDLs (0.050 mg/kg): 1-Methylnaphthalene, 2-Methylnaphthalene, Acenaphthene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(b/j)fluoranthene, Benzo(g,h,i)perylene, Benzo(j)fluoranthene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Indeno(1, 2, 3-cd)pyrene, Naphthalene, Perylene, Phenanthrene, and Pyrene.

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

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

6.2.2.1.1 Metals in Hebron Platform and Reference Area Fillets

Consistent with the 2015 results, arsenic, mercury, and zinc were detected in all American Plaice fillets from both the Hebron Platform and Reference Area in 2018 (Table 6-8). No other metals, hydrocarbons, or PAHs were detected in fillet samples. Results from 2015 also included one value at RDL for aluminum (2.5 mg/kg) and above RDL for selenium (0.63 mg/kg) at the Reference Area, and one above RDL for strontium (2.4 mg/kg) at the Hebron Platform. The concentration of arsenic, mercury, and zinc in fish tissue from 2015 and 2018 EEM program is presented in Figure 6-7.

Separate two-way ANOVA results for arsenic, mercury, and zinc are given in Table 6-10. No significant results for site, year, or site-year interaction were found for arsenic and mercury (α=0.05). For zinc, site and the interaction between site and year were not significant (p=0.72 and p=0.41, respectively). However, zinc was significantly different among monitoring years (p=0.01). Figure 6-7C shows zinc concentrations were lower in 2018 than 2015 (Tukey HSD p=0.011).

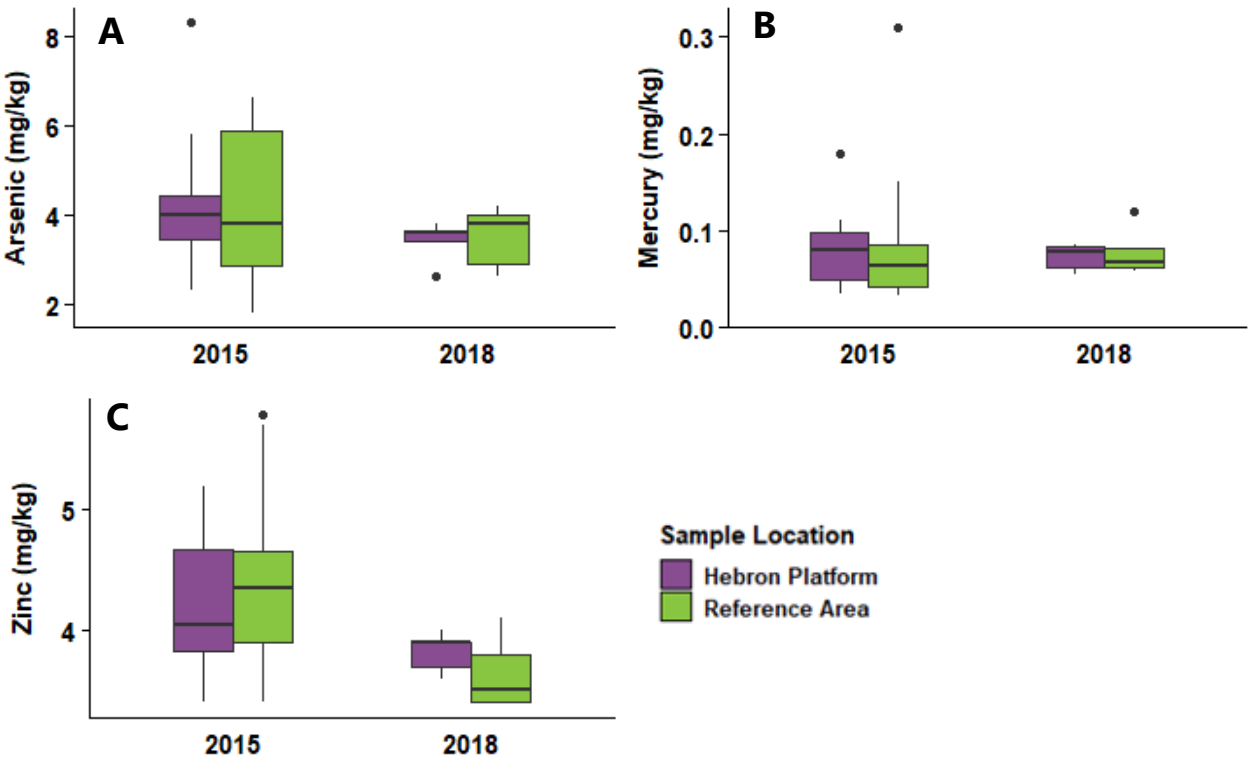

Figure 6-7 Boxplots of arsenic (A), mercury (B), and zinc (C) in American Plaice fillet tissue from the Hebron Platform and Reference Area from 2015 and 2018.

Table 6-10 Two-way ANOVAs for arsenic, mercury, and zinc concentration in fillet tissue from American Plaice collected from Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	0.005	0.0053	0.0024	0.96
Year	1	4.428	4.4282	1.9987	0.17
Site*Year	1	0.020	0.0202	0.0091	0.92
Residuals	26	57.605	2.2156		
Mercury					
Site	1	4.18e-4	4.18e-4	0.130	0.72
Year	1	9.13e-4	9.13e-4	0.283	0.60
Site*Year	1	1.9e-5	1.9e-5	0.006	0.94
Residuals	26	0.0838	0.00322		
Zinc					
Site	1	0.0480	0.0480	0.1338	0.72
Year	1	2.5215	2.5215	7.0274	**0.01**

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Site*Year	1	0.2535	0.2535	0.7065	0.41
Residuals	26	9.3290	0.35881		
Notes: Bolded p-value denotes a significant result (α=0.05)					

6.2.2.1.2 Metals in Hebron Platform and Reference Area Livers

Consistent with the 2015 results, arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in all liver composites for the Hebron Platform and Reference Area in 2018 (Table 6-9). Cobalt, silver, and vanadium have been inconsistently observed in 2015 and 2018 composites. Cobalt was not above the 0.20 mg/kg RDL for 2018 samples but had two values (0.22 and 0.27 mg/kg) above RDL for Hebron Platform in 2015, and one value (0.27 mg/kg) above RDL in the Reference Area in 2015. Silver had no values above the 0.12 mg/kg RDL for Hebron Platform in 2018, but Reference Area 2018 had two values (1.3 and 0.16 mg/kg) above RDL, Hebron Platform 2015 had two values (0.22 and 0.15 mg/kg) above RDL, and Reference Area 2015 had one value (0.13 mg/kg) above as well. Vanadium had one value (1.3 mg/kg) above the 0.50 mg/kg RDL for Hebron Platform 2018, one at the Reference Area 2018 (0.54 mg/kg), two at Hebron Platform in 2015 (0.55 and 0.51 mg/kg), and four at the Reference Area 2015 (0.93, 3.0, 1.7, 1.3 mg/kg).

The eight metals listed above with RDL detections in greater than 50 percent of the samples (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc) were also above RDL in 50 percent of all liver composites from 2015. No difference between years, sites, or site-year interaction was observed for copper, iron, mercury, or zinc (α=0.05; Table 6-11). Arsenic and selenium were significantly different between years (p=0.014 and 0.003, respectively; Table 6-11) and both saw a decrease in concentration from 2015 to 2018 (Figure 6-8). Cadmium was significantly different between sites (p=0.014; Table 6-11) and was higher at the Reference Area across years (Figure 6-8). Manganese had a significant interaction term (p=0.032), with both site (p=0.002) and year (p=<0.001) significant as well (Table 6-11). Manganese levels are higher in 2018 than in 2015, and higher at the Hebron Platform compared to the Reference Area (Figure 6-7).

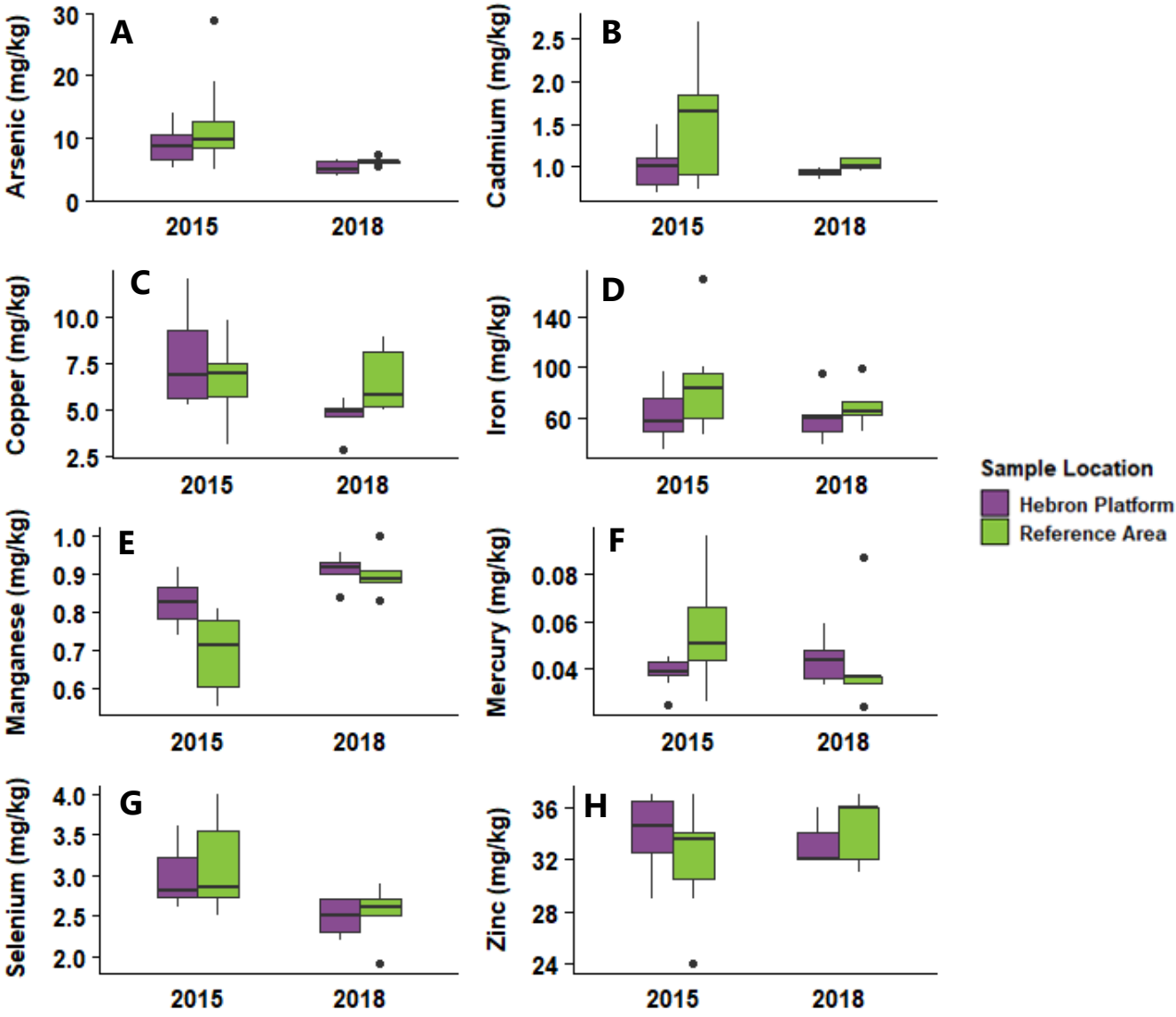

Figure 6-8 Boxplots of arsenic (A), cadmium (B), copper (C), iron (D), manganese (E), mercury (F), selenium (G), and zinc (C) in American Plaice liver composites from the Hebron Platform and Reference Area.

Table 6-11 Two-way ANOVAs for arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc concentration in liver composites from American plaice collected from Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	47.13	47.125	2.2789	0.143
Year	1	144.46	144.460	6.9857	**0.014**
Site*Year	1	8.29	8.288	0.4008	0.532
Residuals	26	537.66	20.679		
Cadmium					
Site	1	1.0231	1.02305	6.3537	**0.018**
Year	1	0.4969	0.49686	3.0857	0.091
Site*Year	1	0.2720	0.27203	1.6894	0.205
Residuals	26	4.1865	0.16102		
Copper					
Site	1	0.033	0.0333	0.0085	0.927
Year	1	16.433	16.4327	4.1700	0.051
Site*Year	1	13.443	13.4427	3.4112	0.076
Residuals	26	102.458	3.9407		
Iron					
Site	1	2784.0	2784.03	4.0062	0.056
Year	1	380.0	380.02	0.5468	0.466
Site*Year	1	410.8	410.82	0.5912	0.449
Residuals	26	18068.1	694.93		
Manganese					
Site	1	0.062563	0.062563	12.4048	**0.002**
Year	1	0.141135	0.141135	27.9838	**<0.001**
Site*Year	1	0.026042	0.026042	5.1635	**0.032**
Residuals	26	0.131130	0.005043		
Mercury					
Site	1	0.0010800	0.00108000	3.4659	0.074
Year	1	0.0000888	0.00008882	0.2850	0.598
Site*Year	1	0.0005582	0.00055815	1.7912	0.192
Residuals	26	0.0081017	0.00031160		
Selenium					
Site	1	0.0963	0.09633	0.5430	0.468
Year	1	1.9802	1.98017	11.1607	**0.003**
Site*Year	1	0.0202	0.02017	0.1137	0.739
Residuals	26	4.6130	0.17742		
Zinc					
Site	1	4.8	4.8000	0.5222	0.476
Year	1	2.4	2.4000	0.2611	0.614
Site*Year	1	15.0	15.0000	1.6318	0.213

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Residuals	26	239.0	9.1923		
Notes: Bolded p-value denotes a significant result (α=0.05)					

6.2.2.1.3 Hydrocarbons in Hebron Platform and Reference Area Tissues

No hydrocarbons were detected in fillets taken from the Hebron Platform or Reference Area in 2018 (Table 6-8). However, all liver composites from both sites contained hydrocarbons in the >C_{16}-C_{21} and >C_{21}-C_{32} range (Table 6-9). For the fuel range hydrocarbons (>C_{16}-C_{21}), the mean value was higher in the Reference Area (51.0 mg/kg) than at the Hebron Platform (35.6 mg/kg), with an RDL of 15 mg/kg (Table 6-9). For lube-range hydrocarbons (>C_{21}-C_{32}), mean values at both locations were not statistically different (Reference Area: 79.0 mg/kg, Hebron Platform: 78.4 mg/kg), with an RDL of 15 mg/kg (Table 6-9). All composites at both sites also contained unidentified compounds in the fuel/lube range (see Maxxam Analytics report in Volume II).

Hydrocarbons in these ranges were detected in 2015 liver composite samples as well (EMCP 2016b). Similar trends were observed at the reference site, with hydrocarbons in the >C_{16}-C_{21} and >C_{21}-C_{32} ranges above the 15 mg/kg RDL. Comparisons across sites and years is presented in Figure 6-9. Hydrocarbons in both ranges significantly differed between years (Table 6-12), with >C_{16}-C_{21} concentrations in 2018 higher than 2015 at both locations and >C_{21}-C_{32} concentrations lower in 2018 than 2015 at both locations (Figure 6-9).

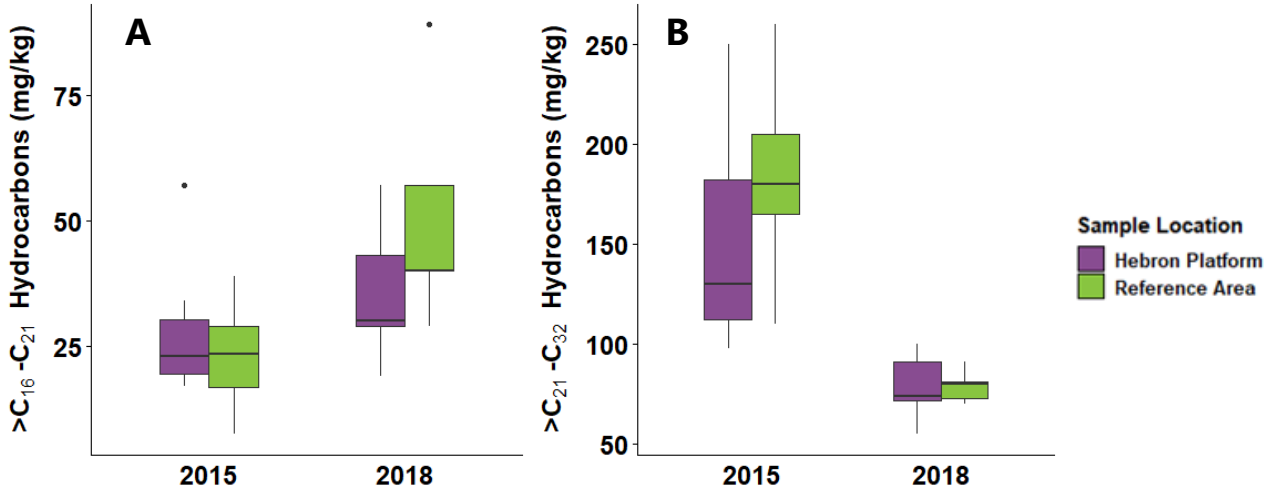

Figure 6-9 Boxplots of >C_{16}-C_{21} hydrocarbons (A) and >C_{16}-C_{21} hydrocarbons (B) in American plaice liver composites from the Hebron Platform and Reference Area from 2015 and 2018.

Table 6-12 Two-way ANOVAs for >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 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
>C_{16}-C_{21} Hydrocarbons					
Site	1	38.5	38.53	0.1894	0.667
Year	1	2318.8	2318.82	11.3994	**0.002**
Site*Year	1	646.8	646.82	3.1798	0.086
Residuals	26	5288.8	203.42		
>C_{21}-C_{32} Hydrocarbons					
Site	1	3741	3741	2.4718	0.128
Year	1	50113	50113	33.1123	**<0.001**
Site*Year	1	1771	1771	1.1704	0.289
Residuals	26	39349	1513		

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

6.2.2.1.4 PAHs in Hebron Platform Tissues

No PAHs were detected in fillet samples from either Hebron Platform or the Reference Area in 2018 (Table 6-8). However, two compounds in liver composites were detected above their 0.050 mg/kg RDLs: acenaphthylene and fluorene (Table 6-9). All liver composites were above RDL for acenaphthylene, with similar concentrations at both Hebron Platform (0.069 mg/kg) and the Reference Area (0.071 mg/kg). For fluorene, two liver composites were above RDL at Hebron Platform (mean: 0.122 mg/kg) and all five liver composites were above RDL at the Reference Area (0.106 mg/kg). However, the Hebron Platform also had two samples for fluorene with elevated lab RDLs due to matrix/co-extractive interference. These new RDL values (0.21 and 0.20 mg/kg) were higher the two detections above their RDLs, leading to the elevated average from half of the elevated RDLs being used in calculations.

No PAHs were detected in fillet samples from either Hebron Platform or the Reference Area in 2015. Neither acenaphthylene nor fluorene were detected in liver composites in 2015. However, other PAHs had values above RDL in liver composites. Five of ten livers at the Hebron Platform and one of ten livers at the Reference Area in 2015 had 2-Methylnaphthalene above the 0.050 mg/kg RDL. For the 2018 report, all composites at both sites for 2-Methylnaphthalene had elevated RDLs due to matrix/co-extractive interference, though no values were above their RDL. Three of ten livers at the shared reference site in 2015 had Naphthalene detected above RDL, with no detections at the Hebron Platform.

Two-way ANOVA results for acenaphthylene in liver composites showed significant differences between years (p=<0.0001; Table 6-13) with no significant interaction term. In 2015, acenaphthylene was all below the 0.050 mg/kg RDL, and so both stations in 2018 were higher (Figure 6-10). Two-way ANOVA results for fluorene showed significant differences between sites (p=0.044; Table 6-13), with no significant interaction term. Even though most results in 2018 were above RDL and no results in 2015 were above their RDLs, the Hebron Platform in 2015 had elevated RDLs for fluorene due to matrix/co-extractive interference in the lab analysis process. Using half-RDL still resulted in a high median and upper quartiles, which is likely contributing to this site difference (Figure 6-10).

Table 6-13 Two-way ANOVAs for acenaphthylene and fluorene concentrations in liver composites from American plaice collected from Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Acenaphthylene					
Site	1	0.0000027	0.0000027	0.0788	0.781
Year	1	0.0134401	0.0134401	392.2786	**<0.001**
Site*Year	1	0.0000054	0.0000054	0.1576	0.695
Residuals	26	0.0008908	0.0000343		
Fluorene					
Site	1	0.17633	0.176333	4.4802	**0.044**
Year	1	0.02158	0.021584	0.5484	0.466
Site*Year	1	0.12604	0.126042	3.2024	0.085
Residuals	26	1.02332	0.039358		

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

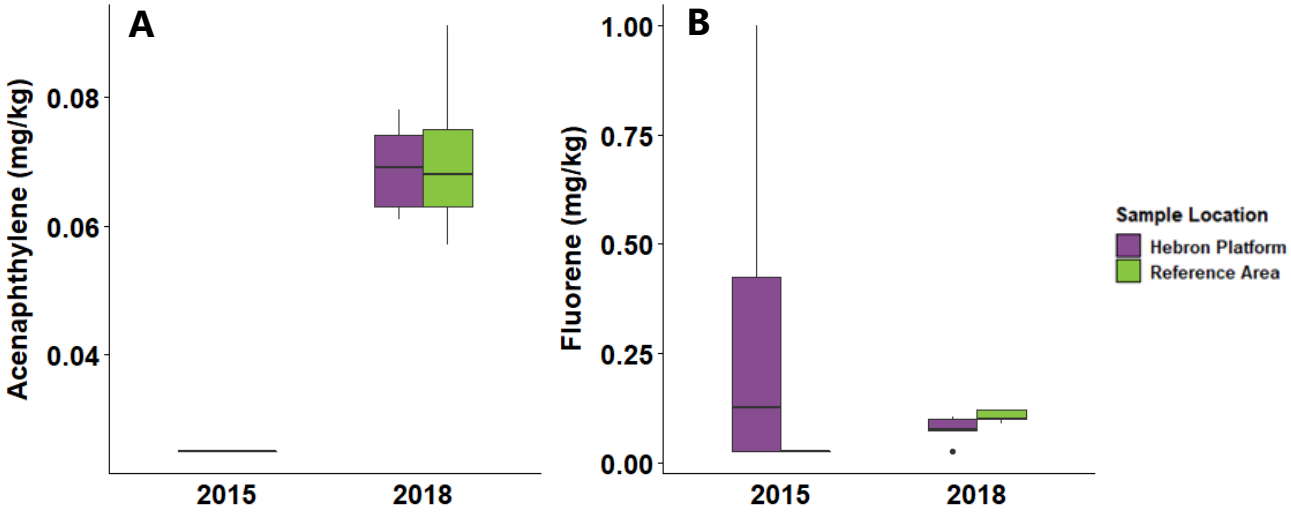

Figure 6-10 Boxplots of acenaphthylene (A) and fluorene (B) in American Plaice liver composites from the Hebron Platform (Hebron) and Reference Area (Reference) from 2015 and 2018.

6.2.2.2 Taste Panels

All fillets were deemed safe for human consumption based on Health Canada guidelines (Health Canada 2018; see 6.1.3.2). For the 2018 EEM program, 9 of 24 panelists were able to successfully discriminate the odd sample which indicates results are not significant (p=0.254). Comments from panelists for the triangle test are in Table 6-14. For the 2018 EEM, hedonic taste tests showed no significant differences between the Hebron Platform and the Reference Area (p=0.306; Table 6-15). Comments from panelists from the hedonic tests are in Table 6-16.

Overall, there were no significant differences between the Hebron Platform and Reference Area for the 2018 EEM taste panel results. These results are consistent with the 2015 results from the Hebron Platform EEM (EMCP 2016b), though these results are comparing the reference site from the 2015 fish characterization study and not the current Reference Area.

Table 6-14 Summary of comments from the triangle test for Hebron Platform and Reference Area American plaice collected in 2018. Brackets are paraphrased text to clarify site.

Correctly guessed odd sample	Incorrectly guessed odd sample
More desired flavour as compared to others	(Reference Area sample) is blander, but not by much
(Reference Area sample) good, bland taste. Others more fishy.	No noticeable difference
(Reference Area sample) tasted the best. The other two samples were really fishy smell and taste.	(Reference Area sample) tastes sweeter
	(Reference Area sample) slightly sweeter
	(Hebron Platform sample) has more strong odor, and flavour compared to others
	Very subtle difference barely detectable, however I feel (Hebron Platform sample) was somewhat different than the other two samples.
	Less fishy taste on (Hebron Platform sample)

Table 6-15 One-way ANOVA of hedonic taste test preference evaluation of American plaice from the Hebron Platform and Reference Area in 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Between Groups	2	5.333	2.667	1.217	0.306
Within Groups	45	98.583	2.191		
Total	47	103.917			

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

Table 6-16 Summary of comments from the hedonic scaling test for Hebron Platform and Reference Area American plaice collected in 2018. Brackets are paraphrased text to clarify site.

Preferred Reference Sample	Preferred Hebron Sample
(Hebron Platform sample) had a stronger flavour.	(Hebron Platform sample) had a slightly more desirable flavour. (Reference Area sample) was bland.
Sweeter taste/mild. (Hebron Platform sample) is also acceptable	(Hebron Platform sample) more. (Reference Area sample) appeared to be more bland
(Hebron Platform sample) tested bitter/soapy. Slight bitter aftertaste	Slightly different taste.
Not quite as much flavour in (Hebron Platform sample) sample.	Not too pronounced difference.

Preferred Reference Sample	Preferred Hebron Sample
(Reference Area sample) pleasant, milkd [sic], sweet, characteristic odour and flavour. (Hebron Platform sample) also ok but a little less desirable in term of overall odour and flavour.	(Hebron Platform sample) had less of an off-taste
(Reference Area sample) has nice flavor and odor[sic]. (Reference Area sample) was tasteless and had strong odor.	Not much difference in either taste or odour.

6.2.3 Fish Health Program

6.2.3.1 Maturity Stages

Sexual maturity stages and the frequency (percentage) of fish presenting in each category at both locations is presented in Table 6-17. During the 2018 EEM program, 20 males and 50 females were collected at the Hebron Platform, and 16 males and 54 females at the Reference Area. Fisher's exact test showed no difference in the ratio of male to female fish between sites (p=0.56). No difference was found between maturity stage frequency for males or females between sites, with the exception of code Mat B-P (530) being significantly higher at the Hebron Platform (p=<0.01) (Table 6-17).

Table 6-17 Frequencies (%) of maturity stages of male (top) and female (bottom) American plaice from the 2018 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	20	10	0	0	85	0	5	0
Reference Area	16	0	0	0	100	0	0	0
p-value		0.49	1.00	1.00	0.24	1.00	1.00	1.00

Female Maturity Stage (% of individuals)										
	n	**Immature (500)**	**Spent L (510)**	**Maturing A-P (520)**	**Mat B-P (530)**	**Maturing C-P (540)**	**Partly Spent P (550)**	**Spent P (560)**	**Spent P Mat N (570)**	**Mat N (580)**
Hebron Platform	50	6	4	30	24	4	12	18	2	0
Reference Area	54	11.1	0	24.1	1.9	14.8	7.4	35.2	0	5.6
p-value		0.49	0.23	0.52	**<0.01**	0.09	0.52	0.08	0.48	0.24

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)

6.2.3.2 Biological Characteristics

6.2.3.2.1 2018 Results

Some significant variations between sites existed for male and female American plaice sampled (Table 6-18). Male fish differed in body weight (p=0.04) and liver weight (p=0.03). Female fish differed in length (p=<0.01), total (p=<0.01) and gutted (p=0.01) weight, liver weight (p=<0.01), and age (p=0.01). Several parameters likely co-vary. For example, gutted weight is expected to increase with total fish length, and liver and gonad weights should increase with gutted weight (regardless of HSI and GSI values). This was controlled for by using analysis of co-variance (ANCOVA) of the regression of the variable of interest on its covariate, compared between sites. These analyses found no significant difference between sites for gutted, liver, or gonad weight for both males and females (Table 6-19). However, male fish still differed between sites for total weight and females differed for total length, weight, and age.

Table 6-18 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 2018.

Parameter	Hebron Platform	Reference Area	p-value
Male			
No. of Fish	20	16	
Length (cm)	34.61 ± 2.67	33.02 ± 2.26	0.07
Total Body Weight (g)	369.0 ± 82.4	312.6 ± 72.0	**0.04**
Gutted Body Weight (g)	323.4 ± 74.2	278.0 ± 66.9	0.07
Liver Weight (g)	5.31 ± 1.26	4.30 ± 1.40	**0.03**
Gonad Weight (g)	4.53 ± 1.59	4.21 ± 2.39	0.63
Age (years) [a]	6.73 ± 1.33	7.71 ± 2.30	0.17
Fulton's Condition Index [b]	0.77 ± 0.07	0.76 ± 0.04	0.55
Hepatosomatic Index [c]	1.67 ± 0.30	1.55 ± 0.35	0.30
Gonadosomatic Index [d]	1.46 ± 0.56	1.49 ± 0.78	0.90
Female			
No. of Fish	50	54	
Length (cm)	41.88 ± 4.02	39.06 ± 4.80	**<0.01**
Total Body Weight (g)	707.1 ± 235.3	557.3 ± 241.6	**<0.01**
Gutted Body Weight (g)	577.2 ± 181.3	471.3 ± 205.0	**0.01**
Liver Weight (g)	11.4 ± 4.7	8.9 ± 4.1	**<0.01**
Gonad Weight (g)	28.7 ± 21.5	24.6 ± 23.4	0.35
Age (years) [e]	9.9 ± 2.1	8.6 ± 2.1	**0.01**
Fulton's Condition Index [b]	0.76 ± 0.07	0.75 ± 0.08	0.46
Hepatosomatic Index [c]	1.98 ± 0.49	1.90 ± 0.45	0.35
Gonadosomatic Index [d]	4.92 ± 3.92	5.30 ± 5.81	0.70

Notes:
All data are expressed as average values ± standard deviation
[a] For male age calculations, n=15 for the Hebron Platform and n=14 for the Reference Area

[b] Calculated as 100 x gutted body weight (g) / length (cm)^3
[c] Calculated as 100 x liver weight (g) /gutted body weight (g)
[d] Calculated as 100 x gonad weight (g) /gutted body weight (g)
[e] For female age calculations, n= 35 for the Hebron Platform and n=36 for the Reference Area
* Bolded p-value denotes significant results (α=0.05)

Table 6-19 Adjusted p-values from ANCOVA analysis of gutted, liver, and gonad weight for male (top) and female (bottom) American plaice from the Hebron Platform and Reference Area in 2018.

Variable	Covariate	Adjusted p-value [a]
Male		
Gutted weight (g)	Length (mm)	0.75
Liver Weight (g)	Gutted weight (g)	0.20
Gonad weight (g)	Gutted weight (g)	0.94
Female		
Gutted weight (g)	Length (mm)	0.42
Liver Weight (g)	Gutted weight (g)	0.25
Gonad weight (g)	Gutted weight (g)	0.86

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

6.2.3.2.2 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 6-20). There were no significant interactions terms. Significant results include male FCI being higher in 2018 than 2015, and male HSI higher at the Hebron Platform compared to the Reference Area (Table 6-20, Figure 6-11). Female HSI was higher in 2018 compared to 2015 (Table 6-20, Figure 6-12).

Table 6-20 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 in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
MALE					
Fulton's Condition Index					
Site	1	0.00010	0.00010	0.0128	0.910
Year	1	0.03342	0.03342	4.0998	**0.046**
Site*Year	1	0.00206	0.00206	0.2527	0.616
Residuals	103	0.83971	0.00815		
Hepatosomatic Index					
Site	1	1.2430	1.2430	8.0929	**0.005**

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Year	1	0.0886	0.0886	0.5768	0.449
Site*Year	1	0.1218	0.1218	0.7933	0.375
Residuals	103	15.8192	0.1536		
Gonadosomatic Index					
Site	1	0.020	0.01979	0.0335	0.855
Year	1	0.631	0.63116	1.0683	0.304
Site*Year	1	0.025	0.02544	0.0431	0.836
Residuals	103	60.855	0.59082		
FEMALE					
Fulton's Condition Index					
Site	1	0.0288	0.0288	1.3939	0.239
Year	1	0.0030	0.0030	0.1464	0.703
Site*Year	1	0.0163	0.0163	0.7901	0.375
Residuals	167	3.4583	0.0206		
Hepatosomatic Index					
Site	1	0.004	0.0041	0.0132	0.909
Year	1	1.293	1.293	4.170	**0.043**
Site*Year	1	0.510	0.510	1.645	0.202
Residuals	167	51.782	0.310		
Gonadosomatic Index					
Site	1	3.2	3.2215	0.1150	0.735
Year	1	10.4	10.4134	0.3717	0.543
Site*Year	1	0.4	0.3867	0.0138	0.907
Residuals	167	4679.2	28.0194		

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

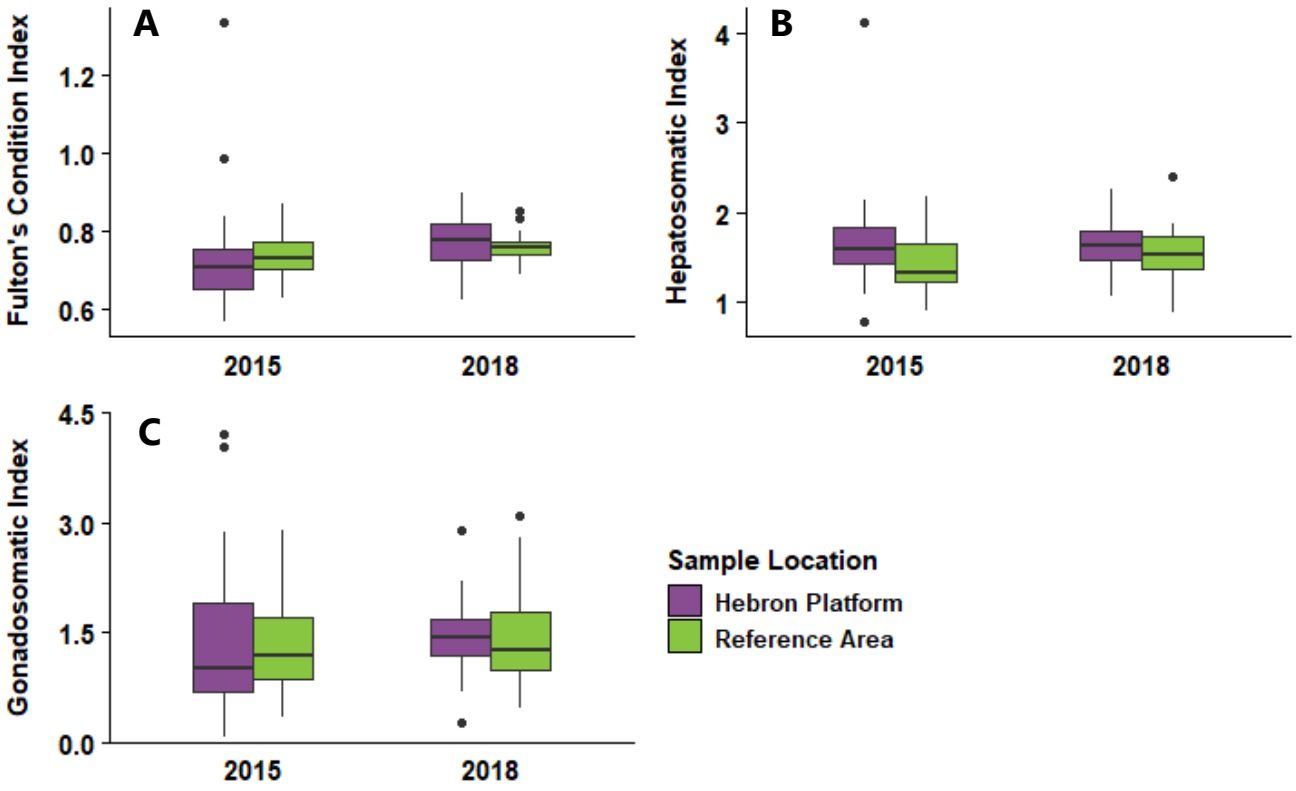

Figure 6-11 Boxplots of Fulton's condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for male American plaice sampled from the Hebron Platform and Reference Area in 2015 and 2018.

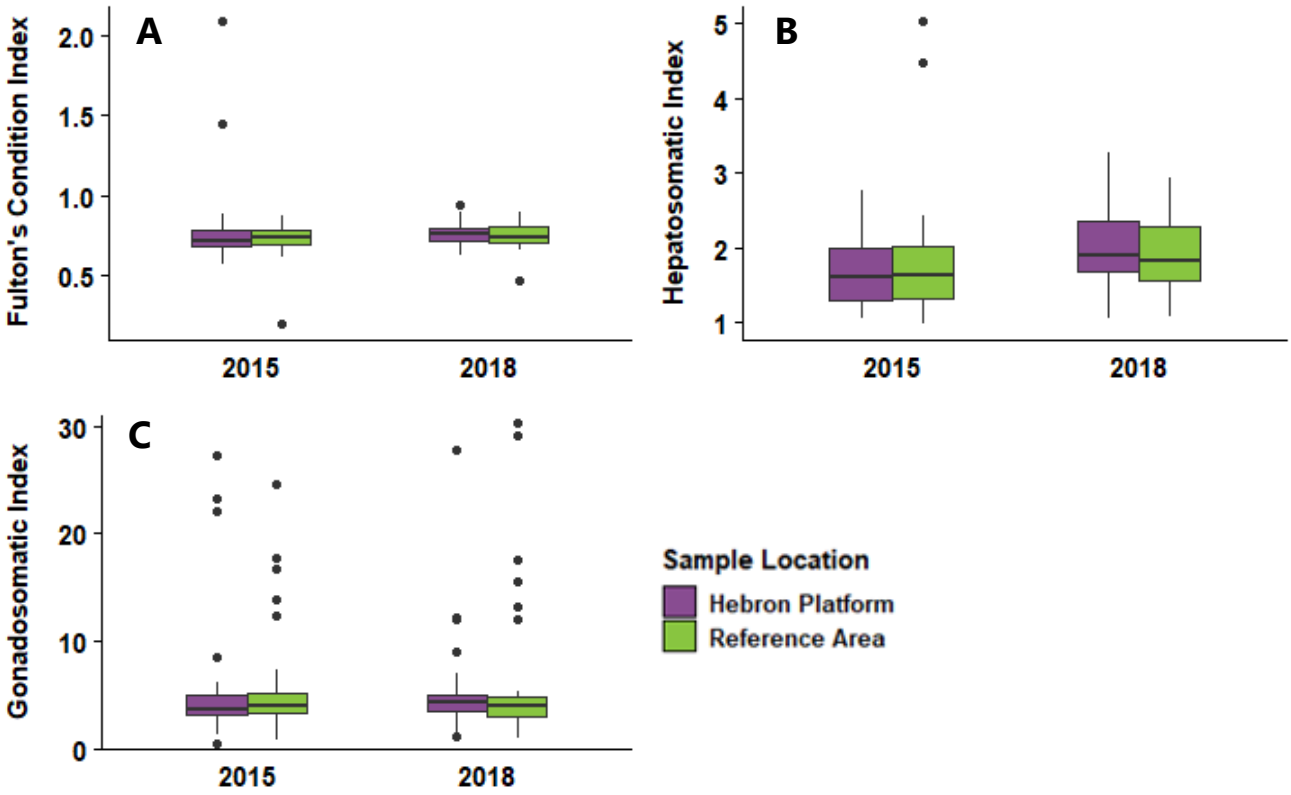

Figure 6-12 Boxplots of Fulton's condition index (A), hepatosomatic index (B), and gonadosomatic index (C) for female American plaice sampled from the Hebron Platform and Reference Area in 2015 and 2018.

6.2.3.3 Gross Pathology

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 6-13. Several minor conditions were noted including mild skin abrasion (likely associated with trawl collection; not shown), localized discolouration on the liver (such as bile accumulation in the anterior region of the liver; Figure 6-13A), thickening or scaring on gill filaments (not shown), and the presence of parasites in or on specimens (Figure 6-13A and B). These conditions and their prevalence at both sites are summarized in Table 6-21 for males and females. There were no significant differences among any of the other parameters examined individually for males or females (Table 6-21). The totals of fish health conditions were compiled and analyzed as the health assessment index (HAI; Table 6-21). There were no significant differences between locations for the HAI or any of its modifications for either male or female fish (Table 6-21).

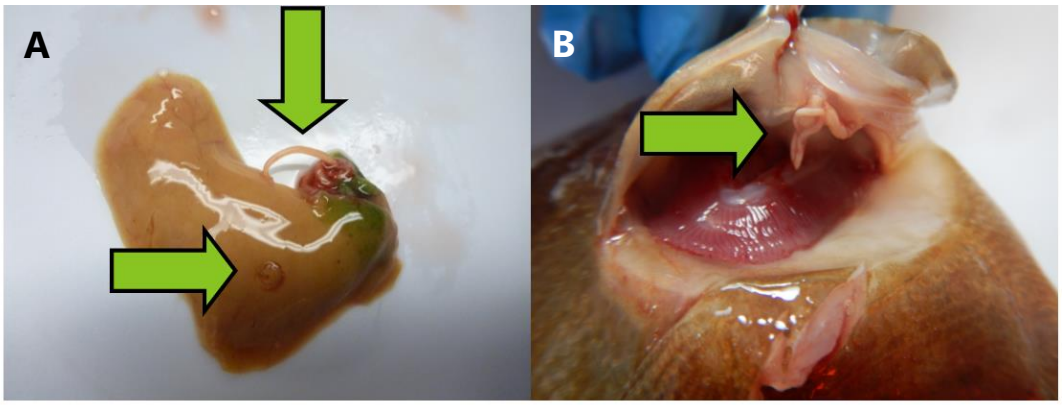

Figure 6-13 Examples of gross pathologies observed among American plaice from the 2018 Hebron Platform EEM biological survey. A) nematodes present on, and emerging from, viscera, and B) parasitic copepod (*Acanthochondria* spp.).

Table 6-21 Pathologies and health assessment index of male (top) and female (bottom) American plaice from the Hebron Platform and Reference Area in 2018.

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Male	**Hebron Platform (n=20)**		**Reference Area (n=16)**			
Fins	0	0	0	0	1.00	Fisher's
Spleen	0	0	0	0	1.00	Fisher's
Hindgut	0	0	0	0	1.00	Fisher's
Kidney	0	0	0	0	1.00	Fisher's
Skin	1	1.43	0	0	1.00	Fisher's
Liver	10	50	6	37.5	0.52	Fisher's
Eyes	0	0	0	0	1.00	Fisher's
Gills	3	15	1	6.25	0.61	Fisher's
Parasites	11	55	11	68.75	0.50	Fisher's
Male	**Hebron Platform (n=20)**		**Reference Area (n=16)**		**p-value**	**Test used**
HAI	28.00 ± 18.52		23.75 ± 15.86		0.47	ANOVA
Modified.HAI.1	27.50 ± 19.16		23.75 ± 15.86		0.53	ANOVA
Modified.HAI.2	19.50 ± 17.61		13.13 ± 15.37		0.26	ANOVA
Female	**Hebron Platform (n=50)**		**Reference Area (n=54)**		**p-value**	**Test used**
Fins	0	0	0	0	1.00	Fisher's
Spleen	0	0	0	0	1.00	Fisher's
Hindgut	2	4	0	0	0.23	Fisher's
Kidney	0	0	0	0	1.00	Fisher's
Skin	0	0	0	0	1.00	Fisher's
Liver [a]	26	52	25	46.30	0.84	Fisher's
Eyes	0	0	0	0	1.00	Fisher's
Gills	3	6	0	0	0.11	Fisher's

Parameter	Fish with Variable Condition	Prevalence (%)	Fish with Variable Condition	Prevalence (%)	p-value	Test used
Male	**Hebron Platform (n=20)**		**Reference Area (n=16)**			
Parasites	38	76	42	77.78	1.00	Fisher's
Female	**Hebron Platform (n=50)**		**Reference Area (n=54)**		**p-value**	**Test used**
HAI	30.60 ± 19.63		25.93 ± 18.68		0.22	ANOVA
Modified.HAI.1	30.60 ± 19.63		25.93 ± 18.68		0.22	ANOVA
Modified.HAI.2	18.20 ± 17.92		13.89 ± 15.10		0.19	ANOVA

Notes:
Bold p-value denotes significant result (α=0.05)
[a] Reference Area sample size for female livers is 51
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

6.2.3.4 Haematology

Blood smears were collected from 50 fish at both the Hebron Platform and Reference Area in 2018, and examples of each cell type can be found in Figure 6-14. These counts are used to prepare percentages of these cells in a minimum of 200 white blood cells.

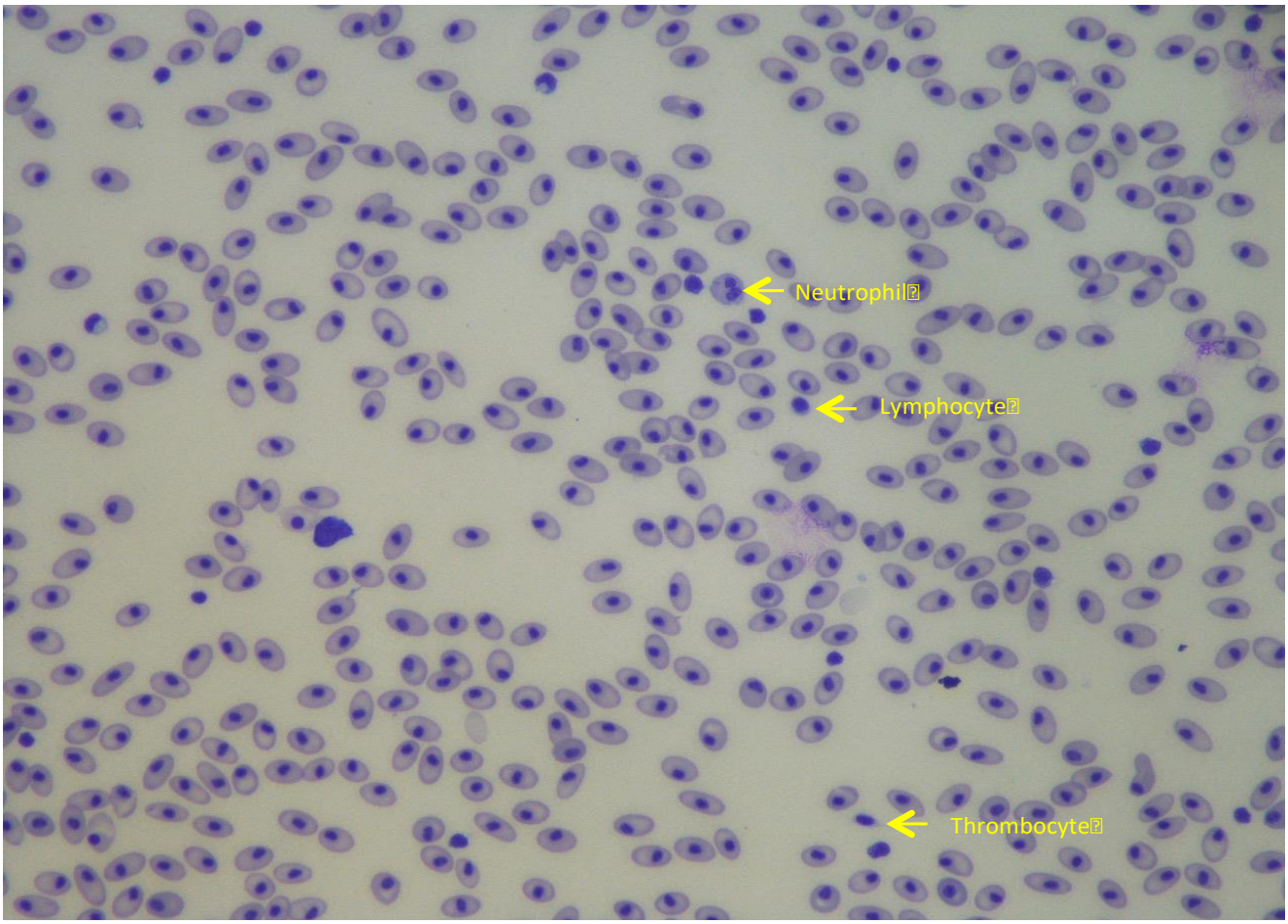

Figure 6-14 Example of cell types in blood smear from American plaice sampled during the 2018 Hebron EEM. Arrows indicate a neutrophil (top), lymphocyte (middle), and thrombocyte (bottom). Image provided by CDRF (MUN).

6.2.3.4.1 2018 Results

No significant differences were found between the Hebron Platform and Reference Area for any blood cell type (neutrophils, lymphocytes, and thrombocytes; Table 6-22), however, thrombocytes were near significance (p=0.06).

Table 6-22 Frequencies of blood cell types in American plaice from the 2018 Hebron biological survey.

Cell Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Lymphocytes (%)	0.93 ± 1.00	1.17 ± 1.01	0.12
Neutrophils (%)	95.05 ± 4.89	96.35 ± 3.35	0.23
Thrombocytes (%)	4.02 ± 4.92	2.48 ± 2.95	0.06
Notes: All data expressed as mean percentage ± standard deviation of each type of cell on at least 200 white blood cells counted per fish.			

6.2.3.4.2 Across-year Comparison

Haematology results taken at the Reference Area in 2015 were not suitable for analysis due to a technical challenge (EMCP 2016b), and so comparisons made here are by year (Hebron Platform only in 2015 compared to Hebron Platform/Reference Area combined in 2018) and by site (Hebron Platform 2015 and 2018 combined compared to Reference Area 2018) with no possible interaction term. Significant differences were found between sites for all three cell types (Table 6-23), 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). Additionally, 2015 had a significantly higher percentage of thrombocytes compared to 2018.

Table 6-23 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 in 2015 and 2018. No data exists for the Reference Area in 2015, and so no interaction term is present.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Neutrophils (%)					
Site	1	32.344	32.344	34.7967	**<0.001**
Year	1	1.462	1.462	1.5725	0.212
Residuals	146	135.71	0.930		
Lymphocytes (%)					
Site	1	1514.45	1514.45	96.4534	**<0.001**
Year	1	42.35	42.35	2.6972	0.103
Residuals	146	2292.39	15.70		
Thrombocytes (%)					
Site	1	1104.09	1104.09	78.5514	**<0.001**
Year	1	59.55	59.55	4.2366	**0.041**
Residuals	146	2052.13	14.06		

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

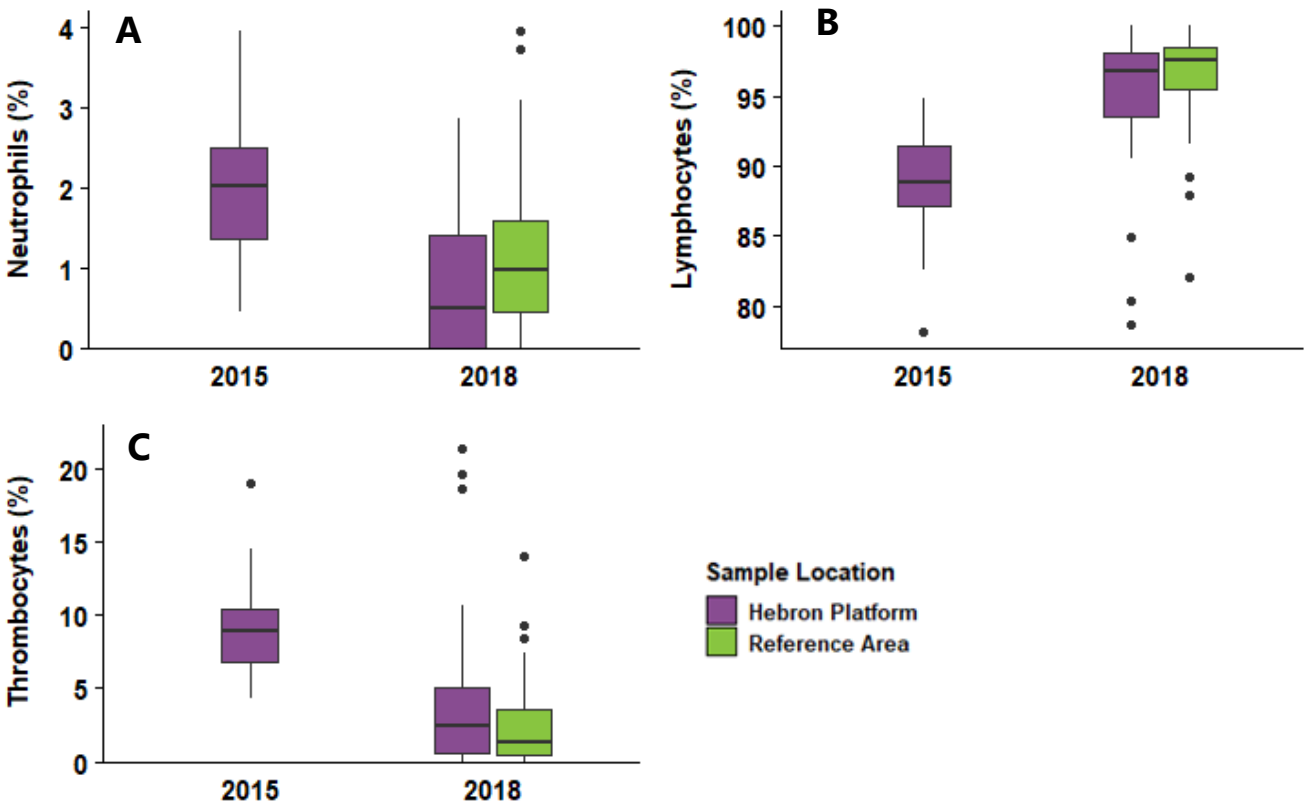

Figure 6-15 Boxplots of the percentage of neutrophils (A), lymphocytes (B), and thrombocytes (C) from blood smears of American Plaice taken from the Hebron Platform and Reference Area in 2015 and 2018. No data exists for the Reference Area in 2015.

6.2.3.5 Mixed Function Oxygenase Activity

6.2.3.5.1 2018 Results

A significant difference was found between male American plaice collected from the Hebron Platform and the Reference Area (p=0.03; Table 6-24). No difference was found for female fish between sites (Table 6-24).

Table 6-24 Mixed function oxygenase activity (pmol resorufin / mg protein / min) from male (top) and female (bottom) American plaice sampled from the Hebron Platform and Reference Area in 2018.

Mixed Function Oxygenase (pmol resorufin / mg protein / min)			
Male	**Hebron Platform (n=15)**	**Reference Area (n=14)**	**p-value**
MFO (EROD)	21.56 ± 15.85	10.75 ± 6.75	**0.03**
Female	**Hebron Platform (n=35)**	**Reference Area (n=36)**	**p-value**
MFO (EROD)	6.62 ± 3.80	6.11 ± 3.51	0.55

Notes:
All data expressed as mean percentage ± standard deviation
Bolded p-value denotes significant result (α=0.05)

6.2.3.5.2 Cross-year Comparison

Two-way ANOVAs were used to compared MFO activity across both sites (Hebron Platform and Reference Area) and years (2015 and 2018) for male and female American plaice. Both analyses had significant results in their interaction terms and between years (Table 6-25). Figure 6-16 shows the cause of the significant interactions, with the Reference Area results higher in 2015 and the Hebron Platform results higher in 2018 for both male and female fish. Results from the reference site in 2015 are extremely varied for both sexes, likely contributing to the majority of the difference observed here.

Table 6-25 Two-way ANOVA of mixed function oxygenase activity (pmol resorufin / mg protein / min) collected from American plaice at the Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Male					
Site	1	612.8	612.8	3.8256	0.054
Year	1	2048.5	2048.5	12.7885	**0.001**
Site*Year	1	5007.9	5007.9	31.2642	**<0.001**
Residuals	76	12173.7	160.2		
Female					
Site	1	12.8	12.78	0.3167	0.5747
Year	1	299.7	299.70	7.4276	**0.007**
Site*Year	1	603.6	603.65	14.9604	**<0.001**
Residuals	115	4640.2	40.35		

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

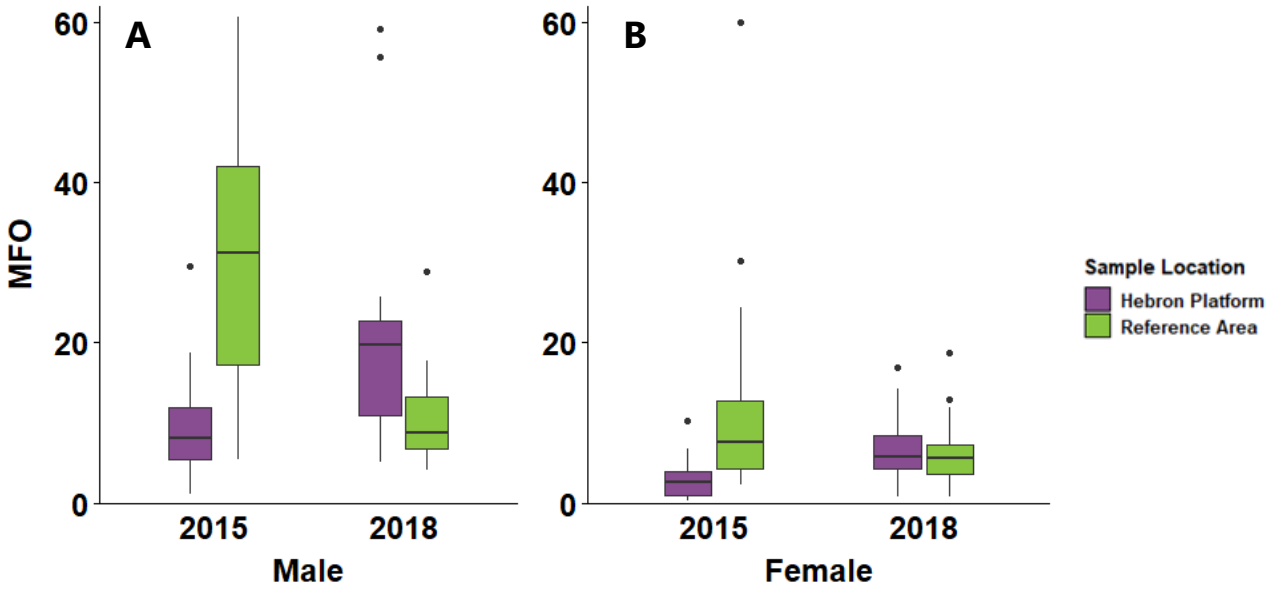

Figure 6-16 Boxplot of mixed function oxygenase (MFO) activity (pmol resorufin / mg protein / min) collected from male (A) and female (B) American plaice at the Hebron Platform and Reference Area in 2015 and 2018.

6.2.3.6 Histopathology

The histological parameters examined for American plaice tissue samples collected for the 2018 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 is shown in Figure 6-17, and examples of gill pathologies in Figure 6-18.

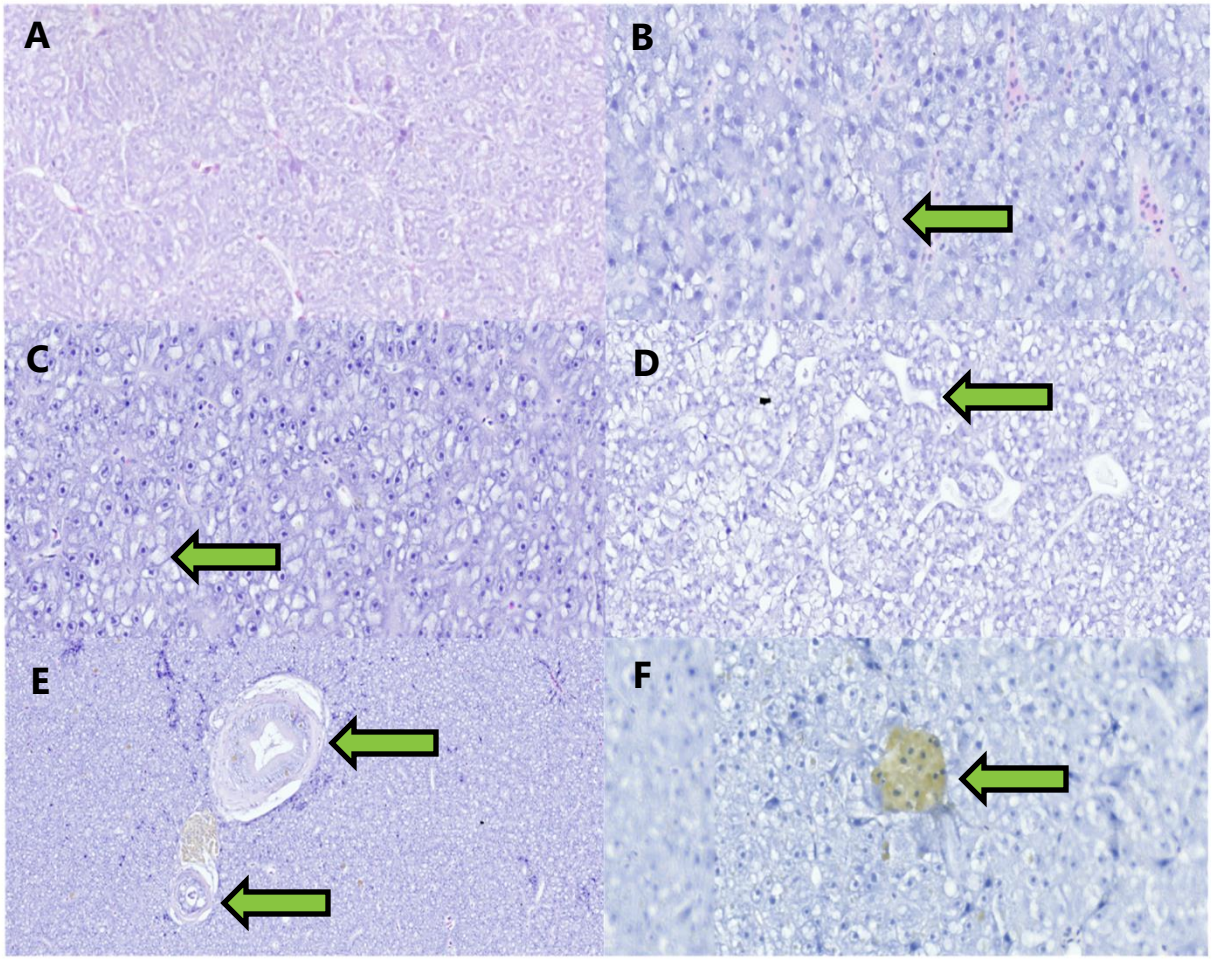

Figure 6-17 Examples of liver pathologies: A) normal liver tissue, B) small hepatocellular vacuoles, C) medium hepatocellular vacuoles, D) large hepatocellular vacuoles, E) bile duct hyperplasia, and F) macrophage aggregate. Photo's provided by the CDRF (MUN).

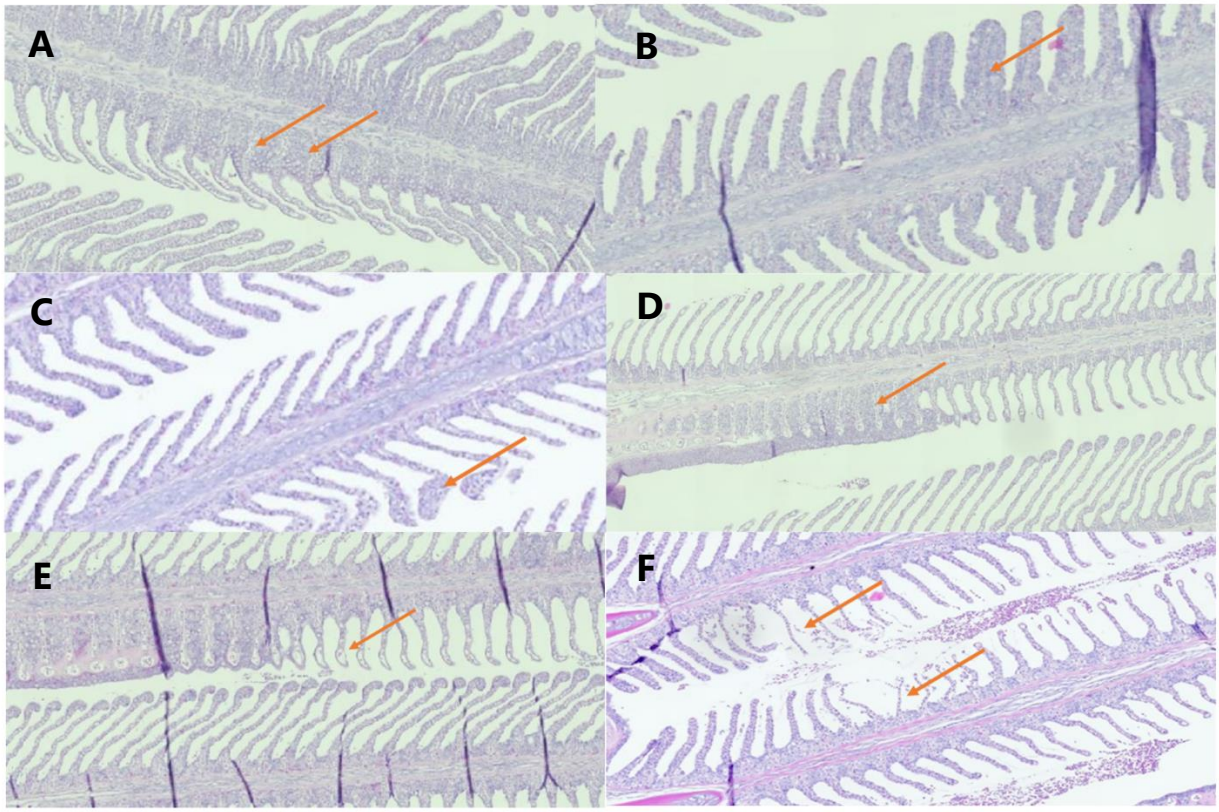

Figure 6-18 Examples of gill pathologies: A) basal hyperplasia, B) distal hyperplasia, C) tip hyperplasia, D) fusion, E) epithelial lifting, and F) thin filaments. Images provided by the CDRF (MUN).

6.2.3.6.1 2018 Results

Several hepatic lesions were observed in American plaice in 2018, including bile duct hyperplasia (Figure 6-17), hepatocellular carcinoma (not shown), macrophage aggregates (Figure 6-17), and hepatocellular vacuoles (Figure 6-17, Table 6-26). Only one lesion type (large hepatocellular vacuoles) was found to significantly differ between the Hebron Platform and the Reference Area ($p=0.005$; Table 6-26), with the Reference Area having a higher occurrence.

Table 6-26 Number and frequency of American plaice with hepatic lesions from the Hebron Platform and Reference Area in 2018.

Lesions	Hebron Platform (n=50)		Reference Area (n=50)		p-value
	Fish Affected	Prevalence (%)	Fish Affected	Prevalence (%)	
Normal	7	14	5	10	0.76
Nonspecific necrosis	0	0	0	0	1.00
Bile duct hyperplasia	15	30	10	20	0.36
Nuclear pleomorphism	0	0	0	0	1.00
Megalocytic hepatosis	0	0	0	0	1.00
Eosinophilic foci	0	0	0	0	1.00
Basophilic foci	0	0	0	0	1.00
Clear cell foci	0	0	0	0	1.00
Hepatocellular carcinoma	20	40	12	24	0.13
Benign tumours	0	0	0	0	1.00
Cholangioma	0	0	0	0	1.00
Cholangiofibrosis	0	0	0	0	1.00
Increase in mitotic activity	0	0	0	0	1.00
Macrophage aggregates[a]	9	18	6	12	0.58
Macrophage aggregates[b]	2	4	0	0	0.49
Hydropic vacuolation	0	0	0	0	1.00
Hepatocellular vacuoles S	7	14	3	6	0.32
Hepatocellular vacuoles M	15	30	11	22	0.49
Hepatocellular vacuoles L	16	32	31	62	**0.005**
Hepatocellular vacuoles A	36	72	43	86	0.14

Notes:
S – small, M – medium, L – large, A – all (small, medium, and large combined)
[a] Defined as scores less than 3 on a 0-7 relative scale
[b] Defined as scores more than 3 on a 0-7 relative scale
Prevalence is the percentage of fish affected
Bolded p-values denotes significant result (α=0.05)

Gills abnormalities were also observed in fish from both areas, with no significant difference between the Hebron Platform and the Reference Area (Table 6-27). Distal hyperplasia was found to be barely above significance (p=0.054) between sites, with a higher occurrence at the Hebron Platform (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 2018.

Lesion Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Percentage of Secondary Lamellae Affected by Lesions			
Normal	93.15 ± 6.10	94.79 ± 4.50	0.13
Tip Hyperplasia [a]	0.51 ± 0.85	0.80 ± 1.00	0.12
Basal Hyperplasia [b]	1.79 ± 2.10	1.12 ± 1.67	0.08
Distal Hyperplasia [c]	1.17 ± 2.52	0.43 ± 0.82	0.05
Fusion	3.16 ± 3.85	2.66 ± 3.62	0.51
Telangiectasia	0.06 ± 0.26	0.00 ± 0.00	0.09
Thin Lamellae	0.13 ± 0.63	0.05 ± 0.25	0.09
Epithelial Lifting	0.03 ± 0.11	0.14 ± 0.53	0.37
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.18 ± 0.48	0.08 ± 0.34	0.14

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

6.2.3.6.2 Across-year Comparison

A multivariate analysis of variance (MANOVA) was performed using the factors listed in Table 6-26 that were detected in fish (i.e., excluding those with 0 fish affected). This left eight factors: bile duct hyperplasia, hepatocellular carcinoma, macrophage aggregates (0-3), macrophage aggregates (4-7), hepatocellular vacuoles (small), hepatocellular vacuoles (medium), hepatocellular vacuole (large), and hepatocellular vacuoles (all). Table 6-28 (top) presents the results of the MANOVA, with significant differences between years (p=<0.001) and the interaction term (p=<0.001). Two-way ANOVAs were then run on each individual factor to determine which are contributing to the significance in the MANOVA. Table 6-28 (bottom) shows the individual ANOVAs, with five factors having significant results: hepatocellular carcinomas (year significant, p=0.002), macrophage aggregates (0-3) (interaction significant, p=0.027), small hepatocellular vacuoles (interaction significant, p=0.018), large hepatocellular vacuoles (both year and interaction significant, p=0.043 and <0.001, respectively), and all hepatocellular vacuoles (both year and interaction significant, p=0.029 and 0.010, respectively).

Figure 6-19 shows each of the five factors with significant results found in Table 6-28. For hepatocellular carcinoma, 2018 had significantly higher prevalence rates compared to 2015. Macrophage aggregates and small hepatocellular vacuoles had only significant interactions terms, with higher prevalence at the reference site in 2015 and higher prevalence at the Hebron Platform in 2018. For large hepatocellular vacuoles and overall, higher prevalence was observed at the Hebron Platform in 2015 and at the Reference Area in 2018. In addition, 2018 had a higher prevalence for both factors compared to 2015.

Table 6-28 MANOVA (eight factor) and individual two-way ANOVAs of each factor of detected liver histopathologies from American plaice collected at the Hebron Platform and Reference Area in 2015 and 2018.

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
MANOVA (8 factors)					
Site	1	8	0.0326	0.7920	0.610
Year	1	8	0.1609	4.5063	**<0.001**
Site*Year	1	8	0.1526	4.2307	**<0.001**
Residuals	195				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Bile duct hyperplasia					
Site	1	0.194	0.194	0.7484	0.388
Year	1	0.341	0.341	1.3181	0.252
Site*Year	1	0.092	0.092	0.3561	0.551
Residuals	195	50.508	0.259		
Hepatocellular carcinoma					
Site	1	0.340	0.340	2.012	0.158
Year	1	1.678	1.678	9.916	**0.002**
Site*Year	1	0.352	0.352	2.078	0.151
Residuals	195	32.997	0.169		
Macrophage aggregates (0-3)					
Site	1	0.076	0.076	0.726	0.395
Year	1	0.187	0.187	1.795	0.182
Site*Year	1	0.516	0.516	4.949	**0.027**
Residuals	195	20.327	0.104		
Macrophage aggregates (4-7)					
Site	1	0.020	0.020	2.06	0.152
Year	1	0.021	0.021	2.08	0.150
Site*Year	1	0.021	0.021	2.11	0.148
Residuals	195	1.918	0.010		
Hepatocellular vacuoles (small)					
Site	1	0.018	0.018	0.203	0.653
Year	1	0.000	0.000	0.001	0.983
Site*Year	1	0.512	0.512	5.716	**0.018**
Residuals	195	17.460	0.090		
Hepatocellular vacuoles (medium)					
Site	1	0.025	0.025	0.139	0.710
Year	1	0.090	0.090	0.502	0.480
Site*Year	1	0.091	0.091	0.507	0.477
Residuals	195	35.160	0.180		
Hepatocellular vacuoles (large)					

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Site	1	0.010	0.010	0.046	0.831
Year	1	0.904	0.904	4.155	**0.043**
Site*Year	1	4.680	4.680	21.508	**<0.001**
Residuals	195	42.436	0.218		
Hepatocellular vacuoles (all)					
Site	1	0.015	0.015	0.076	0.783
Year	1	0.947	0.947	4.865	**0.029**
Site*Year	1	1.319	1.319	6.778	**0.010**
Residuals	195	37.960	0.195		
Notes: Bolded p-value denotes a significant result (α=0.05)					

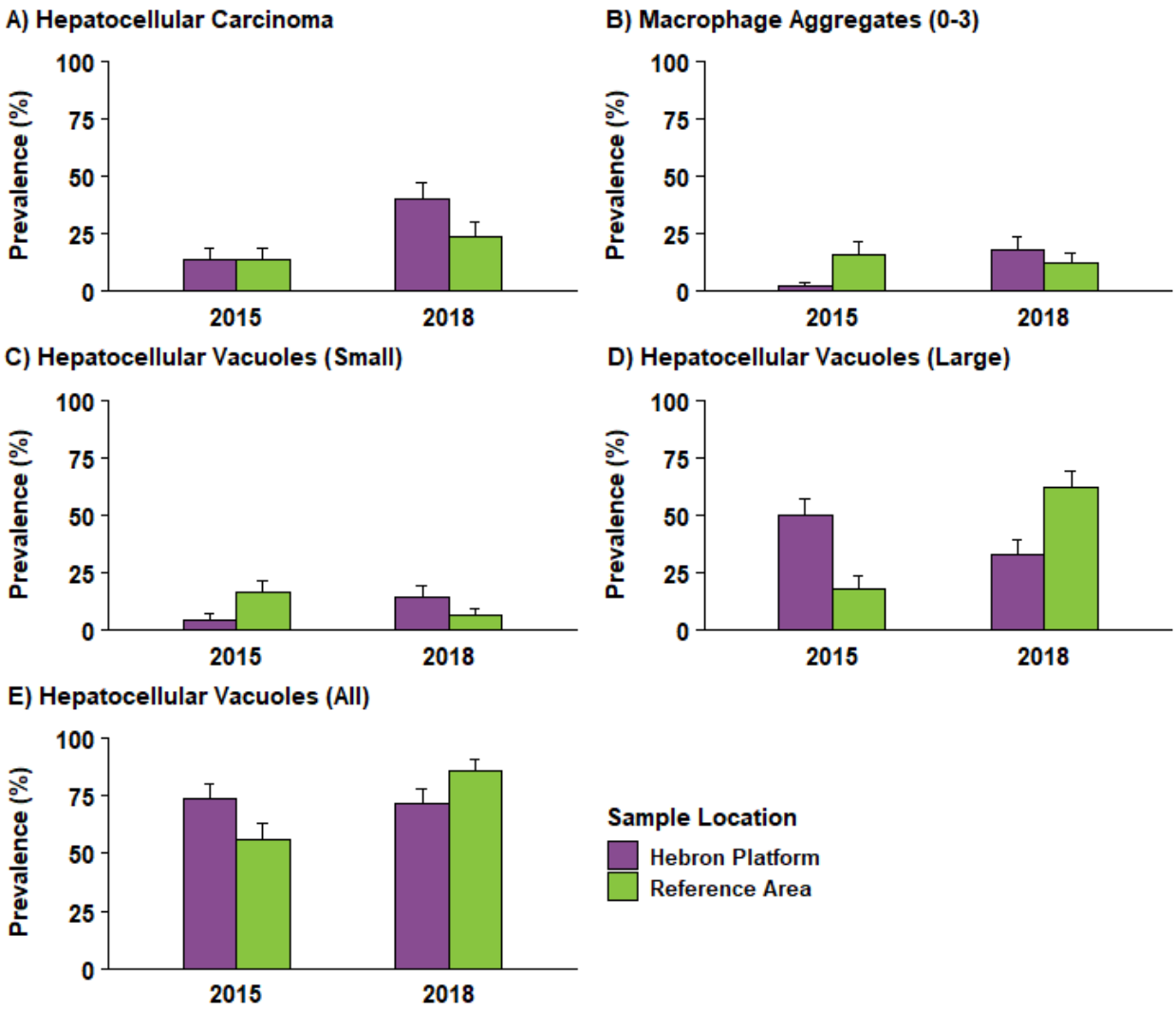

Figure 6-19 Bar graphs of the prevalence (%) of hepatocellular carcinoma (A), macrophage aggregates (0-3) (B), small hepatocellular vacuoles (C), large hepatocellular vacuoles (D), and all hepatocellular vacuoles (small, medium, and large) (E) from livers of American Plaice taken from the Hebron Platform and Reference Area in 2015 and 2018. Bars indicate standard error.

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. This left seven factors: hyperplasia (tip, basal, and distal), fusion, telangiectasia, thin lamellae, and epithelial lifting. Table 6-29 (top) shows the results of the MANOVA, with significant differences between sites (p=0.018), years (p=<0.001) and the interaction term (p=0.004). Two-way ANOVAs were then run on each individual factor to determine which are driving the significance in the MANOVA. Table 6-29 (bottom) shows the individual ANOVAs, with six factors having significant results: hyperplasia tip (year and interaction significant, p=<0.001 and 0.005, respectively), basal (site and year significant, p=0.020 and <0.001, respectively), and distal (site and year significant, p=0.047 and 0.014, respectively), fusion (year significant, p=<0.001), telangiectasia (site significant, p=0.011), and thin lamellae (interaction significant, p=0.007).

Figure 6-20 shows each of the six factors with significant results found in Table 6-29. For tip hyperplasia, 2018 had a higher prevalence overall, with the Hebron Platform having higher prevalence in 2015 and the Reference Area higher in 2018. For both basal and distal hyperplasia, 2018 had high prevalence compared to 2015 and the Hebron Platform was higher than the reference site. Fusion had a higher prevalence in 2018 compared to 2015. Telangiectasia was higher at the Hebron Platform compared to the Reference Area. Thin lamellae had no affected fish at the Hebron Platform in 2015 or the Reference Area in 2018, leading to a significant interaction term.

Table 6-29 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 in 2015 and 2018.

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
MANOVA (8 factors)					
Site	1	7	0.085	2.502	**0.018**
Year	1	7	0.241	8.507	**<0.001**
Site*Year	1	7	0.104	3.118	**0.004**
Residuals	194				
Factor	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**F Value**	**p value**
INDIVIDUAL FACTOR ANOVAS					
Hyperplasia (tip)					
Site	1	0.002	0.002	0.003	0.955
Year	1	8.487	8.487	17.047	**<0.001**
Site*Year	1	4.013	4.013	8.061	**0.005**
Residuals	194	96.581	0.498		
Hyperplasia (basal)					
Site	1	12.60	12.603	5.504	**0.020**
Year	1	46.36	46.356	20.243	**<0.001**
Site*Year	1	1.62	1.615	0.705	0.402
Residuals	194	444.25	2.290		
Hyperplasia (distal)					
Site	1	8.14	8.137	4.010	**0.047**
Year	1	12.40	12.400	6.111	**0.014**
Site*Year	1	5.66	5.661	2.790	0.096
Residuals	194	393.65	2.029		
Fusion					
Site	1	0.54	0.542	0.066	0.798
Year	1	199.54	199.536	24.195	**<0.001**
Site*Year	1	8.45	8.445	1.024	0.313
Residuals	194	1599.92	8.247		
Telangiectasia					
Site	1	0.410	0.410	6.665	**0.011**
Year	1	0.056	0.056	0.912	0.341
Site*Year	1	0.042	0.042	0.677	0.412
Residuals	194	11.934	0.062		

Factor	Degrees of Freedom	Number of Degrees	Pillai's Trace	Approximate F Value	p value
Thin lamellae					
Site	1	0.034	0.034	0.638	0.425
Year	1	0.038	0.038	0.716	0.398
Site*Year	1	0.396	0.396	7.432	**0.007**
Residuals	194	10.349	0.053		
Epithelial lifting					
Site	1	0.003	0.003	0.009	0.925
Year	1	0.077	0.077	0.209	0.648
Site*Year	1	0.301	0.301	0.814	0.368
Residuals	194	71.826	0.370		

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

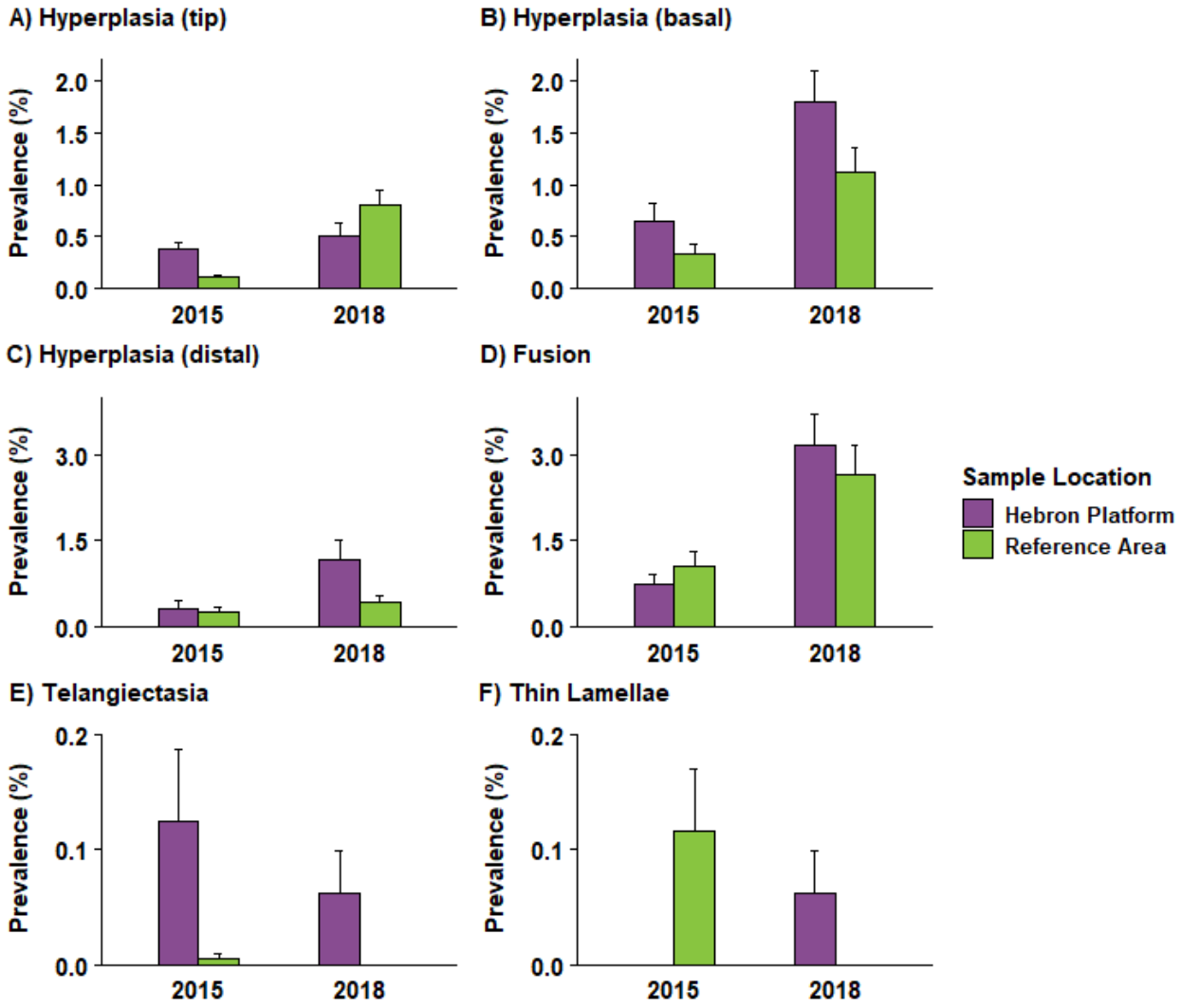

Figure 6-20 Bar graphs of the prevalence (%) of hyperplasia - tip (A), basal (B), and distal (C), fusion (D), telangiectasia (E), and thin lamellae (F) from livers of American Plaice taken from the Hebron Platform and Reference Area in 2015 and 2018. Bars are standard error.

6.3 Summary of Results

6.3.1 Summary of Chemical Profiles of American Plaice

Composite American plaice tissue sampled at the Hebron Platform and Reference Area in 2018 consistently showed the presence of arsenic, mercury, and zinc. Aside from lower zinc values in 2018, these results are consistent with the results from 2015. For liver composites, eight metals have been consistently detected in both 2015 and 2018, with three other metals occasionally above their RDLs. Metal concentrations were either similar across years or lower in 2018, with the exception of manganese which was higher in 2018. Hydrocarbons in the lower fuel range (>C_{10}-C_{16}) were not detected, while those in the upper fuel range (>C_{16}-C_{21}) were significantly higher in 2018, and those in the lube range (>C_{21}-C_{32}) were significantly lower in 2018. Acenaphthylene and fluorene levels were above their respective RDLs in 2018 but were not in the previous monitoring year.

6.3.2 Summary of Fish Health Program

Overall, several statistically significant differences in fish health indices were detected among American plaice surveyed in 2018 (Table 6-30). No significant results were detected for gross pathology.

For maturity stages of female plaice, the Hebron Platform and Reference Area significantly differed in 2018 for the second of three maturing codes (Mat B-P, code 530) stage ($p = <0.01$). For biological characteristics, even with ANCOVA removing variance from covariate factors, male fish significantly differed for total body weight ($p=0.04$) and female fish differed in fish length ($p = <0.01$), total weight ($p = <0.01$), and age ($p=0.01$) between sites. Cross-year comparisons between 2015 and 2018 for three indices (Fulton's condition index (FCI), hepatosomatic index (HSI), and gonadosomatic index (GSI)) had significant results for male FCI (higher in 2018 than 2015; $p=0.046$), and male HSI higher at the Hebron Platform compared to the Reference Area ($p=0.005$). Female HSI was higher in 2018 compared to 2015 ($p=0.043$).

For haematology, no differences were detected in the 2018 EEM program. However, cross-year comparisons had significant results between sites for neutrophils, leucocytes, and thrombocytes ($p = <0.001$ for all three), and between years for thrombocytes ($p=0.041$). However, there were no results for 2015 at the Reference Area making comparison sample sizes uneven.

For MFO, male fish significantly differed between the Hebron Platform and Reference Area in 2018 ($p=0.03$). Cross year comparisons had significant results across years and significant interaction terms for both male and female fish ($p = <0.01$ for both sexes).

For liver histopathology, the Hebron Platform and Reference Area significantly differed for large hepatocellular vacuoles in 2018 ($p=0.005$). A MANOVA with eight liver histology factors showed significant differences between years and in the interaction term ($p = <0.001$ for both). Significant differences between years existed for hepatocellular carcinoma (higher in 2018, $p=0.002$), large hepatocellular vacuoles (higher in 2018, $p=0.043$), and all hepatocellular vacuoles combined (higher in 2018, $p=0.029$).

For gill histopathology, no significant differences were found in 2018. However, a MANOVA for seven gill histology factors detected significant results across sites ($p=0.018$) and years ($p=0.001$), with a significant interaction term ($p=0.004$). Significant differences between sites largely due to basal and distal hyperplasia (both at Hebron Platform, $p=0.020$ and 0.047, respectively), and telangiectasia (higher at Hebron Platform, $p=0.011$). Significant differences between years was driven by tip, distal, and basal hyperplasia (all higher in 2018, $p = <0.001$, <0.001, and 0.014, respectively), and fusion (higher in 2018, $p = <0.001$). Significant interactions were observed in liver tissue for macrophage aggregates (0-3), and small, large, and all hepatocellular vacuoles ($p=0.027$, 0.018, <0.001, and 0.010, respectively). Significant interactions in gill tissue were observed for tip hyperplasia and thin lamellae ($p=0.005$ and 0.007, respectively).

Table 6-30 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
Maturity Stages	-	Yes	Yes
Fish length	Yes	No	Yes
Fish weight	No	No	Yes
Liver weight (post-ANCOVA)	-	Yes	No
Age	-	No	Yes
Hepatosomatic Index	No	Yes	No
Mixed-function oxidase	Yes	Yes	Yes
Liver Histopathology	Yes	Yes	Yes
Gill Histopathology	Yes	Yes	No

Notes:
[a] See Appendix A comparing Hebron Platform 2015 results with EEM Reference Area
- Indicates a lack of results for comparisons (too few male fish or no comparison made)
Fish characterization compared the Hebron Platform with a suggested reference area, and the Addendum uses the current EEM Reference Area (results taken from 2015 Hibernia Southern Extension EEM program)

7 DISCUSSION AND INTERPRETATION

The Hebron Program is committed to conducting an EEM program to detect changes in the surrounding environment that may be attributed to the Project (EMCP 2017). The Hebron EEM program consists of assessments on the chemistry and toxicity of sediment quality, and the health, size and body burden chemistry of fish (as per Table 7-1). Hebron also includes a water sampling component to assess the chemistry of water quality (though in 2018 produced water was not continuous, and so the water quality component was not implemented).

Table 7-1 Hebron Platform EEM program sediment and biological sampling program component parameters and analysis

Program Component	Parameters	Analysis
Sediment quality	Chemistry	Particle size, organic and inorganic carbon, barium, metals, hydrocarbons, ammonia/sulphide/redox potential and sulphur
	Toxicity	Petrotox, Amphipod survival, and benthic community
Water quality (no sampling in 2018)	Chemistry	Metals, hydrocarbons, nutrients
	CTD	Oxygen temperature, salinity and pH profiles
Commercial fish (American plaice)	Tissue chemical profiles	Body burden (metals, hydrocarbons, PAHs)
	Sensory evaluation	Taint / taste testing
	Health indicators	Haematology, histopathology, mixed function oxygenase
	Morphometrics and life history characteristics	Size, weight, sexual maturity

7.1 Sediment Component

7.1.1 Physical and Chemical Characteristics

Analysis of physical and chemical analytes showed some differences between 2018 and 2014 samples. Clay increased to the south, southwest, and northwest at distances up to 4,000 m from the platform and at distances >6,000 m towards the northeast. These results are within the predicted cutting deposition models (EMCP 2017). Drill cutting deposition models predicted the highest cutting thickness increases (1 to 10 mm) to occur within 1 to 3 km from the platform (EMCP 2017). There was a notable increase of percent silt at Site 8-250. All other sediment fractions (sand, and gravel) changed little between sampling years across all distances.

Barium increased between years at sites in the Near-field (<1,000 m from the platform). Lead concentrations increased at Site 8-250 between sample years. Hydrocarbon >C_{10}-C_{21} and C_{21}-C_{32} concentrations were similar between 2014 and 2018, with the exception of the Near-field sites 8-250 and 4-250. There was no difference in concentration between years for iron or manganese.

Site 8-250 reported higher levels of several analytes including clay, silt, lead, barium, and >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons, and others. This is likely a project-related effect as this site is located near cutting disposal and water discharges chute of the platform (EMCP 2017). These results, however, agree with the CSR that predicted effects < 2,000 m from the platform due to cuttings disposal and produced water (though no produced water was released in 2018). The results reported at this site were isolated with adjacent sites reporting either no change or relatively smaller increases in analyte levels.

7.1.2 Toxicity

All samples from stations at distances greater than 500 m passed Petrotox (threshold is <150 mg/kg >C_{10}-C_{21}) testing and were screened out of further toxicity testing. Mandatory toxicity testing was conducted on samples collected within 500 m of the platform (four stations). Amphipod survival in 2018 sediment samples was greater than 98 percent in all four sampling stations and results indicate the sediment is non-toxic. This is consistent with results from the 2014 samples (EMCP 2016a).

7.1.3 Benthic Community Structure

Total abundance (n) and number of taxa (S) decreased between years within the study area (2014: n=19,465, S=182 and 2018: n=9,745, S=162). While abundance and taxa decreased, the overall trends in community structure between sites were consistent between sampling years. In both sampling years, sites far (>3,000 m) from the platform (Far-field distance bins) reported higher abundances, more taxa, and a higher diversity of taxa than sites near the platform. Sites in Near-field distance bins (<1,000 m) had some of the lowest reported number of taxa and abundances in both sampling years.

The taxa assemblages also changed between years. At Near-field stations in 2014, a total of 10 taxa accounted for 38 percent of assemblage variations. The various polychaete groups with the greatest assemblage variation contributed between 7.1 and 2.5 percent in 2014. In 2018, four taxa accounted for 43 percent of the assemblage variation.

Taxa such as oligochaetes (Clitellata) and polychaetes (Capitellidae and Spionidae) are indicators for polluted or highly organic areas (Behling 2013, Pocklington and Wells 1992; Diaz-Castaeda and Reish 2009) when found in high numbers. Oligochaetes were present at sites in the Near-field (12.3 percent) in 2014 and their contribution to total site abundance decreased in 2018 to 9.75 percent (Clitellata). Clitellata were also present in Mid-field and Far-field distance bins (8.3 and 8.6 percent) in 2018. Three polychaete families (Syllidae, Paraonidae, Spionidae) contributed between 7.0 and 5.5 percent in 2018. The opportunistic early colonizers, Capitellidae, were present in low abundance at Near-field and Mid-field distance bins in 2014 (n=6) and 2018 (n=3), and Far-field sites 2014 (n=141) and 2018 (n=61). Spionidae were present at all distances in both sampling years (2014: n=2,678, 2018: n=880). The most abundant species of Spionidae found in both sampling years was the *Prionospio steenstrupi*. All other sample sites had low (<20) or zero Spionidae abundance. This pattern was similarly observed in 2014, with Far-field sites in the northeast cluster reporting more Spionidae than Near-field and Mid-field sites. While, the Spionidae family was observed in high numbers (at stations farthest from the platform), there is no evidence that this is at the exclusion of other species and may not indicate a project-related effect.

Comparisons between faunal and environmental data through multivariate analysis, has found that assemblage structure is attributed to influences from percent total organic carbon, sand, gravel, and redox potential. Sites at Far-field distances in the NE part of the sampling area had a higher percent gravel than other sites which provides different habitat availability than the Near-field or Mid-field sites. Percent gravel was also a main contributor in explaining model variance in 2014. Sediment fraction analysis found no change in gravel composition at these sites between years. Project effects between sampling years have been subtle or absent. Differences in community assemblage structure will continue to be monitored.

7.2 Commercial Fish Program

7.2.1 Chemical Profiles of American Plaice

American plaice is a species of commercial importance in the Newfoundland offshore region that are monitored in all EEM programs in the Newfoundland Offshore. This section seeks to describe project effects on body burden of metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAH), and perceptible tainting of fillets,

as well as reporting catch numbers and species for trawls. Several statistically significant differences were determined within 2018 data, and in comparisons to 2015 data. However, this report details results from the first year of monitoring and so the overall assessment of the effects of the project on the environment should be based on multi-year trends. As the current reference area was not sampled as part of the 2015 fish characterization report, data from the 2015 HSE EEM report is used as both programs share a Reference Area and have similar sampling methodologies.

Fourteen different species were caught as part of the 2018 Hebron EEM program (Table 6-4). No difference was observed for catch per unit effort (CPUE) for all species across either year or between the Hebron Platform and Reference Area (Table 6-7). The most commonly caught species was sand lance, followed by American plaice and yellowtail flounder (Figure 6-3). Similar catch results were observed in the 2015 fish characterization report, with sand lance having the highest abundance, followed by northern shrimp and American plaice (EMCP 2016b). CPUE for American plaice was consistent for both sites in 2015 and the Reference Area in 2018, but significantly higher at the Hebron Platform in 2018 (Table 6-7). Nogueira et al. (2016) surveyed American plaice biomass from 2002 to 2014 on the Grand Banks and reported high fluctuations between years. A longer time series of CPUE at these sites may yield better insights.

For American plaice fillets, three metals were detected above their RDLs in the 2018 EEM program: arsenic, mercury, and zinc (Table 6-8). No significant difference was detected in these metals between the Hebron Platform and Reference Area (Table 6-8). No hydrocarbons or PAHs were above their RDLs in 2018. This is consistent with 2015 results, as the same three metals were detected. Cross-year comparison showed no significant difference between the two sites or years for arsenic or mercury, but zinc had a significant difference between 2015 and 2018 (Table 6-10, Figure 6-7). Zinc in fillets decreased in 2018 with no significant interaction term and so overall, no project related effects are apparent in American plaice fillet tissues. These analytes are also consistent with other platforms, including Terra Nova (DeBlois et al. 2014c) and Hibernia (HMDC 2017, 2019). These values appear steady across years and sites and are likely natural levels of these metals.

In American plaice liver composites, eight metals, two hydrocarbon groups, and two PAHs were detected above their RDLs in the 2018 program (Table 6-9). No significant difference was detected between sites for arsenic, iron, manganese, mercury, selenium, and zinc. Cadmium was significantly higher at the Reference Area in 2018, and copper was nearly significant with the Reference Area as well (Table 6-9, Figure 6-8). Hydrocarbons in the upper fuel ($>C_{16}$-C_{21}) and lube ($>C_{21}$-C_{32}) ranges were above their RDLs, but no difference was detected between sites in 2018 (Table 6-9). The PAHs acenaphthylene and fluorene were detected but no difference was detected between sites (Table 6-9). Fluorene was nearly significant and higher at the Hebron Platform, but this is due to the highly elevated RDL for some samples due to co-matrix interference. Even though three out of five samples were below RDL at the platform, the half RDL was used in the analysis for these samples and the elevated RDLs raised the overall results. Therefore, chemical profiles for liver composites for the 2018 EEM were similar between the Hebron Platform and Reference Area.

Cross year comparisons of American plaice liver composites show several significant results. The same eight metals (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc) detected in 2018 were also detected in all liver composites from 2015. No significant difference was found between years, sites, or year by site interaction for copper, iron, mercury, or zinc (Table 6-10). Arsenic and selenium were significantly different between years (Table 6-10) and both saw a decrease in concentration from 2015 to 2018 (Figure 6-8). Cadmium was significantly different between sites (Table 6-10) and was higher at the Reference Area across years (Figure 6-8). Manganese had a significant interaction term, with both site and year significant as well (Table 6-10). Manganese levels are higher in 2018 than in 2015, and higher at the Hebron Platform compared to the Reference Area (Figure 6-8). Both upper fuel and lube range hydrocarbons were detected in 2015, and a significant difference was detected across years for both (Table 6-12). However, hydrocarbons in the fuel range increased in

2018 and those in the lube range decreased in 2018 (Figure 6-9). Acenaphthylene was not detected in 2015, and so was significantly higher (Table 6-13, Figure 6-10). Fluorene was not above its RDL in 2015, however a significant difference was found between sites and not year (Table 6-13). Figure 6-10 shows that the RDL for the Hebron Platform in 2015 was elevated due to co-matrix interference and is likely driving the significant result across sites. No significant interaction terms were detected for hydrocarbons or PAHs. Overall, three points to consider for future monitoring studies were detected in American plaice liver composites: an increase in manganese levels at the Hebron Platform area and across years, an increase in fuel range hydrocarbons in 2018, and detections of two PAHs above their RDLs in 2018.

Sediment data collected in 2018 does not show any significant increase in manganese levels in any of the near-field stations around the Hebron Platform (Figure 4-22, Figure 4-23). Manganese has been consistently detected at other platforms including Hibernia but varies significantly between years with no particular trend (HMDC 2017). Data from 2018 is also comprised of five composite samples as compared to ten composites in 2015. This smaller sample size may be contributing the detected significance, as there is less variance for the test to act on, in addition to making the test uneven. Taking more samples in the future could help increase statistical power. Longer term monitoring for this variable is needed to determine any persistent trends as well.

An increase was observed in the sediment levels for hydrocarbons in both the fuel and lube range, with one station in particular directly northwest of the Hebron Platform showing large increases (Figure 4-28 to Figure 4-31). This sediment station is the closest to the cuttings disposal chute, which has fuel range (C_{10}-C_{21}) hydrocarbons as a tracer (EMCP 2016a). However, these values are not significantly higher in the near-field Hebron Platform and are changing between years evenly in the platform and Reference Area fish livers. Additionally, the lube range hydrocarbons were found to have decreased in liver composites even though increased amounts were found in sediment samples. Similar to the discussion above for manganese, only five composite samples were taken in 2018, 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). Analysis of chromatographs from the hydrocarbon sampling showed compounds were likely biogenic in origin (pers. comm. Maxxam Analytics). Longer term monitoring of these variables is needed to capture potentially natural variation before any further recommendations can be made.

Acenaphthylene and fluorene were novel detections in the 2018 EEM commercial fish program. Acenaphthylene significantly increased in 2018 but did not differ between the Hebron Platform and Reference Area. It was not detected above it's RDL in the sediment program in 2015 or 2018 (Section 5.3). Though it was not above its RDL in 2015, fluorene typically showed an elevated RDL value due to matrix or co-extractive interference during lab analysis. This varied from a doubled RDL up to an RDL 26 times above the base value. No value in 2015 at the Reference Area had an elevated RDL, and so the Hebron Platform has a very high half RDL value even though no samples exceeded their RDLs. This is likely the cause of the significant difference between the Hebron Platform and Reference Area for fluorene. PAHs are a component in most hydrocarbons, and near the Hebron Platform may be present in drilling muds, natural seeps, or other hydrocarbon sources (Harman et al. 2009). As PAHs in the 2018 program were not significantly different between the Hebron Platform and the Reference Area, this is likely not a project related effect. PAHs are occasionally detected in the Hibernia EEM program, though typically only a few samples exceed their RDL (HMDC 2017). Terra Nova reported some American plaice with PAHs present in 2012, but attributed these findings to contamination on deck and have otherwise never reported any PAHs (Suncor Energy 2017).

7.2.2 Fish Health Program

A broad variety of biological factors were analyzed based on current literature revolving around the effects of oil platforms on fish. Factors analyzed for American plaice include general biological characteristics, gross pathology of organs, white blood cells counts, MFO, 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 2018. Male and female fish were assigned maturity codes based on their condition using the index provided in Templeman et al. (1978). No difference was detected between male maturity codes at the two sites, but female fish differed in the maturing in current year (B) (Mat. B-P, code 530) maturity code with a higher incidence at the Hebron Platform (Table 6-17). Maturity codes A-P, B-P, and C-P are different progress stages towards full maturity in the present year (Templeman et al. 1978). Maturity code C-P (Mat C-P) and spent in current year (spent P) were near significance, and both had higher values at the Reference Area (Table 6-17). Delayed maturity was detected in wild populations of fish following the Exxon Valdez oil spill (Sol et al. 2000), and so the higher proportion of fish in a lower maturity stage at the Hebron Platform could be evidence of a delay in spawning. However, no differences were detected in hydrocarbon levels between the Hebron Platform and Reference Area in the 2018 EEM program. Additionally, determining maturity stages can be subjective on the part of individual biologists and this alone is not evidence of any project related effects.

Certain biological characteristics were found to differ between sites in the 2018 EEM program. Male American plaice had a higher total body weight and liver weight at the Hebron Platform compared to the Reference Area and were nearly significantly different for fish length and gutted body weight as well (Table 6-18). Adjusting the p-value by compensating for co-varying measures (e.g., liver weight and total body weight) removed significance for liver weight and gutted weight (Table 6-19). However, indices using these values (Fulton's condition index (FCI), hepatosomatic index (HSI), and gonadosomatic index (GSI)) did not differ between sites in 2018 (Table 6-18). This may point to the Hebron Platform acting as a reef or shelter for larger and older fish, due to the lack of fishing pressure and addition food sources. Many studies have shown both current and decommissioned oil platforms act as highly productive artificial reefs, mainly through the addition of hard substrate for attachment (Page et al. 1999, Sargent et al. 2006, Macreadie et al. 2011, Claisse et al. 2014). Hibernia has similar findings in most EEM years, though exceptions do exist (2000, 2004, and 2011; HMDC 2017)

Comparisons across years for the three indices (FCI, HSI, and GSI) had some significant results. FCI for male plaice and HSI for female plaice both differed across years, with both being higher in 2018 (Table 6-20, Figure 6-11, Figure 6-12). HSI for male plaice differed between sites, being higher at the Hebron Platform in both years (Table 6-20, Figure 6-11). Higher FCI values indicates larger fish at size (Stevenson and Woods 2006), and the significantly higher value for male plaice in 2018 may be another indication of the Hebron Platform acting as a reef, though female plaice did not show a significant difference. An increase in the HSI points to greater energy stores in the liver (Jan and Ahmed 2016), and so increases at the Hebron Platform (male plaice) and across years (female plaice) may be from similar effects. EEM results from Hibernia occasionally find difference in biological characteristics, but they were not significant in the most recent published report (HMDC 2017). The Hibernia EEM also has 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 detected between the Hebron Platform and Reference Area in 2018 for gross pathology (Table 6-21). No results are available from 2015 for comparisons across years. Future programs will compare the three health assessment indexes, as they incorporate all gross pathologies with scores given for severity of various pathologies (Goede and Barton 1990, Adams et al. 1993). Mathieu et al. (2011) report very few, if any, gross pathologies in American plaice taken as part of the Terra Nova EEM program. Hibernia reports

similar pathologies, and incidence rates are also similar to those in this study, with parasites typically as the most common incidence (HMDC 2017).

Blood haematology had no significant differences in the 2018 EEM for neutrophils, lymphocytes, or thrombocytes, through thrombocytes was very near significance (Table 6-22). Cross-year comparisons were made using data only from the Hebron Platform, as it was discarded from the 2015 HSE EEM (Reference Area for comparison in 2015). Significant results were found between sites for all three blood cell types, as well as differences between years for thrombocytes (Table 6-23). Neutrophils and thrombocytes were higher at the Hebron Platform, while lymphocytes were higher at the Reference Area. Thrombocytes were higher in 2015. 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 2018, neutrophils and thrombocytes were higher. No difference was detected between sites in the 2018 program, and so this finding may simply be a regional pattern in this area of the Grand Banks. As these proportions are related to each other, clear long-term trends will take longer to identify.

Mixed function oxygenases (MFOs), in particular ethoxyresorufin-O-deethylase (EROD), is used to measure industrial contamination as it acts to detoxify the liver (Hodson et al. 1991, van der Oost et al. 2003). Specific contaminants stimulate the release of MFOs designed to increase the solubility, and therefore increase the ability of a given substance to be excreted (Hodson et al. 1991). In the 2018 EEM, male plaice had significantly higher EROD values at the Hebron Platform compared to the Reference Area, while females did not (Table 6-24). Cross-year comparisons showed a significant difference between years, and a significant interaction term, for both sexes (Table 6-25). Both sexes had a higher value in 2015 compared to 2018, and the interaction term points to the trend changing due to the Hebron Platform (the Reference Area was higher in 2015, and the Hebron Platform higher in 2018; Figure 6-16). Though the Hebron Platform value is higher in 2018, the overall trend is negative across years. Both Terra Nova and Hibernia have found differences in some years between their respective platform and reference areas, but there is no clear pattern as the reference area is as likely to be higher as the platform (Mathieu et al. 2011, HMDC 2017).

Of the 19 different liver histopathology lesions tested for, only large hepatocellular vacuoles were found to differ between the two sites, with a greater occurrence at the reference area (Table 6-26). A MANOVA comparing across sites and years found a significant difference between years, with a significant interaction term (Table 6-28). Each term in the MANOVA was subjected to a two-way ANVOA, and those that differed between years were hepatocellular carcinoma (higher in 2018), and both large hepatocellular vacuoles and all hepatocellular vacuoles grouped (both higher in 2018) (Figure 6-19). Four results have significant interaction terms, with varying trends between years indicating a potential project effect (Table 6-28, Figure 6-19). Hepatocellular vacuoles is the accumulation of fluid, typically lipids, in the cells of the liver, and is regarded as pre-neoplastic change (Feist et al. 2004). Hepatocellular carcinoma is a malignant neoplasm present in the liver, that can be caused by contaminants but are also present in older fish (Feist et al. 2004). An increase in these factors over time may be due to sampling bias towards older, larger fish or may be natural variation within the population as no corresponding increase at the Hebron Platform was observed. A separate analysis (not reported here) for both sexes comparing carcinoma incidence and age using a one-way ANVOA found no significant difference. A longer time series will allow for better comparisons across years. The same laboratory does liver histopathology for the Hibernia Platform EEM, and very similar pathologies and incidence rates were observed in the 2016 program (HMDC 2019), though these rates are elevated compared to past Hibernia EEM programs and Terra Nova likely due to observer bias (Mathieu et al. 2011, Wolf et al. 2015, HMDC 2017, 2019).

Seven gill histologies, as well as oedema, were observed in the 2018 EEM. No significant difference was detected between sites, though distal hyperplasia was very near significance and higher at the Hebron Platform (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 effect (Table 6-29). Two-way ANOVAs for each factor were used to see which factors contribute to the differences. Basal and distal hyperplasia, as well as telangiectasia, differed between sites and were all higher at the Hebron Platform (Table 6-29, Figure 6-20). Tip, basal, and distal hyperplasia, as well as fusion, differed between years, and were all higher in 2018 (Table 6-29, Figure 6-20). 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 had 93.2 percent and 94.8 percent of fish present normal gill histologies, respectively (Table 6-27). In the 2018 EEM program, 17 of 140 fish (12 percent) analyzed had gill parasites present. A separate analysis (not reported here) found no relation between parasite incidence and any form of hyperplasia using three one-way ANOVAs. No difference was found between sites in the 2018 EEM for any metal, hydrocarbons, or PAHs aside from cadmium being higher at the Reference Area. Though some histologies were higher in 2018 and at the Hebron Platform, many also had significant interactions terms with shifting trends between years (some higher at the Hebron Platform in one year and higher at the Reference Area in the next, and vice versa) (Figure 6-20). A longer time series is needed to verify the direction of these changes.

Histopathology results for the 2018 Hebron EEM program for both liver and gill are similar to findings from the Hibernia and HSE EEM results in 2016 and 2015 (HMDC 2019). 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). This has been attributed to observer effects, as different levels of expertise or individual biases have been found to change results (Wolf et al. 2015). Throughout the course of the Hibernia EEM program, large differences in reported histologies have been detected with different observers (HMDC 2017, Wolf et al. 2015). Hebron and Hibernia have both used the same laboratory for gill and liver histopathology since 2015 and therefore have more comparable results.

7.3 EEM Interpretation

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

7.3.1 Sediment Quality Hypotheses

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

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

The effects predicted in the CSR include increased fine class sediments close the to installed platform and increases in certain metals and hydrocarbons from the drill cuttings near the discharge point. Though comparison of the near, mid, and far field found no statistical difference, these effects were detected at the sampling site closest to the cuttings disposal. No statistical differences were noted for Petrotox or amphipod survival. Differences were noted between years for benthic community, but variations may be natural and so a longer data series is needed to be sure of an effect. Therefore, the sediment quality null hypothesis is not rejected for the 2018 EEM program.

7.3.2 Commercial Fish Hypotheses

Generic monitoring hypotheses for the commercial fish component are:

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

Panelists could not distinguish any difference in perceptible taint from fillets collected at the Hebron Platform, and those collected from the Reference Area in the 2018 EEM. The levels of chemical analytes in American plaice fillets were not significantly different between sites in 2018. Therefore, the first commercial fish null hypothesis is not rejected for the 2018 EEM program.

No significant differences were seen for chemical profiles of American plaice, though some variation existed between years. Larger fish were caught at the Hebron Platform, but this is not an adverse effect and is likely due to an artificial reef effect from the physical structures at the platform. Male fish had elevated EROD concentrations at Hebron Platform, but this is likely natural variation as other platforms note shifts from year to year with MFO often higher at the reference area or the platform. A longer time series is needed for any definitive proof of an adverse effect; therefore, the second commercial fish null hypothesis is not rejected for the 2018 EEM program.

8 RECOMMENDATIONS

8.1 Commercial Fish Program

8.1.1 Chemical Profiles of American Plaice

A larger sample size for both fish fillet and liver composites would allow for clearer interpretation of results. Any one sample deviating from the other four is likely to overestimate the amount of variation present, and potentially create significant differences between sites where none may truly exist. Though only five samples were taken, outliers existed in bar graphs (e.g., Figure 6-8) indicating that certain samples were outside the second quartile. Comparing to 2015 results, the boxplots appear tighter as well, and so the composites may be skewing the results towards the "median" of all the fish that go into making the blended composite (e.g., Figure 6-8). This may mask some of the natural variation present and may be the cause of several across-year significant differences. A larger sample size is likely to capture the natural variation present and allows for more statistical confidence and power in stating the existence of any differences between sites. Collecting a minimum of 10 samples would be in line with the Hibernia EEM program, as well as the 2015 Hebron EEM program (EMCP 2016b, HMDC 2017). As current fillet composites are 10 fish in each of 5 composite samples, a simple adjustment to 5 fish in each of 10 composite samples could give a greater natural range of values for analysis. A power analysis could also aid with sample size determinations.

8.1.2 Fish Health Program

Future recommendations for histopathology include analyzing the colour of collected livers. This is based on a personal communication from Dr. Khan indicating that pale livers are indicative of large hepatocellular vacuoles. Current gross pathology for livers includes a code for pale discolouration, but this code is superseded by higher liver codes (e.g., green discolouration of liver). Out of the 140 fish in the 2018 report, only 11 had the code for pale discoloration but many possessed higher codes that would override it. Future gross pathology should include a paint colour palette in the photo with each liver for a quantitative measure of colour, as well as a separate code for pale livers.

Another recommendation is the official addition of bile duct hyperplasia to the liver histopathology program. This parameter has been assessed by Dr. Khan for the entire Hebron EEM program so far, but it is not officially included in the design plan. Though no differences have been found between the Hebron Platform and Reference Area, bile duct hyperplasia was observed in 20-30% of fish in the 2018 EEM program. Bile duct swelling and proliferation has been observed in fish exposed to oil contamination (Khan 1995, Agamy 2012), and so should be monitored in future years as a potential indicator of exposure.

Another potential metric for measuring fish response to contamination is measuring hemosiderin in American plaice spleens. This has proven to be a useful metric in fish studies (e.g., Khan and Nag 1993, Fournie et al. 2001), and is very simple to measure. Spleen sections would be stained with Perl's Prussian Blue or Harris' hematoxylin and eosin and counts of aggregates are taken. These aggregates are stained very dark, and computer programs could be used to automatically count incidence of the dark pigmented areas. This could be compared alongside other histopathology parameters.

9 CONCLUSION

This report on the 2018 Hebron EEM has been prepared for the exclusive use by EMCP. The project was conducted using standard practices by qualified Wood staff and in accordance with verbal and written requests from the client.

Yours sincerely,

Wood Environment & Infrastructure Solutions,
a Division of Wood Canada Limited

Prepared by:

Kyle Millar, M.Sc.
Environmental Biologist

Prepared by:

Lara Miles, M.Sc.
Environmental Biologist

Reviewed by:

James McCarthy, M.Sc., CFP
Senior Associate Biologist, Ecosystems Group Lead

Justin So, M.Sc.
Senior Biologist

10 REFERENCES

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

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

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

APHA (American Public Health Association). 1995. Standard Methods for the Examination of Water and Wastewater 10200.

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

Behling, S. 2013. Oligochaeta: Biological Indicators. http://winvertebrates.uwsp.edu/behling_361_2013.html.

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

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

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

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

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

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

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2006. Canada-Newfoundland and Labrador Development Plan Guidelines.

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2012. Hebron Development Application: Canada-Newfoundland and Labrador Offshore Petroleum Board. Page 6. Decision Report.

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

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

DeBlois, E. M., M. D. Paine, B. W. Kilgour, E. Tracy, R. D. Crowley, U. P. Williams, and G. G. Janes. 2014b. Alterations in bottom sediment physical and chemical characteristics at the Terra Nova offshore oil development

over ten years of drilling on the grand banks of Newfoundland, Canada. Deep Sea Research Part II: Topical Studies in Oceanography 110:13–25.

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

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

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

EMCP (ExxonMobil Canada Properties). 2011. Hebron Project Comprehensive Study Report.

EMCP (ExxonMobil Canada Properties). 2016a. Hebron Environmental Characterization: 2014 Physical (Sediment and Water) Survey-Report to inform EEM Plan Results and Analysis. Page 79. OIMS Reference Document.

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

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

EMCP (ExxonMobil Canada Properties). 2018. Environmental Compliance Monitoring Plan Drilling and Production Operations. Document Control Number: CAHE-EC-OOREF-01-006-5004-000.

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

Fournie, J. W., J. K. Summers, L. A. Courtney, and V. D. Engle. 2001. Utility of Splenic Macrophage Aggregates as an Indicator of Fish Exposure to Degraded Environments. Journal of Aquatic Animal Health 13:105–116.

Francesconi, K. 2010. Arsenic species in seafood: Origin and human health implications. Pure and Applied Chemistry 82:373–381.

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

Gomez Gesteira, J. L., J. C. Dauvin, and M. Salvande Fraga. 2003. Taxonomic level for assessing oil spill effects on soft-bottom sublittoral benthic communities. Marine Pollution Bulletin 46:562–572.

Gray, J., K. Clarke, R. Warwick, and G. Hobbs. 1990. Detection of initial effects of pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series 66:285–299.

Harman, C., K. V. Thomas, K. E. Tollefsen, S. Meier, O. Bøyum, and M. Grung. 2009. Monitoring the freely dissolved concentrations of polycyclic aromatic hydrocarbons (PAH) and alkylphenols (AP) around a Norwegian oil platform by holistic passive sampling. Marine Pollution Bulletin 58:1671–1679.

Health Canada. 2018, September 17. List of Contaminants and other Adulterating Substances in Foods. https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/contaminants-adulterating-substances-foods.html.

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

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

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

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

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

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

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

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

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

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

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

Khan, R. A. and K. Nag. 1993. Estimation of Hemosiderosis in Seabirds and Fish Exposed to Petroleum. Bulletin of Environmental Contamination and Toxicology 50:125–131.

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

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

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

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

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

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

Neff, J. M., K. Lee, and E. M. DeBlois. 2013. Produced Water: Overview of Composition, Fates, and Effects. Pages 1–13 in K. Lee and J. Neff, editors. Produced Water. Springer Science+Business Media.

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

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

Paine, M. D., E. M. DeBlois, B. W. Kilgour, E. Tracy, P. Pocklington, R. D. Crowley, U. P. Williams, and G. Gregory Janes. 2014. Effects of the Terra Nova offshore oil development on benthic macro-invertebrates over 10 years of development drilling on the Grand Banks of Newfoundland, Canada. Deep-Sea Research Part II: Topical Studies in Oceanography 110:38–64.

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

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

R Core Team. 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Sargent, P. S., R. S. Gregory, and D. C. Schneider. 2006. Density Responses of Subarctic Coastal Marine Fish and Crabs to Artificial Reefs. Transactions of the American Fisheries Society 135:348–360.

Sol, S. Y., L. L. Johnson, B. H. Horness, and T. K. Collier. 2000. Relationship Between Oil Exposure and Reproductive Parameters in Fish Collected Following the Exxon Valdez Oil Spill. Marine Pollution Bulletin 40:1139–1147.

Stantec Consulting Ltd. 2013. Development of a Marine Sediment Quality Guideline for Puredrill IA-35. Prepared for Hibernia Management and Development Company Limited, St. John's, NL. ii + 15pp.

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

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

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

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

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

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

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

US EPA (United States Environmental Protection Agency). 1997. Arsenic and Fish Consumption. EPA-822-R-97-003.

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

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

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

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

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

Appendix A 2015 Reference Area Summary

1.0 COMMERCIAL FISH PROGRAM

The 2018 Hebron EEM program uses data collected from the Hebron Platform in the 2015 fish characterization report, and data from the Reference Area taken from the 2015 Hibernia Southern Extension (HSE) report. This is the same reference area used for the 2018 report and going forward for the Hebron EEM. This document compares data collected from the Hebron Platform in 2015 and the Reference Area used by HSE in 2015.

1.1 Chemical Profiles of American Plaice Tissue

Three metals were consistently detected in American plaice fillets at both the Hebron Platform and Reference Area: arsenic, mercury, and zinc (Table 1.1). No hydrocarbons or PAHs were detected in fillets. Selenium was detected in one sample from the Reference Area but was not screened in for analysis. Eight metals were detected in all liver composites at both areas: arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc (Table 1.2). No hydrocarbons were detected in the lower fuel range ($>C_{10}$-C_{16}), though hydrocarbons in the upper fuel range ($>C_{16}$-C_{21}) and lube range ($>C_{21}$-C_{32}) were detected in more than half of all samples (Table 1.2). The only detected PAH was 2-Methylnaphthatlene, which was found in five samples at the Hebron Platform and one Reference Area sample.

No significant difference in fillets was found between sites for arsenic, mercury, or zinc (Table 1.3). Liver composites had significant differences for cadmium, mercury, and manganese (Figure 1-1, Table 1.4). Cadmium and mercury were higher in fillets at the Reference Area, while manganese was higher at the Hebron Platform.

Table 1.1 Summary statistics of 2015 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
Hebron Platform Fillet (n=10)								**Reference Area Fillet (n=10)**					
Metals								**Metals**					
Arsenic	0.50	10	4.27	1.73	4.0	2.3	8.3	10	4.26	1.76	3.8	1.8	6.6
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	0.083	0.043	0.080	0.035	0.180	10	0.091	0.084	0.064	0.032	0.310
Selenium	0.50	0	-	-	-	<RDL	<RDL	1	0.51	0.04	0.50	<RDL	0.63
Zinc	1.5	10	4.24	0.60	4.1	3.4	5.2	10	4.45	0.79	4.4	3.4	5.8
Hydrocarbons								**Hydrocarbons**					
None above 50% detection limit [a], RDL (15 mg/kg)								None detected, all samples <RDL (15 mg/kg)					
Alkyl-PAHs								**Alkyl-PAHs**					
None detected, all samples <RDL (0.050 mg/kg) [b]								None detected, all samples <RDL (0.050 mg/kg) [b]					

Notes:

[a] 3 samples in >C_{21}-C_{32} range above detection

[b] RDL for Benzo(b/j)fluoranthene is 0.10 mg/kg

Table 1.2 Summary statistics of 2018 Hebron Platform and Reference Area liver composite body burden data (mg/kg).

Parameter	RDL (mg/kg)	Hebron Platform Fillet (n=10)						Reference Area Fillet (n=10)					
		No. ≥ RDL	Mean	St. Dev	Median	Min	Max	No. ≥ RDL	Mean	St. Dev	Median	Min	Max
Metals													
Arsenic	0.50	10	8.84	2.89	8.7	5.2	14.0	10	12.09	7.11	9.8	5.1	29.0
Barium	1.5	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL
Cadmium	0.050	10	1.00	0.24	1.0	0.7	1.5	10	1.50	0.64	1.7	0.7	2.7
Chromium	0.50	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL
Copper	0.50	10	7.63	2.45	6.9	5.3	12.0	10	6.75	1.87	7.0	3.2	9.8
Iron	15	10	60.9	20.1	57	35	97	10	85.4	35.5	84	47	170
Lead	0.18	0	-	-	-	<RDL	<RDL	0	-	-	-	<RDL	<RDL
Manganese	0.50	10	0.83	0.05	0.83	0.74	0.92	10	0.69	0.10	0.72	0.55	0.81
Mercury	0.01	10	0.039	0.006	0.039	0.025	0.045	10	0.057	0.023	0.051	0.026	0.096
Selenium	0.50	10	2.97	0.34	2.8	2.6	3.6	10	3.12	0.56	2.9	2.5	4.0
Zinc	1.5	10	34.1	2.73	35	29	37	10	32.3	3.80	34	24	37
Hydrocarbons								**Hydrocarbons**					
>C_{10}-C_{16}	15	None detected, all samples <RDL						2	15.1	0.32	15	<RDL	16
>C_{16}-C_{21}	15	10	26.8	12.1	23	17	57	8	24	7.8	24	<RDL	39
>C_{21}-C_{32}	15	10	148.8	48.4	130	98	250	10	182	43.2	180	110	260
PAHs [b, c]								**Alkyl-PAHs**					
2-Methylnaphthatlene	0.050[b]	5	0.082	0.037	0.073	<RDL	0.160	1	0.100	0.070	0.058	<RDL	0.200

Notes:

[a] Two samples above RDL (15 and 16 mg/kg)

[b] Several PAHs had elevated RDLs due to matrix/co-extractive interference: 2-Methylnaphthalene, Fluoranthene, and Fluorene.

[c] The following requested PAHs were below their RDLs (0.050 mg/kg): 1-Methylnaphthalene, Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(b/j)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, and Pyrene.

Table 1.3 One-way ANOVAs of metals found in American plaice fillets

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	0.000	0.0005	0.0002	0.990
Residuals	18	54.725	3.0403		
Mercury					
Site	1	0.00037	0.00037	0.0827	0.777
Residuals	18	0.08052	0.00447		
Zinc					
Site	1	0.2205	0.2205	0.4485	0.512
Residuals	18	8.8490	0.49161		
Notes: Bolded p-value denotes a significant result (α=0.05)					

Table 1.4 One-way ANOVAs of metals detected in American plaice liver composites

Factor	Degrees of Freedom	Sum of Squares	Mean Square	F Value	p value
Arsenic					
Site	1	52.81	52.81	1.792	0.197
Residuals	18	230.47	29.47		
Cadmium					
Site	1	1.2701	1.2701	5.500	**0.031**
Residuals	18	4.1565	0.2309		
Copper					
Site	1	3.872	3.8720	0.8149	0.379
Residuals	18	85.526	4.7514		
Iron					
Site	1	3001.3	3001.25	3.606	0.074
Residuals	18	14981.3	832.29		
Manganese					
Site	1	0.088	0.088	14.789	**0.001**
Residuals	18	0.108	0.006		
Mercury					
Site	1	0.0016	0.0016	5.639	**0.029**
Residuals	18	0.0052	0.0003		
Selenium					
Site	1	0.113	0.113	0.5278	0.477
Residuals	18	3.837	0.213		
Zinc					
Site	1	16.2	16.20	1.4802	0.240
Residuals	18	197.0	10.94		
Notes: Bolded p-value denotes a significant result (α=0.05)					

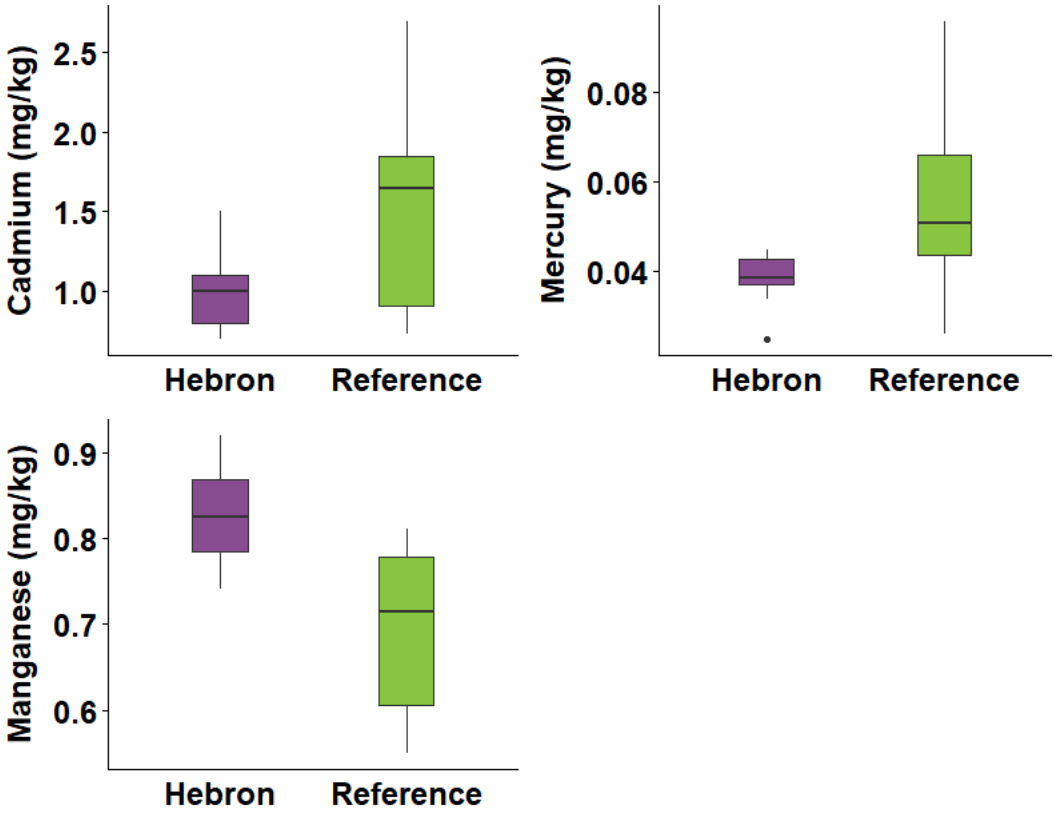

Figure 1-1 Average concentration (mg/kg) of cadmium, mercury, and manganese in American plaice liver composites.

1.2 Taste Panels

Taste panel results are not able to be compared side-by-side between the two sampling programs. Within each sampling program, no significant results were observed. See individual EEM reports for details (EMCP 2016, unpublished HSE 2015 report).

2.0 2015 FISH HEALTH PROGRAM RE-ANALYSIS

The Hebron fish health survey is conducted to qualitatively assess American plaice (*Hippoglossoides platessoides*) collected adjacent to the Hebron Platform, and from the Hebron Reference Area. The original design in 2015 had a designated GBS reference area. Subsequently, it was decided that the Hebron EEM going forward would use a shared reference area with the Hibernia EEM project. This document compares data from the original Hebron fish data and compares it to the reference fish data collected from the Hibernia Southern Extension EEM report (which also shares a reference area with the Hibernia platform). Fish were collected using a Campelen trawl aboard the *FRV Nuliajuk*.

2.1 Maturity Stages

Frequency (percentage) of fish presenting in each sexual maturity code at both locations is presented in Table 2.1. Spent in previous year (code 110) in males and maturing in current year (code 540) in females were both more prevalent at the Hebron Platform, and spent in previous year (code 510) for females was higher at the Reference Area.

Table 2.1 Frequencies (%) of maturity stages of male (top) and female (bottom) American plaice from the 2015 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	34	8	6	19	1	0	0	0
Reference area	39	8	0	24	6	0	0	1
p-value		1.00	**0.01**	0.64	0.11	1.00	1.00	1.00

Female Maturity Stage (% of individuals)										
		Immature (500)	**Spent L (510)**	**Maturing A-P (520)**	**Mat B-P (530)**	**Maturing C-P (540)**	**Partly Spent P (550)**	**Spent P (560)**	**Spent P Mat N (570)**	**Mat N (580)**
Hebron Platform	36	1	0	2	11	21	1	0	0	0
Reference area	31	1	18	1	3	5	0	3	0	0
p-value		1.00	**<0.01**	1.00	0.07	**<0.01**	1.00	0.09	1.00	1.00

Notes:
Maturity stages were defined according to procedures used by DFO (Templeman et al. 1978).
p-values obtained with the Fisher's Exact Test
Bolded p-value indicates significant difference (α=0.05)

2.2 Biological Characteristics

Morphometric characters compared include 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) (Table 2.2). 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. Male fish had a higher liver weight and hepatosomatic index at the Hebron Platform compared to the Reference Area (Table 2.2). Even after adjusting the p-value for covariates, liver weight is still significant higher (Table 2.3).

Table 2.2 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 2018

Parameter	Hebron Platform	Reference Area	p-value
Male			
No. of Fish	34	39	
Length (cm)	336 ± 26.1	325 ± 35.6	0.14
Total Body Weight (g)	314 ± 72.1	293 ± 109.0	0.34
Gutted Body Weight (g)	275 ± 71.6	264 ± 98.5	0.58
Liver Weight (g)	4.54 ± 1.35	3.77 ± 1.81	**0.05**
Gonad Weight (g)	3.91 ± 3.45	3.66 ± 2.77	0.72
Age (years) [a]	6.38 ± 1.06	6.39 ± 1.10	0.95
Fulton's Condition Index [b]	0.72 ± 0.14	0.73 ± 0.05	0.62
Hepatosomatic Index [c]	1.69 ± 0.53	1.40 ± 0.30	**0.01**
Gonadosomatic Index [d]	1.36 ± 1.01	1.30 ± 0.61	0.74
Female			
No. of Fish	36	31	
Length (cm)	411 ± 37.3	396 ± 41.3	0.13
Total Body Weight (g)	657 ± 159.1	587 ± 228.4	0.15
Gutted Body Weight (g)	527 ± 123.6	466 ± 157.9	0.08
Liver Weight (g)	8.82 ± 2.60	8.25 ± 4.18	0.49
Gonad Weight (g)	29.60 ± 34.78	25.54 ± 22.36	0.58
Age (years) [e]	9.50 ± 1.63	8.77 ± 1.77	0.15
Fulton's Condition Index [b]	0.77 ± 0.27	0.72 ± 0.12	0.33
Hepatosomatic Index [c]	1.70 ± 0.43	1.83 ± 0.87	0.41
Gonadosomatic Index [d]	5.52 ± 5.91	5.71 ± 5.52	0.90

Notes:
All data are expressed as average values ± standard deviation
[a] For male age calculations, n=24 for the Hebron Platform and n=28 for the Reference Area
[b] Calculated as 100 x gutted body weight (g) / length $(cm)^3$
[c] Calculated as 100 x liver weight (g) /gutted body weight (g)
[d] Calculated as 100 x gonad weight (g) /gutted body weight (g)
[e] For female age calculations, n= 26 for the Hebron Platform and n=22 for the Reference Area
Bolded p-value denotes significant result (α=0.05)

Table 2.3 Adjusted p-values from ANCOVA analysis of gutted, liver, and gonad weight for male (top) and female (bottom) American plaice from the Hebron Platform and Reference Area in 2018

Variable	Covariate	Adjusted p-value[a]
Male		
Gutted weight (g)	Length (mm)	0.08
Liver Weight (g)	Gutted weight (g)	**0.02**
Gonad weight (g)	Gutted weight (g)	0.99
Female		
Gutted weight (g)	Length (mm)	0.39
Liver Weight (g)	Gutted weight (g)	0.70
Gonad weight (g)	Gutted weight (g)	0.88

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

2.3 Gross Pathology

No gross pathology was done in 2015.

2.4 Haematology

Haematological changes are thus strongly related to fish health in response to environmental changes (Corrêa et al. 2016).

No Haematology was completed at the reference area in 2015.

Table 2.4 Frequencies of blood cell types in American plaice from the 2018 Hebron biological survey

Cell Type	Hebron Platform (n=49)	Reference Area (n=0)	p-value
Lymphocytes (%)	2.04 ± 0.87	-	-
Neutrophils (%)	88.92 ± 3.45	-	-
Thrombocytes (%)	9.04 ± 3.03	-	-

Notes:
All data expressed as mean percentage ± standard deviation of each type of cell on at least 200 white blood cells counted per fish.

2.5 Mixed Function Oxygenase Activity

MFO values were much higher at the Reference Area for both sexes compared to Hebron Platform (Table 2.5).

Table 2.5 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 2018

Mixed Function Oxygenase (pmol resorufin / mg protein / min)			
Male	**Hebron Platform (n=34)**	**Reference Area (n=39)**	**p-value**
MFO (EROD)	9.75 ± 6.57	32.10 ± 16.20	**<0.001**
Female	**Hebron Platform (n=36)**	**Reference Area (n=31)**	**p-value**
MFO (EROD)	3.05 ± 2.71	11.73 ± 12.97	**0.002**

Notes:
All data expressed as mean percentage ± standard deviation
bolded p-value denotes significant result (α=0.05)

2.6 Histopathology

Histopathology for both programs in 2015 were assessed by the same individual and should be comparable. Several significant differences existed between liver pathologies, with significantly more normal fish and macrophage aggregates at the Reference Area, and significantly more nuclear pleomorphisms, clear cell foci, and large hepatocellular vacuoles at the Hebron Platform.

Table 2.6 Number and frequency of American plaice with hepatic lesions from the Hebron Platform and Reference Area in 2018

Lesions	Hebron Platform (n=50)		Reference Area (n=50)		p-value
	Fish Affected	Prevalence (%)	Fish Affected	Prevalence (%)	
Normal	6	12	15	30	**0.048**
Nonspecific necrosis	0	0	0	0	1.000
Bile duct hyperplasia	9	18	8	16	1.000
Nuclear pleomorphism	25	50	9	18	**0.001**
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	29	58	8	16	**<0.001**
Hepatocellular carcinoma	7	14	7	14	1.000
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]	1	2	8	16	**0.031**
Macrophage aggregates[b]	0	0	0	0	1.000
Hydropic vacuolation	0	0	0	0	1.000
Hepatocellular vacuoles S	2	4	8	16	0.092
Hepatocellular vacuoles M	10	20	11	22	1.000
Hepatocellular vacuoles L	25	50	9	18	**0.001**
Hepatocellular vacuoles A	37	74	28	56	0.093

Notes:
S – small, M – medium, L – large, A – all (small, medium, and large)
[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-value denotes significant result (α=0.05)

Several significant differences between sites were observed in gill pathologies, with tip hyperplasia, telangiectasia, and oedema condition higher at the Hebron Platform, and thin lamellae higher at the Reference Area.

Table 2.7 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 2018.

Lesion Type	Hebron Platform (n=50)	Reference Area (n=50)	p-value
Percentage of Secondary Lamellae Affected by Lesions			
Normal	97.7 ± 2.37	98.0 ± 2.24	0.594
Tip Hyperplasia [a]	0.38 ± 0.45	0.11 ± 0.22	**<0.001**
Basal Hyperplasia [b]	0.64 ± 1.18	0.33 ± 0.71	0.115
Distal Hyperplasia [c]	0.32 ± 0.81	0.27 ± 0.62	0.689
Fusion	0.73 ± 1.25	1.06 ± 1.80	0.291
Telangiectasia	0.13 ± 0.43	0.01 ± 0.04	**0.050**
Thin Lamellae	0 ± 0	0.12 ± 0.38	**0.037**
Epithelial Lifting	0.09 ± 0.28	0.16 ± 0.97	0.629
Scale of Affected Lesions			
Oedema (Scale 1-3)	0.35 ± 0.67	0.03 ± 0.09	**<0.001**

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

3.0 REFERENCES

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

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

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

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

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