The Canadian Oil Spill Shoreline Research Program: Establishing a Baseline Dataset for the Marine Coast of Northern British Columbia

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The dispersal and weathering processes of crude and fuel oils have been studied for decades and significant scientific information has been published. However, the fate and behaviour of spilled nonconventional crude oil such as diluted bitumen products are less well understood. There is concern that a spill of the oil sands diluted bitumen may come into contact with marine shorelines as it is transported throughout Canada. There is uncertainty related to the fate of spilled diluted bitumen and potential interactions with shorelines. A Shoreline Oil Spill Research and Development Program was undertaken by Environment and Climate Change Canada (ECCC). In 2013, a 3-year study was initiated and focused on the marine shorelines of northern British Columbia (BC). Four field campaigns were conducted along the entire length of coast throughout the Douglas and Granville channels as well as Banks and Haida Gwaii islands. The field campaigns were used as an opportunity to develop and employ a new approach to collect and compile an extensive pre-spill baseline dataset. Data included an aerial survey with high definition video and a ground survey of representative shorelines where samples were collected and analyzed for petroleum hydrocarbons, carboxylic acid, pesticides, heavy metals, calcium carbonate and sediment grain size. Baseline levels of hydrocarbons in the sediment of the study areas were estimated based on the analysis of total petroleum hydrocarbons (TPH), *n*-

alkanes ranging from n-C_9 to n-C_{40}, petroleum related biomarkers such as terpanes and steranes, polycyclic aromatic hydrocarbons (PAHs) and their alkylated homologues (APAHs).

1 Objective

The purpose of this paper is to present an overview of the new approaches used by ECCC to establish pre-spill baseline environmental shoreline data as well as an in-depth case study of the petroleum hydrocarbon analysis to demonstrate the importance of comprehensive baseline data collection to distinguish the source of any hydrocarbons present prior to an incident.

2 Introduction

Canada has an extensive history of investing in Research and Development (R&D) in response to the development of the oil industry. In the 1980's and 90's, the important ECCC R&D projects on the contamination of shorelines were: the BIOS project in the Arctic (Blackhall and Sergy, 1981); development of SCAT guides (Owens and Sergy, 2000); research on specific products such as Orimulsion (Guénette et al, 1998); and others.

During the past decade, there has been significant resource development in the oil sands regions of northern Alberta. The Canadian oil sands contain the world's third-largest oil reserves after Saudi Arabia and Venezuela (Alberta Energy, 2011). It is realistic to think that the extraction and export of bitumen will become an even more important industry for Canada and the quantities transported will be considerable. With an increase in the quantity of bitumen-based nonconventional oils transported throughout Canada, it became a priority to focus new studies on this major gap in our research. In 2013, a new shoreline program was developed to address concerns surrounding the uncertainties as to the fate and behaviour of spilled diluted bitumen (dilbit) if it were to reach any type of shoreline.

A number of research projects were undertaken by Emergencies Science and Technology Section (ESTS), ECCC under this initiative. The projects that have been developed include the fate and behaviour of dilbit, the effectiveness of spill treating agents and the penetration and retention of dilbit in different types of sediments, and the baseline Pre-SCAT data on shorelines in different regions in Canada. This paper addresses baseline Pre-SCAT data and shoreline classification work undertaken for the northern BC coastline by ESTS between 2013 and 2015.

3 Study Sites and Classification of the Shorelines

Canada has the longest coastline in the world with approximately 243,042 km of shorelines and borders on three oceans (Statistics, 2011). The coastal environment throughout Canada possesses a wide range of ecological sensitivities as well as being economically important. Over the past 30 years, some of those shorelines were studied to acquire baseline data suitable for oil spill preparedness and response. The existing 30 years of baseline data was for coastlines primarily near major shipping routes or population centres. The lack of baseline data relevant to oils spills for the northern BC coastline is a notable gap that needed to be addressed.

The study sites were located on the coastline throughout the Douglas Channel, a principal inlet along the BC coast, and Haida Gwaii, one of the most environmentally sensitive areas in Canada (Figure 1). There are many First Nation communities (e.g. Haida, Gitga'at, Haisla and Gitxaala) in this area of northern BC with a corresponding large number of traditional sites and protected areas (Laforest et al., 2014).

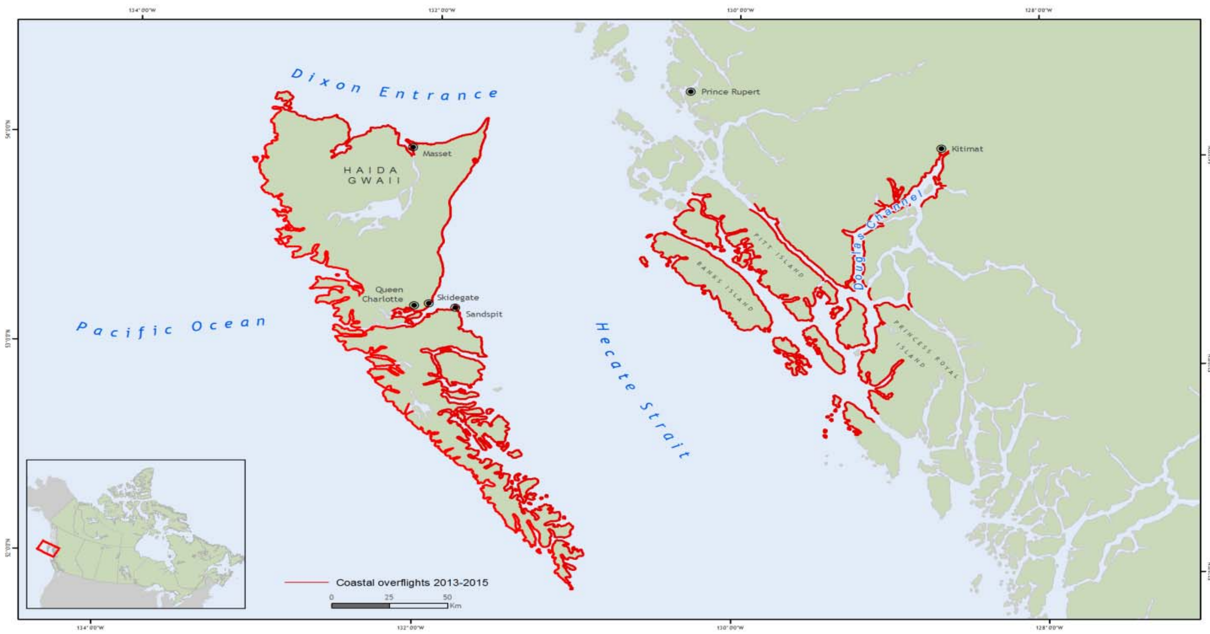

Figure 1: Study Sites in Northern British Columbia between 2013 and 2015.

In Canada, ECCC developed a classification system to identify the type of shoreline to be used during the segmentation process. A detailed description of ECCC's SCAT classification system can be found in Sergy (2008). The marine shoreline types are described within 19 classes (Table 1). In northern BC, 11 of the 19 classes (Table 1) were observed based on the review of the aerial surveys.

Table 1: Canadian Classification of Shoreline in British Columbia.

Type of Shoreline in Canada	Northern British Columbia
Bedrock – Cliff/vertical	Presence
Bedrock – Sloping/Ramp	Presence
Bedrock - Platform	Presence
Man-made Solid	Absence
Man-made Permeable	Presence
Sand Beach	Presence

Mixed Sediment Beach (fine mixed and coarse mixed)	Presence
Pebble/Cobble Beach	Presence
Boulder Beach	Presence
Mud Flat	Presence
Sand Flat	Presence
Mixed Sediment Flat	Absence
Pebble/Cobble/Boulder Flat	Absence
Wetland (Marine marsh)	Presence
Peat Shoreline	Absence
Tundra Cliff – Ice Rich (Arctic only)	Absence
Tundra Cliff – Ice Poor (Arctic only)	Absence
Inundated Low Lying Tundra (Arctic only)	Absence

The study area is predominantly occupied by bedrock cliff and sloping/ramp on the shorelines. The majority of the rocky shorelines are covered by micro-fauna and plants (Figure 2), which typically increases the environmental sensitivity of the shorelines. The second major shoreline type is coarse mixed sediment beach. It is also possible to find armored beaches where a surface veneer of cobble-boulder overlays the sand in the subsurface (Figure 3, source Harper et al, 2016). Generally, all of the other types of shorelines are found along the northern BC coastline; however the variety of shoreline types is greater on Haida Gwaii than in the mainland channels.

Figure 2: Bedrock cliff covered by micro-fauna – northeast section of the Douglas Channel.

Figure 3: Oblique aerial photo of an armored beach.

4 Pre-SCAT: Aerial and Ground Surveys

Much of the critical information used by the SCAT program during a response may be compiled in advance. It is more practical to collect/assess certain data before an incident ("pre-spill"), when there is more time available to address important issues, rather than under the pressure of an initial emergency response (ECCC, 2017 *in press*). The following is a description of the data that were compiled in the pre-spill baseline survey of northern BC.

Aerial Surveys

For the aerial survey, low altitude helicopter flights were conducted at each study site to capture video of the shoreline characteristics. High definition video was collected of the upper part of the intertidal zone (UI; main area where oil would be deposited and where cleanup activities would take place), which included audio commentary and geotagging (using VMS 300 video mapping system combined with nanoFlash recorder).

The videos and photos of shorelines were used to cut the shoreline into homogenous segments and create a pre-spill database (Figure 4). This pre-spill database is presented on an internal ECCC web mapping system called EEMAP used by ECCC Environmental Emergencies Officers. Under limited circumstances the segmentation layer may be shared with oil spill research partners in Canada.

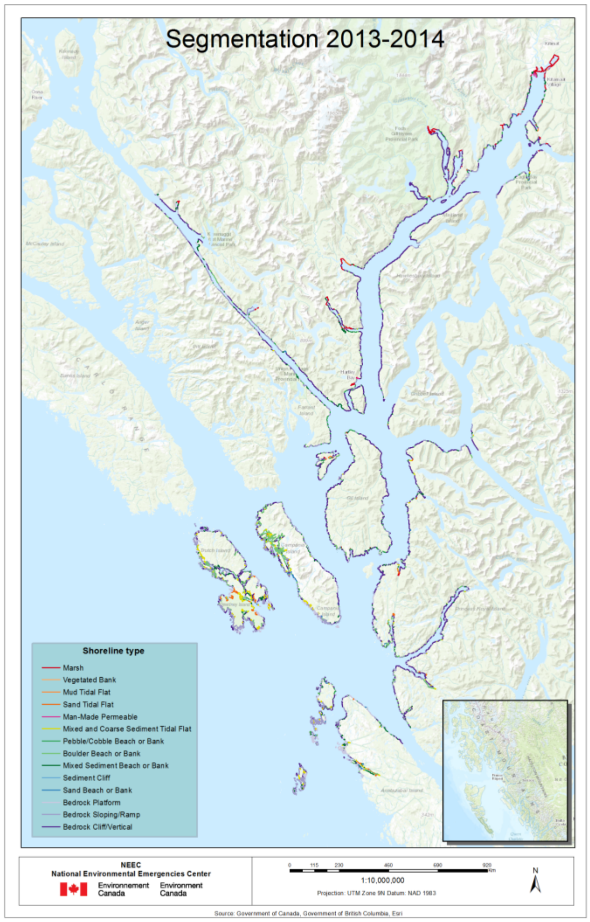

Figure 4: Part of the segmentation in the Douglas Channel.

Ground Surveys

For the ground surveys, each of the selected segments was visited by a team of experts in SCAT, and the biological or ecological resources (e.g., birds, fisheries) of northern BC. Results from the ecological resource survey will be presented in future reports. At each site the pre-SCAT survey included data collection of the geologic characteristics such as the primary type of shoreline, the layers of substrate, the slope of the shoreline, and the physical and chemical characteristics of the shoreline. For some designated shorelines more than one sampling point was selected. A total of 27 ground survey sites (Figure 5) were visited from 2014 to 2015 with approximately 54 samples collected from different types of substrates. The samples were collected in the upper and lower intertidal zone for each segment. When the segment was more than 200 m in length, the data were acquired at the beginning and end of the segment. The segments were assessed by the combined team of experts who surveyed the full length and width of the shoreline to concurrently collect the geological and biological data at low tide. All sampling included the necessary QA/QC such as duplicates (i.e., field replicates) and field blanks to meet the highest standards for laboratory analysis.

Figure 5: The 27 ground survey sites visited from 2014 to 2015.

The data from the aerial and ground surveys were gathered and summarized in a report titled “A Compilation of Baseline Physical, Geographic, Biological and Chemistry Data of Selected Shorelines in Northern British Columbia” (ECCC, 2016); these data were compiled by site visited. Although still in draft, the intention of this report is to help stakeholders with planning activities, in the event of an oil spill, to identify the best response tactics and treatment options for shorelines (Laforest et al, 2016).

5 An Overview of Physical and Chemical Baseline Analysis of the Sediment Samples

Sediment samples collected from the selected shoreline sites underwent subsequent laboratory analysis to determine baseline levels of various parameters. Laboratory analysis included an examination of the sediment for a comprehensive suite of petroleum hydrocarbon compounds including n-alkanes, polycyclic aromatic hydrocarbons (PAHs) and biomarkers. In addition, analysis included characterization of the sediment particle size, carboxylic acids, heavy metals, pesticides, and calcium carbonate. A report on the carboxylic acids was prepared by Zhang et al. (2016) and further reports on the remaining baseline data will follow.

Baseline data is important to determine environmental impacts and restoration. It contributes by increasing the knowledge of the shoreline ecosystem and hence provides more informed advice during an oil spill response. Additionally, it helps to inform decisions related to forensic science, such as the identification of potential pollution sources. These baseline data have been applied to other shoreline research projects. For example, the sediment particle size results were incorporated into the experimental design for a parallel meso-scale shoreline study on the penetration and retention of diluted bitumen on marine substrates (Laforest et al, 2015).

6 Petroleum Hydrocarbon Analysis for Sediment Samples

For the purposes of this paper, the petroleum hydrocarbon analysis is presented as a case study of baseline data and the application to pre-spill surveys.

The potential existing petroleum hydrocarbon contamination of the shorelines along Douglas Channel and Haida Gwaii was assessed based on analyzing total petroleum hydrocarbon (TPH), n-alkanes from n-C9 to n-C40, petroleum biomarkers terpanes and steranes, and polycyclic aromatic hydrocarbons (PAHs) and their alkylated homologues (APAHs) in 54 sediment samples collected during the 2014-15 field campaign. The sample preparation and laboratory analysis procedure is described in detail in the reference Yang et al. (2016).

7 Results and Discussion

TPH and Occurrence Aliphatic Hydrocarbons

The quantified TPH at the sampling sites ranged from 1.6 to 8.4 µg/g (dried weight) in Kitimat Arm, 6.0 to 12.2 µg/g in South Douglas Channel, and 9.7 to 14.6 µg/g for all samples, except for the one sample from Masset Harbour, Haida Gwaii. The TPH in Masset Harbour was determined to be 39.9 µg/g, with the unresolved complex mixture (UCM) accounting for 69.3% of TPH. The low TPH values and the chromatographic character essentially reveal that all the sampling sites, except for Masset Harbour, were free from petroleum hydrocarbon contamination. The apparent petroleum hydrocarbon input was observed in Masset Harbour due to the higher TPH value and the presence of unresolved complex mixture (UCM).

Aliphatic hydrocarbons studied in the samples collected include *n*-alkanes and petroleum biomarkers of hopanes, terpanes and steranes. Traditionally, *n*-alkanes occur almost ubiquitously in sediments, although they comprise a small percentage of the organic matter. Their distributions have been widely used to identify the sources of organic matter (Wang et al., 2012). The box plots of individual *n*-alkanes in Figure 6 depict their full range of variation in different sampling regions. Similar distribution profiles of *n*-alkanes were noted for all the sampling sites, except for Masset Harbour, Haida Gwaii. Specifically, the detected *n*-alkanes fall in the range of $n\text{-}C_{15}$ to $n\text{-}C_{37}$ with a maximum between $n\text{-}C_{27}$ to $n\text{-}C_{29}$ and an obvious odd to even carbon preference. The carbon preference index (CPI) values and the maximal peaks of $n\text{-}C_{27}$ to $n\text{-}C_{29}$

indicate the main input of n-alkanes is from terrestrial plants (Wang et al., 2012). It is noted that the sample from Masset Harbour has the highest concentrations of *n*-alkanes spanning from n-C_9 to n-C_{40} and that a plot of concentration versus n-alkane carbon number (not included) has a classic bell shape with a maximal peak of n-C_{20} and a CPI of 1.08. In consideration of this information, it may be concluded that Masset Harbour was impacted by the input of petroleum hydrocarbons.

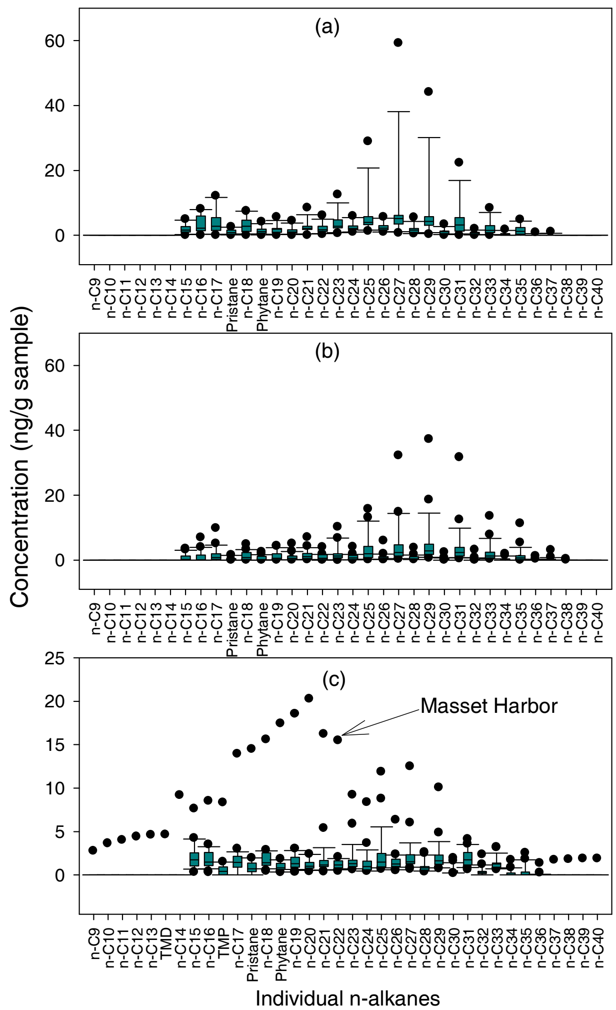

Figure 6: Box plots of *n*-alkanes in three sampling regions. (a), Kitimat Arm; (b), South Douglas Channel; (c), Haida Gwaii.

The biomarkers terpanes and steranes were non-detectable in all sampling sites except for Masset Harbour and Gil Island/York Point. The levels at Masset Harbour were about 10 times the levels of Gil Island/York Point. The evidence suggests that Masset Harbour was impacted by petroleum input. The presence of petroleum biomarkers in Gil Island/York Point, but *n*-alkanes with obvious biogenic input, suggests the contribution of petroleum hydrocarbons from a historic spill.

Occurrence and Source Apportionment of Alkylated PAHs and Non-alkylated PAHs

The comparison of the box-plots of the detected alkylated PAHs (APAHs) in the three sampling regions shows a similar distribution profile for almost all the samples except for the one from Masset Harbour (Figure 7). Very low concentrations of APAHs were detected in all these sampling sites. The analysis of the composition profile of APAHs shows that the non-alkylated PAH congeners are more abundant than their homologues with higher degree of alkylation in most of the APAH families. This is the typically pyrogenic character of PAHs (Wang et al., 1994).

In Masset Harbour, all APAH congeners were detected (Figure 7). Among them, C_i-FL, especially for C_0-FL, are the most abundant components; followed by C_i-C, and C_i-P; then C_i-B, C_i-F, C_i-N, and C_i-D. Similar to the other samples from this study, the non-alkylated PAH congener at this site was more abundant than their homologues with higher alkylation degree in most of the APAH families, indicating the main pyrogenic input of PAHs (Wang et al., 1994). Based on a review of the information, the direct release of petroleum hydrocarbons was significant in this harbor, while the non-alkylated PAHs are mainly originated from pyrogenic input.

Non-alkylated PAHs are ubiquitous in the environment and generally originate from three main sources, *i.e.*, petrogenic, pyrogenic, and biogenic (Lu et al., 2015). Non-alkylated PAHs shown in Figure 8 demonstrate that their detection frequencies vary with the sampling areas. In Masset Harbour, all target PAHs were detected with the level ranging from 0.5 to 151 ng/g of dry sample. The composition analysis indicates that fluoranthene and pyrene have the highest abundance, followed by BbF, BaP, IcdP, and BghiP. It is clear that 3-6 rings non-alkylated PAHs are more abundant compared to 2- to some of 3-ring congeners in this site. The contamination of these non-alkylated PAHs is significantly higher than all the other sampling sites in the present study, further suggesting this specific harbor has been impacted by human activity.

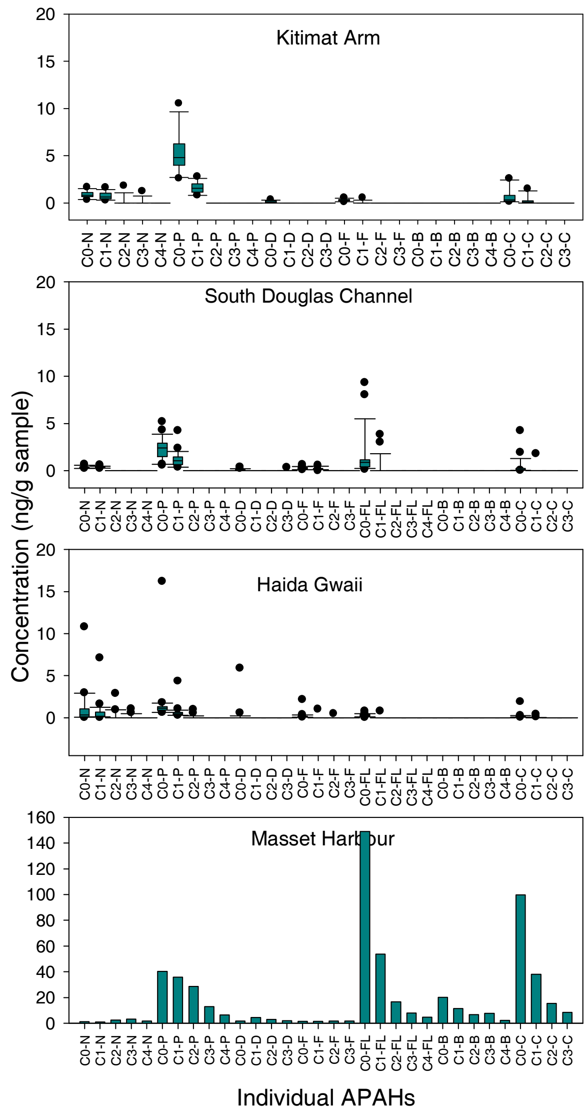

Figure 7: Box plots of APAHs in three sampling areas and their distribution profile in Masset Harbour.

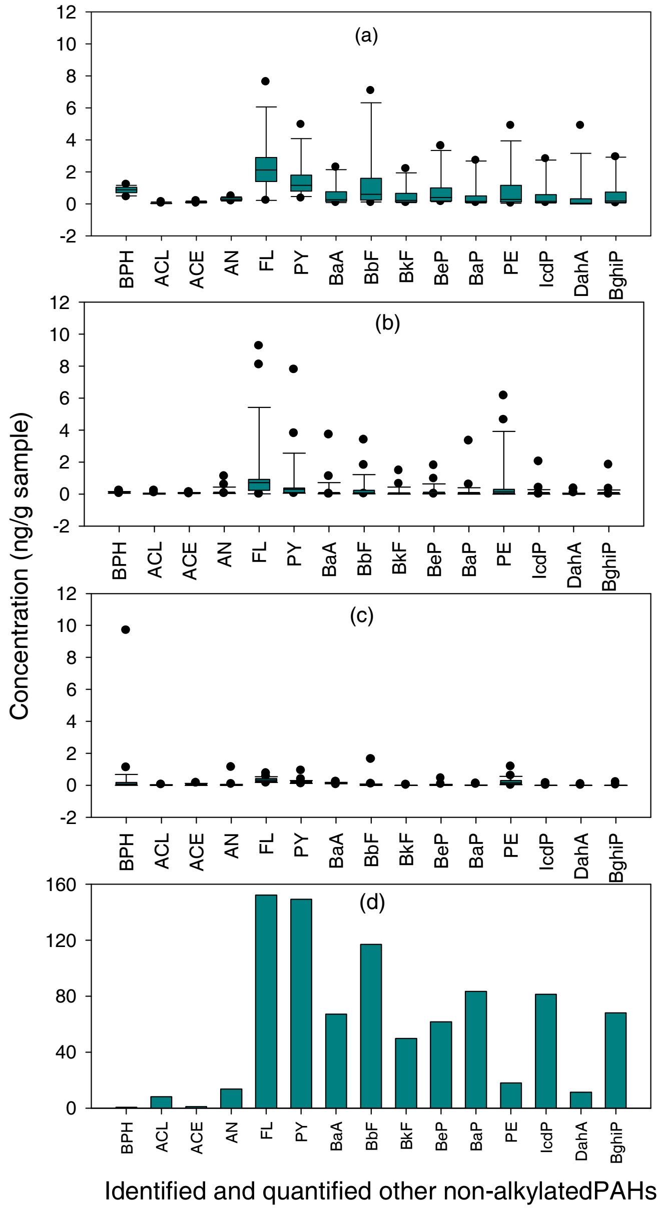

Figure 8: Box plots of other non-alkylated PAHs in three sampling regions and their distribution profile in Masset Harbour. (a), Kitimat Arm; (b), South Douglas Channel; (c), Haida Gwaii; (d), Masset Harbour.

8 Conclusion

A scientific review was undertaken and highlighted a lack of data on the baseline environmental characteristics of the coastline in the northern part of BC. This gap would pose a challenge for oil spill response decision-makers having to address potential shoreline impacts and treatment. Over a 3-year period from 2013 to 2015, ECCC led a project to collect and catalogue an extensive set of baseline data along the coast of northern BC. The project included three field campaigns to shorelines throughout northern BC by a multidisciplinary team of scientists. The team compiled baseline physical, geographic, biological, and chemical data for the convenience of planning, response and monitoring activities, and decision-makers to reduce the environmental consequence of an oil spill on shorelines.

Shoreline sediment samples were collected and underwent extensive laboratory testing to characterize physical and chemical properties. This paper presents the petroleum hydrocarbon results as a case study to demonstrate the importance of baseline data to characterize existing pre-spill conditions. Results show that for all the sampling sites, except Masset Harbour, the levels of the detected TPH, n-alkanes and PAHs were low. The detected n-alkanes mainly came from terrestrial plant input. The measured PAHs were mainly sourced from the mixed contribution of liquid fossil fuel and solid fuel combustion. The presence of petroleum biomarkers, but not petroleum n-alkanes and APAHs, in Gil Island/York Point suggested this site was affected by historical petroleum contamination. The sample from Masset Harbour showed the clear presence of petroleum hydrocarbons. Further, the non-alkylated PAH congeners were more abundant than their alkylated congeners, suggesting that the pyrogenic input was the main source for the non-alkylated PAH contamination in this harbor.

Finally, the baseline dataset has been collected for shorelines in northern BC. The current R&D will help to support the protection and restoration of shorelines in the case of a potential oil spill. ECCC is working to develop tools to help the response during an oil spill. In the future, these techniques will be applied to other regions to gather additional shoreline information for planning, response, and applied research purposes.

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