fjord & fish sciences

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Final

2025 Summary Report

Long-Term Environmental Monitoring Program

PREPARED FOR

Prince William Sound Regional Citizens' Advisory Council
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Acronyms and Abbreviations

ANS	Alaska North Slope
BWTF	Ballast Water Treatment Facility
EPA	U.S. Environmental Protection Agency
EVOS	Exxon Valdez Oil Spill
LTEMP	Long-Term Environmental Monitoring Program
NOAA	National Oceanic and Atmospheric Administration
PAHs	Polycyclic aromatic hydrocarbons
PPB (or ng/g)	Parts Per Billion (or nanograms per gram)
PWSRCAC	Prince William Sound Regional Citizens' Advisory Council

1. Abstract

Following the 1989 Exxon Valdez oil spill, concerned citizens and congressional legislation established the Prince William Sound Regional Citizens' Advisory Council (Council). The Council's mission is citizens promoting the environmentally safe operation of the Valdez Marine Terminal and associated oil tanker activities within the spill-affected area. Since 1993, annual monitoring of marine sediments and intertidal blue mussels (*Mytilus trossulus*) has been conducted, focusing on polycyclic aromatic hydrocarbons (PAHs), saturated hydrocarbons, and petroleum geochemical biomarkers essential for oil spill forensics. Sampling sites include areas with current oil tanker activities (e.g., loading, anchoring, transport routes), previously oiled sites from the Exxon Valdez spill, and reference locations with varying hydrocarbon sources.

Over the past 32 years of the Council's Long-Term Environmental Monitoring Program (LTEMP), the data have shown fluctuating hydrocarbon levels in sediments and mussels, with some measurements indicating toxic concentrations. Monitoring in the last two decades has generally recorded low levels of hydrocarbons. However, localized spikes—such as from the 2020 spill at the Valdez Marine Terminal—indicate small-scale oil releases. Low levels of petroleum hydrocarbons, traceable to Alaska North Slope crude oil, have been detected in marine sediments near the Valdez Marine Terminal. However, pyrogenic compounds from combustion processes are also prevalent. In 2025, we see hydrocarbon concentrations in the low parts per trillion in seawater (Total PAHs <20 ng/L), low parts per billion in marine sediments (Total PAHs <250 ng/g dry weight), and low parts per billion in intertidal mussel tissue (<10 ng/g wet weight) in Port Valdez at LTEMP sites. We find that 2025 sediment, tissue, and water concentrations are unlikely to elicit adverse effects when compared with US EPA, international, and independently assessed concentration thresholds that predict toxic effects on marine organisms.

This extensive dataset contains 263,135 chemical data points from sediments, mussels, and seawater (i.e., 249,902 in the sediment/tissue database and 13,233 in the seawater database) collected at numerous remote and rural sites on the traditional lands and waters of the Chugach, Eyak, and Alutiiq/Sugpiaq peoples. This program provides valuable information about temporal trends in petroleum hydrocarbon contamination in the region and baseline data critical for detecting and monitoring lingering contamination, impacts from current activities, and potential future releases. With the breadth and longevity of this dataset, we propose additional analysis and publication in a peer-reviewed scientific manuscript to increase the visibility and utilization of this important work. The LTEMP holds significant potential for further exploration, offering insights into environmental change, hydrocarbon weathering, fate and transport processes, lingering oil, and the biological impacts of hydrocarbons. The utility of the LTEMP in maintaining a robust baseline hydrocarbon database continues to be critical in light of rapid environmental change and continued petroleum pollution risk.

2. Introduction

The Long-Term Environmental Monitoring Program (LTEMP), managed by the Prince William Sound Regional Citizens' Advisory Council (PWSRCAC), is in its 32nd year of monitoring hydrocarbons after the Exxon Valdez oil spill (EVOS) in 1989. Through LTEMP, we aim to determine the sources of hydrocarbons and the potential adverse effects on the ecosystem associated with Alyeska Pipeline Service Company's Valdez Marine Terminal (terminal) and tanker activity. These data have been insightful in understanding the influence of terminal and non-terminal sources of hydrocarbons and environmental factors on hydrocarbon dynamics across Prince William Sound and the Gulf of Alaska.

Hydrocarbons are a highly diverse group of compounds that comprise the bulk of petroleum products, such as crude oil and fuels, and of maritime products, such as hydraulic and motor oils. However, hydrocarbons are also readily created by marine and terrestrial plants, locked up in organic sediments and rocks, and produced by combustion. Hydrocarbons in the environment undergo weathering, including dissolution, evaporation, ultraviolet degradation, and microbial degradation. Weathering changes hydrocarbons' physical and chemical properties, altering their relative abundance, environmental fate, transport, and toxic potential. Polycyclic aromatic hydrocarbons (PAHs) are a group of hydrocarbons in oil with varying numbers of benzene rings that are relatively resistant to degradation and toxic to living organisms. This group of chemicals tends to adsorb rapidly on suspended materials and sediments and accumulate in biological tissues once released into the marine environment.

As a group, PAHs comprise hundreds of compounds, each with its own degree of toxicity, and their mixtures can exhibit a wide range of toxicities. Specific hydrocarbons, patterns, and diagnostic compounds (i.e., (petro-geo) chemical biomarkers) aid in identifying specific hydrocarbon sources and indicate their weathering history (e.g., degree of weathering, degradation, dissolution). PAH profiles are used to identify petrogenic (of crude oil origin) or pyrogenic (of combustion origin) based on well-established pattern changes (e.g., on the ratio of parent and alkylated compounds). Chemical biomarkers, comprising the hopanes, steranes, terpenes, tri-aromatic, and monoaromatic steroids, are much more resistant to degradation in the environment and thus used to confirm sources (e.g., between different crude oils) even when the PAH patterns are heavily weathered. Saturated hydrocarbons (n-alkanes) are used to identify naturally occurring plant hydrocarbons and determine the degree of weathering and biodegradation.

While aquatic vertebrates such as fish can metabolize PAHs, marine invertebrates, such as Pacific blue mussels, are less efficient at processing these compounds. Mussels remain sedentary in one spot and filter particles from their environment, making them effective natural samplers and indicators of overall environmental PAH exposure (Neff & Burns, 1996). Adverse effects of PAH exposure on aquatic organisms include impaired reproduction, developmental problems, tissue damage, cellular stress, oxidative stress, genetic damage, and death. Although knowledge of the harmful effects of petroleum exposure is extensive, details regarding PAH mixtures, exposure routes, duration, intensity, species and life stages affected, and other environmental factors that may interact are challenging to predict. This underscores the importance of ongoing monitoring efforts by LTEMP.

The ubiquity of hydrocarbons and their sources necessitates the use of multiple matrices to understand their sources, environmental fate, and potential ecotoxicological effects. Marine sediments, which accumulate hydrocarbons, petro-geochemical biomarkers, and saturated hydrocarbons, are appropriate for source analysis and risk assessment. Sources investigated for the present study are those associated with terminal operations, including Alaska North Slope (ANS) crude oil pumped through the trans-Alaska pipeline and loaded into tankers at the terminal. Sessile filter-feeding organisms, such as intertidal blue mussels, reflect chemicals that bioaccumulate in local native biota and can pose ecotoxicological risks. Passive sampling devices measure the dissolved, bioavailable fraction of hydrocarbons, which may pose risks to organisms and ecosystems.

The following study presents the 2025 results from the LTEMP and aims to determine the following:

- The extent, if any, to which the terminal and associated tankers' hydrocarbon fingerprint is present in 2025 samples, with varying ranges from the terminal.
- The potential ecotoxicological risk posed by the measured hydrocarbon contribution from the terminal and tankers.
- The historical trends, ecotoxicological risk, and hydrocarbon fingerprint from mussels collected from extended sampling sites across greater Prince William Sound in 2025.
- The ecotoxicological relevance of these results, given other factors (e.g., environmental or anthropogenic) that may influence the presence and composition of hydrocarbons in 2025 samples.
- Recommendations for future monitoring of petroleum hydrocarbons at the terminal and in Prince William Sound.

3. Briefly, The Methods

Sediment, passive sampling device, and Pacific blue mussel tissue samples were collected in late May of 2025 from annual monitoring stations in Port Valdez. The sampling program investigated three matrices: sediment, Pacific blue mussels, and seawater. Sediments were sampled at Alyeska's Valdez Marine Terminal and Gold Creek (Figure 1). Pacific blue mussel samples were taken from four sites around the Port of Valdez with a focus on the terminal – Alyeska's Valdez Marine Terminal (also referred to as Saw Island), Jackson Point, Gold

Creek, and Valdez Small Boat Harbor entrance (RED - a site that is chemically different from the ANS terminal source signature and currently acts as a high human use, non-ANS reference site). Water was sampled with passive sampling devices at three sites in 2025 — Gold Creek, Jackson Point, and the terminal/Saw Island. Sampling was replicated using triplicates collected from each site across each matrix with three sediment grabs, three composite blue mussel samples, and three composite passive sampling device samples.

Samples were analyzed for PAHs, saturated hydrocarbons, and geochemical petroleum biomarkers using advanced analytical techniques at Pace Analytical Services in Mansfield, Massachusetts (sediments and tissues), and the Oregon State University Food Safety and Environmental Stewardship lab in Corvallis, Oregon (passive sampler, PAHs only). These are the same laboratories that have participated in the LTEMP effort for the last nine years. Briefly, the results continue to be of acceptable precision and accuracy and can be compared to previous years' data. The physical characteristics of sediments were also reported in laboratory results, though they are not presented herein.

Many compounds, especially in the mussel tissues, were below or near the analytical methods detection limit, or were not detected in the sample. Sediment and mussel tissue concentrations are plotted and discussed as a sum of multiple PAHs (sum PAH) either by

Figure 1. Long-Term Environmental Monitoring Program sites from the 2025 campaign in Port Valdez. The color of the points represents differences in sampling matrices at each site.

dry weight or wet weight, and corrected by factors influencing bioavailability, like total organic carbon in sediments or lipid content in mussel tissues. Passive sampling device concentrations have been converted by the analytical lab into the dissolved-phase water concentration, C-free concentration. By converting the concentration units, comparisons can be made across other studies, areas, and ecotoxicological effect thresholds. Concentrations below the method level of detection threshold were provided by the lab as an estimate. These estimated concentrations were plotted on PAH profile figures and included in sum calculations; compounds that were not detected in a sample or were biased by laboratory issues (i.e., matrix interference) were not included in the sum calculations. Forensic interpretation was done using analyte profile pattern comparisons for ANS crude for geochemical petroleum biomarkers in sediment samples. Blue mussels and passive sampling devices tentative forensic assertions were made by qualitative ratios of parent to alkylated compounds, and low and high molecular weight PAH compounds. Analytical results and calculations for all samples and all analytes, pattern profiles, forensic ratios, and laboratory blanks are presented in the Technical Summary (Fjord & Fish, 2025) to support the assertions made in this summary report.

4. Results & Discussion

4.1. Subtidal Marine Sediments

Hydrocarbons were detected in all sediments sampled at the terminal and Gold Creek sites in the low parts per billion range (ppb or ng/g). One (1) ng/g or one ppb can be visualized as the concentration of 50 drops in an Olympic-sized swimming pool. In 2025, the highest sum (∑) PAH concentrations were found at the terminal (250 ± 212 ng/g dry weight) compared to Gold Creek sediment (36 ± 10 ng/g dry weight; Figure 2). Parent and alkylated 2 ring dibenzothiophenes, 3-ring naphthalenes, phenanthrenes/anthracenes, 4-ring fluoranthenes/pyrenes made up the bulk of PAHs at the terminal in 2025 (Figure 3). At Gold Creek, similar compounds made up the bulk of detectable PAHs but with greater contribution from naphthalenes and parent PAHs generally. Greater variability in PAH analytes from the terminal sediments indicates a heterogeneous distribution, likely reflecting the distance of grab samples from the outfall pipe. For comparison, PAH concentrations across both Port Valdez sites are lower than those reported in Norwegian fjords, Novia Scotia small boat harbors, and the Baltic Sea (Oen et al., 2006; Davis et al., 2018; Pikkarainen, 2010). Present Port Valdez concentrations were more similar to those reported from sediments of Cook Inlet and St. Paul Island, Alaska (Nesvacil et al., 2016).

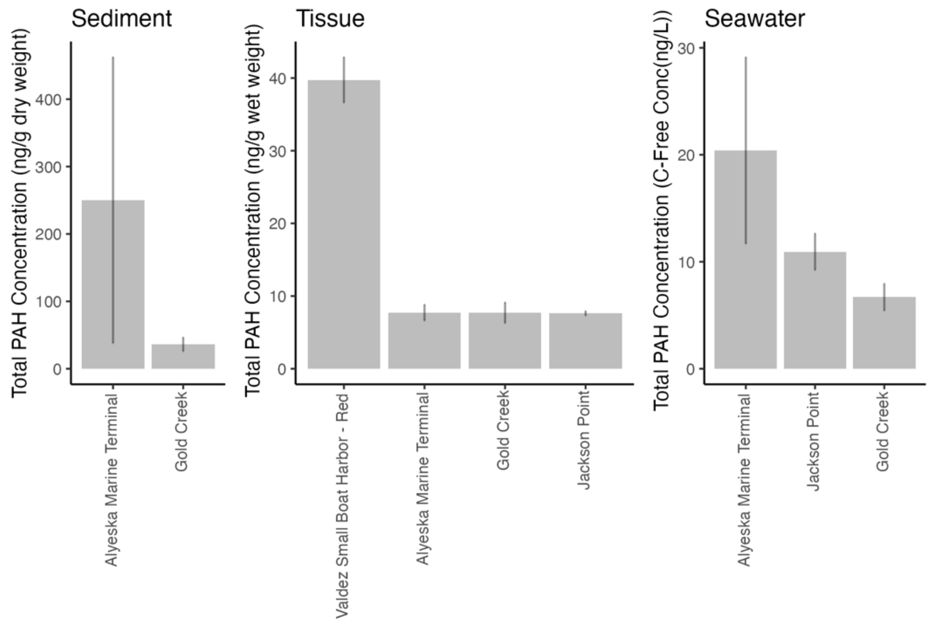

Figure 2. Sum PAH concentrations for 2025 sediments, Pacific blue mussel tissues, and water sampled via passive sampling devices by site plotted at the mean ± 1 standard deviation. Note the unit difference between matrices (i.e., parts per billion for sediments and mussel tissues, and parts per trillion for passive sampling devices).

4.1.1. Sediments - Ecotoxicological Interpretation

In 2025, individual and total PAH concentrations in sediment at the terminal and Gold Creek sites pose little to no risk, either acute or chronic, for marine organisms, with all concentrations at least ten times lower than U.S. Environmental Protection Agency (EPA) sediment quality PAH benchmarks for aquatic life. Specifically, this assessment used the Equilibrium Partitioning Sediment Benchmarks for PAH Mixtures (EPA, 2003) with organic carbon–corrected concentrations. Measured concentrations are also below protective regulatory thresholds in other countries, such as Norway (Bakke et al., 2010). While these benchmarks might not fully reflect the benthic communities adapted to Port Valdez's cold, sediment-rich waters, previous monitoring around the terminal has shown little to no change in benthic communities despite varying PAH concentrations (Shaw & Blanchard, 2021). The sediment's total organic carbon content is low (0.4–0.5%), indicating higher bioavailability of PAHs to marine life. Though high molecular weight PAHs are detected—particularly at the terminal—their concentrations do not surpass any protective benchmarks. Carcinogenic PAHs are present at low levels at both sites.

4.1.2. Sediments - Site-Specific Source Identification

The hydrocarbons in the 2025 terminal sediments are determined to be derived from ANS crude oil. Biomarker patterns closely match ANS crude oil; however, PAH profiles indicated ANS crude with other sources, as high molecular weight PAHs with greater than four rings were overrepresented compared to the ANS standard. The diagnostic biomarkers and their ratios confirm ANS crude oil as the source of hydrocarbons at the terminal. Additional hydrocarbons from non-ANS sources are present in the Ballast Water Treatment Facility (BWTF) effluent, contributing to the PAH profile and the elevated sum PAH concentration. The ratios of several PAHs differed between the terminal and Gold Creek, suggesting some petrogenic sources at the terminal compared to more pyrogenic and weathered sources at Gold Creek.

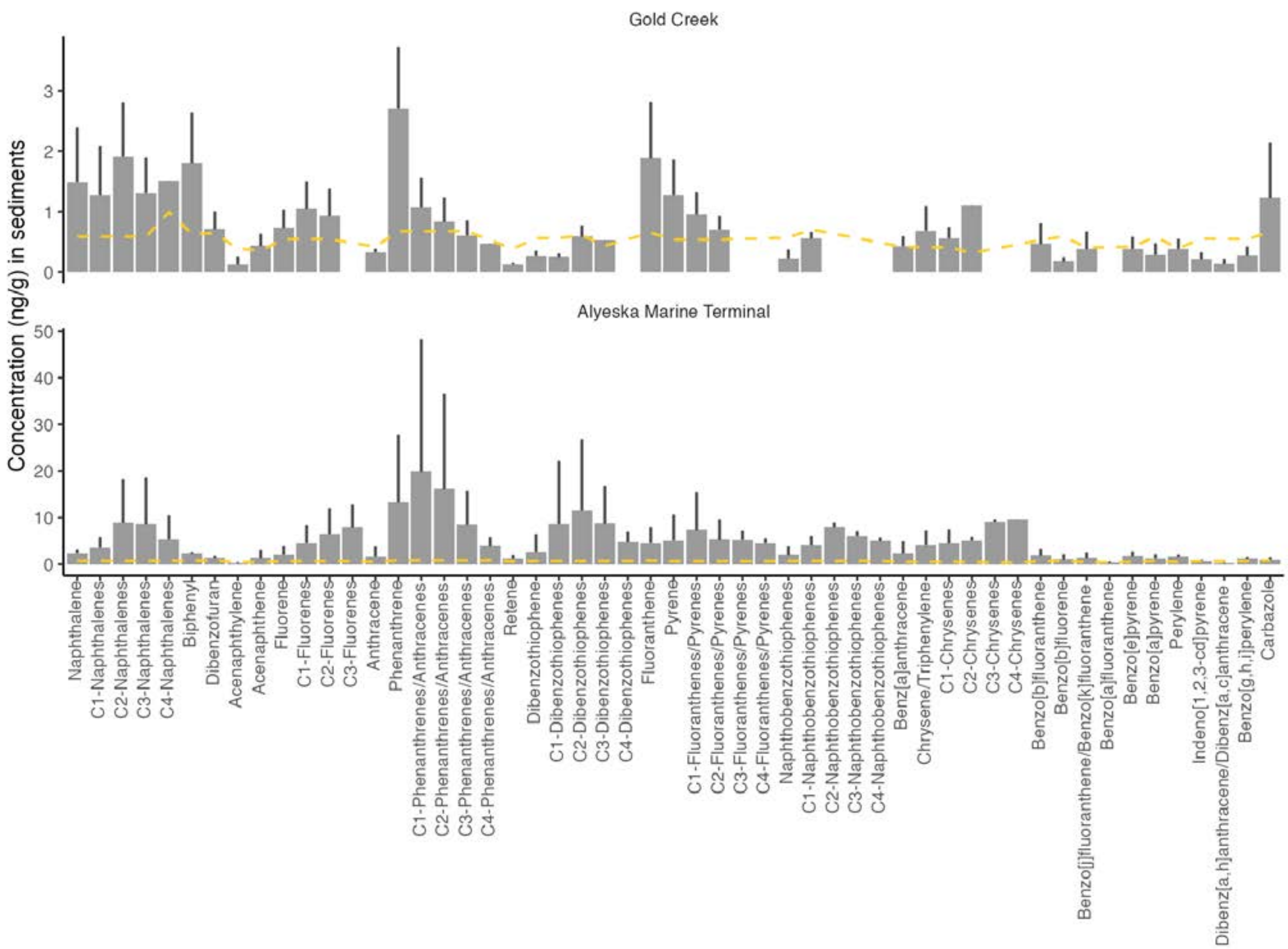

Figure 3. 2025 PAH profiles from sediments sampled at Gold Creek and the Valdez Marine Terminal site plotted as the mean ± 1 standard deviation for the three replicate samples. A dashed, yellow line indicated the analyte-specific method detection limit. Note the difference in scale between the two panels.

Diagnostic ratios point to wood combustion and petrol emissions sources. Saturated hydrocarbons at both sites reveal strong microbial degradation and weathering of the hydrocarbons, leaving the higher molecular weight saturated compounds (and, in some cases, terrestrial plant wax compounds).

At Gold Creek, chemical biomarkers were sparse compared to those at the terminal; still, petrogenic biomarker traces confirm the oil signal as a distant source. However, the PAH patterns are mixed petrogenic and pyrogenic. Gold Creek sediments are moderately weathered with a near-complete loss of saturated hydrocarbons, except those contributed by terrestrial plants. In summary, hydrocarbon concentrations in the terminal sediments are linked to the terminal activities and are similar to incidents and activities reported in previous LTEMP reports (e.g., BWTF effluent, spills, and combustion) with residues that have undergone environmental degradation and accumulated over time. Gold Creek sediments show lower hydrocarbon levels and fewer constituents, likely indicative of less recent sources.

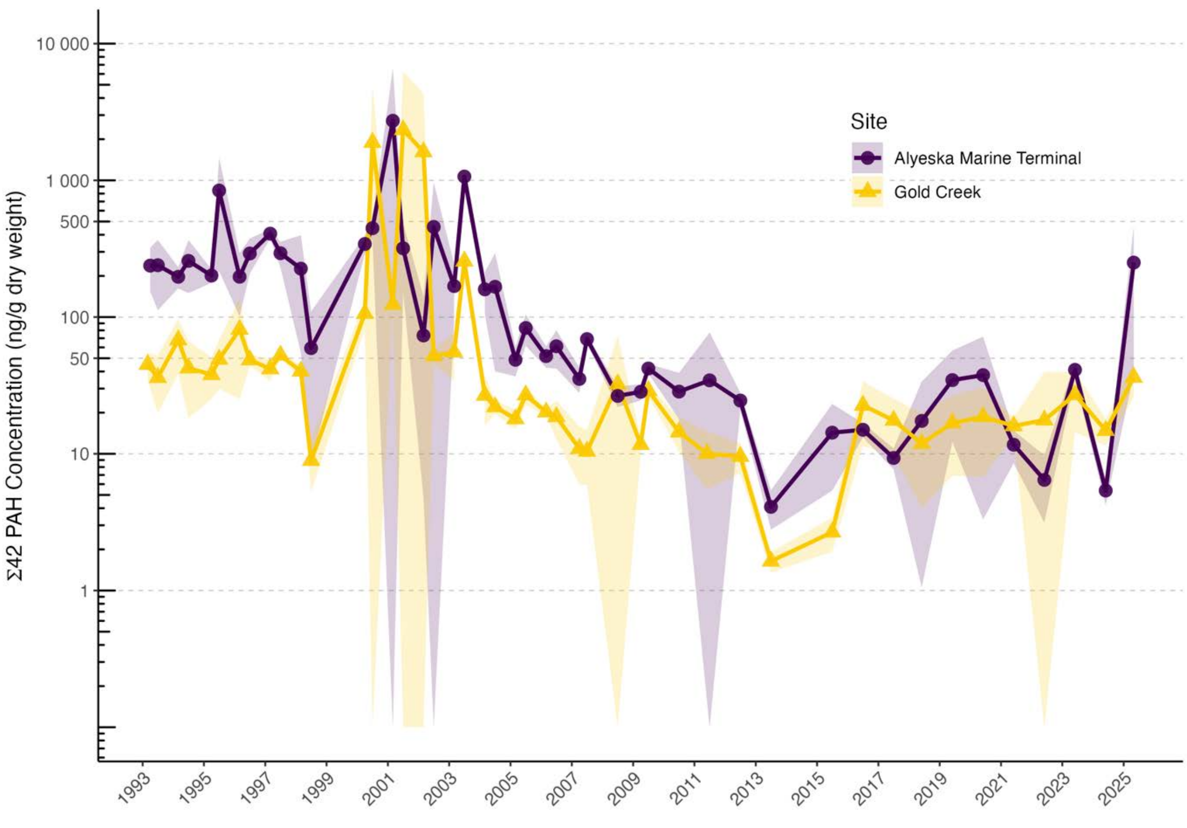

Figure 4. Sum PAH concentrations in sediments over the duration of LTEMP. Colors and shapes indicate the sampling site; mean values ± 1 standard deviation are plotted for each sampling event.

4.1.3. Sediments - Historical Perspective

Hydrocarbon concentrations have varied widely throughout the LTEMP monitoring period from 1993 to the present (Figure 4). The highest sediment PAH concentrations were measured in the early 2000s. Since 2005, hydrocarbon concentrations have remained low. While recent years have seen similar hydrocarbon concentrations between the two sites, the 2025 terminal concentrations were substantially higher than values at Gold Creek or any site in the last 19 years. Terminal sediments have generally contained higher, more variable PAH loads than Gold Creek, although considerable overlap in PAH concentration ranges between the two stations has persisted from 2008-2024.

4.2. Pacific Blue Mussels

PAHs were detected in Pacific blue mussels at low concentrations at all LTEMP sites in 2025 (Figure 2), with low to moderate concentrations measured at the non-ANS positive control site Valdez Small Boat Harbor site (39.7 ± 3.1 ng/g wet weight). Valdez Marine Terminal (i.e., Saw Island), Jackson Point (terminal downstream), and Gold Creek had indistinguishable PAH tissue levels in 2025 (7.6-7.7 ng/g wet weight).

Phenanthrene was the most abundant PAH at LTEMP sites (Figure 5). Most PAHs were at or under detection limits (<1.0 ng/g) at LTEMP sites. When compared to other Alaska marine species in a recent meta-analysis, hydrocarbon tissue concentrations in 2025 mussel measurements are greater than average values in non-mussel invertebrates and seaweed but less than the average values of fish, seals, and whales (Fjord & Fish, 2025b). The 2025 tissue PAH concentrations in Port Valdez are comparable to those found in relatively pristine locations in national parks, national forests, and National Oceanic and Atmospheric Administration (NOAA) Mussel Watch sites around southcentral and southeast Alaska, and well below the high concentrations (>1000 ng/g dry weight (138 ng/g wet weight when using mean conversion factor from LTEMP mussel data)) found in the harbor at Skagway, Alaska (Rider, 2020). Additionally, mussel tissue PAH concentrations were comparable to those measured in pelagic zooplankton in Valdez Arm (Carls et al., 2006) and to mussels caged two kilometers or greater from an oil rig in the North Sea (Sundt et al., 2011). Mussels from the Valdez Small Boat Harbor exceeded NOAA's national long-term monitoring status "Low Concentration" range (0–173 ng/g dry weight (0–24 ng/g wet weight)). At the Valdez Small Boat Harbor, larger PAHs, such as fluoranthene, were more prevalent than at LTEMP standard sites (i.e., terminal upstream and downstream, and Gold Creek). Like the Valdez Small Boat Harbor location, fluoranthene was also the most abundant PAH in mussels in a Norwegian fjord with moderate human activity, where the sum PAH concentrations were comparable to this study (Schøyen et al., 2017).

4.2.1. Mussels - Ecotoxicological Interpretations

At the 2025 tissue concentrations, no adverse biological effects are predicted at the low exposure levels (Bowen et al., 2018). Similar mussel tissue concentrations did not elicit early warning signs for genotoxicity or cellular toxicity in laboratory and field studies (Hylland et al., 2008; Sundt et al., 2011). Sampled mussels did not approach the calculated food safety threshold for bivalves in the European Union nor the U.S. Food and Drug Administration risk criteria levels for vulnerable populations developed after the BP Deepwater Horizon oil spill (Rotkin-Ellman et al., 2012; Shen et al., 2020).

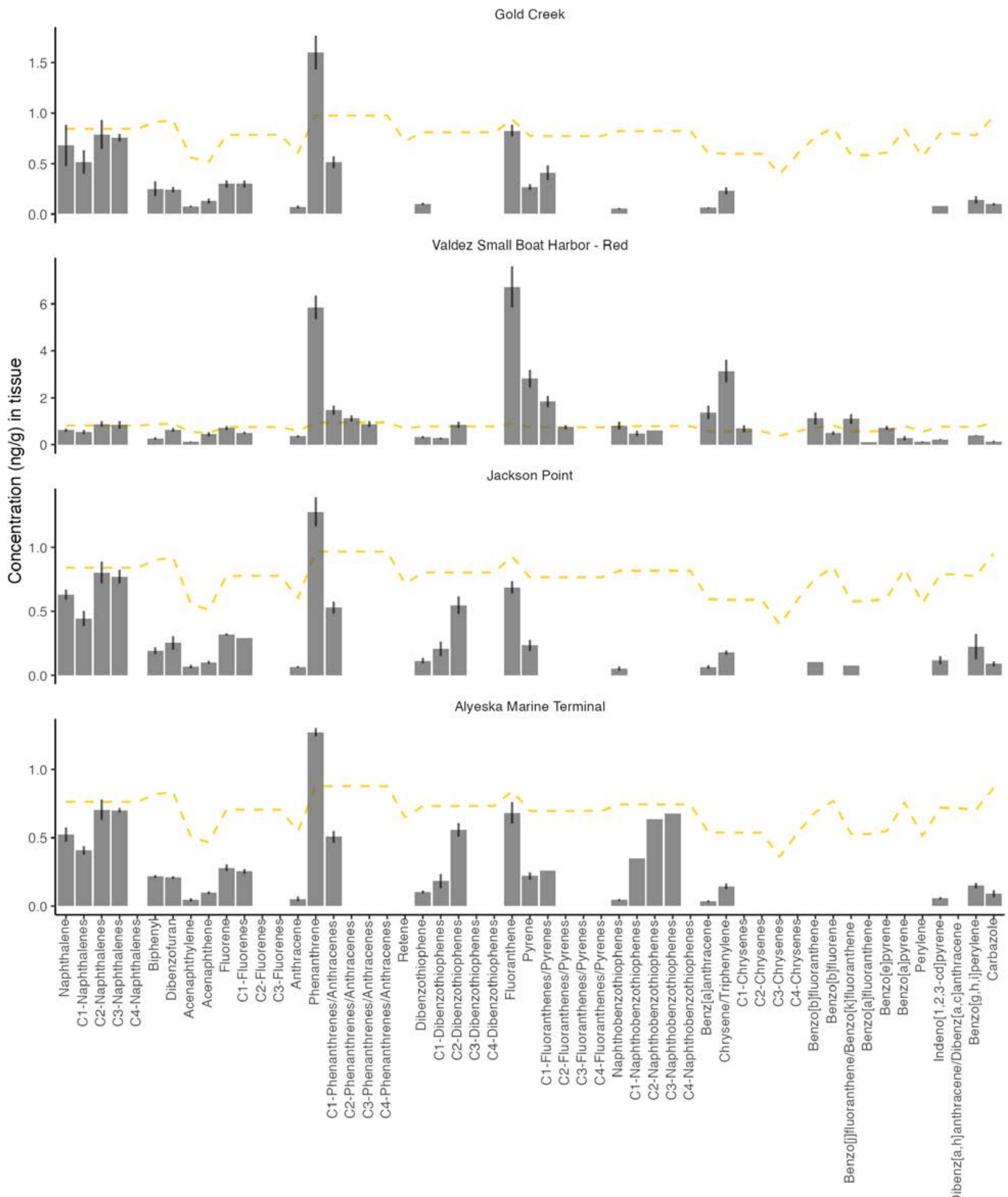

Figure 5. 2025 PAH profiles from Pacific blue mussels plotted as the mean ± 1 standard deviation for the three replicate samples. A dashed, yellow line indicates the analyte-specific method detection limit. Note the difference in y-axis scale between the panels.

4.2.2. Mussels - Site-Specific Source Identification

As tissue hydrocarbon concentrations and chemical compositions are driven by the bioavailability of compounds, environmental conditions, and physiological, cellular, and molecular processes in the mussels, which govern exposure, uptake, metabolism, and elimination, source identification analysis should be performed cautiously.

In 2025, Gold Creek, Jackson Point, and Valdez Marine Terminal (i.e., Saw Island) mussels exhibited similar PAH profiles with very few PAHs and petroleum biomarkers detected, indicating low bioavailability of petroleum hydrocarbons. A general comparison of low molecular weight to high molecular weight PAHs reveals petrogenic sources for these sites across all samples, although not specifically ANS origin. Petro-geochemical biomarkers show oil-derived material and microbial degradation of straight-chain alkanes at these sites (Technical Supplement Table 10). Diagnostic ratios of PAHs strongly support pyrogenic, non-ANS sources of hydrocarbons at the Valdez Small Boat Harbor; this site also had the least weathered hydrocarbon input as interpreted by higher saturated hydrocarbon levels compared to other sites.

4.2.3. Mussels - Historical Perspective

Historical trends in Pacific blue mussel tissue PAH concentrations are variable, reflecting known oil spill incidents in 2004 at Gold Creek, and 2017 and April 2020 at the terminal (Figure 7). Within the broader trend, PAH variability and mean tissue concentrations have remained stable since 2003, in the absence of known spills. In non-spill conditions, mussel tissue concentrations have remained below <100 ng/g dry weight, indicating the mussels are likely not under PAH exposure-induced stress. However, high values have been recorded following spill incidents (e.g., 244,000 ng/g wet weight after the April 2020 terminal spill, not shown in Figure 7). The 2025 PAH concentrations in Port Valdez mussel tissues are within the historical range of locations with limited human use and not oiled during the Exxon Valdez oil spill (Boehm et al., 2004). Positive control non-ANS site at the Valdez Small Boat Harbor continues to have elevated PAH levels compared to the standard LTEMP sites.

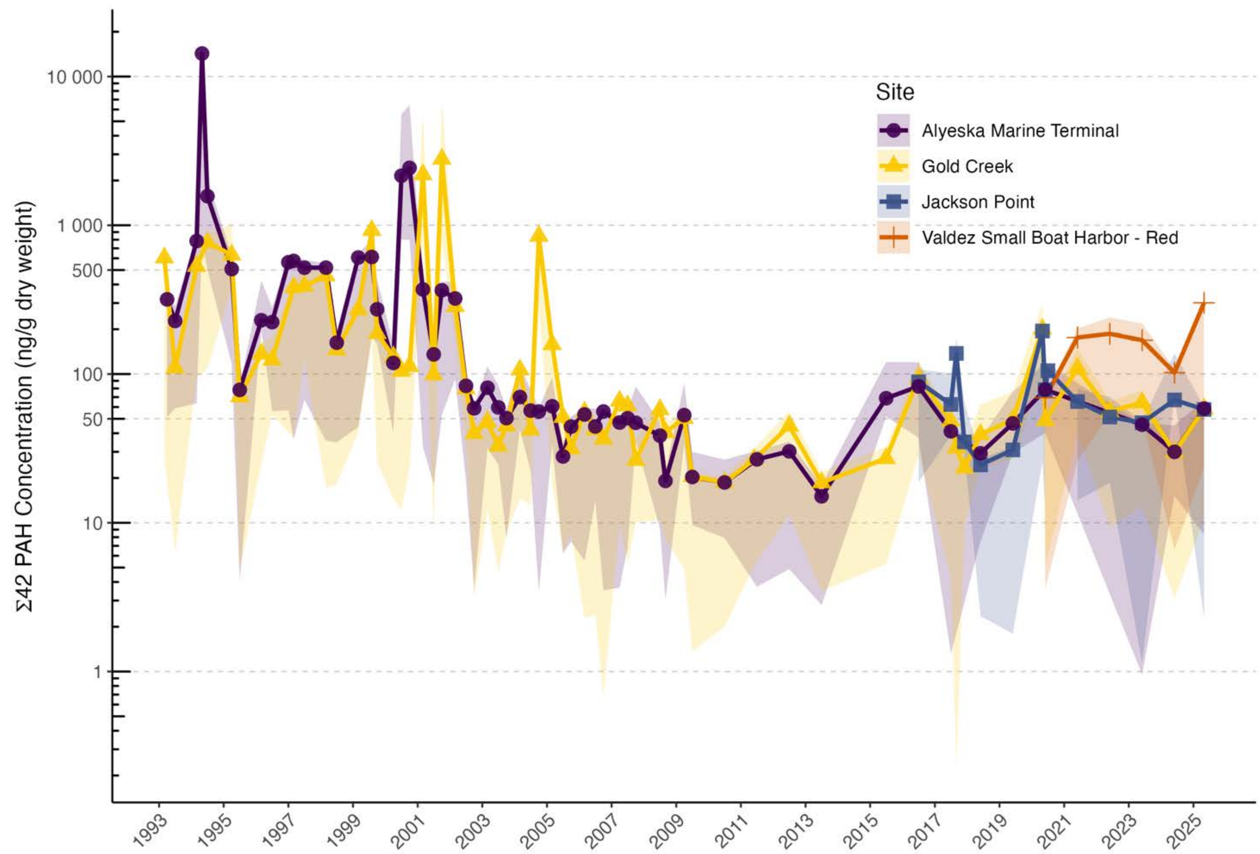

Figure 7. Sum PAH concentrations in Pacific blue mussel tissue over the entire duration of the LTEMP. Colors distinguish sampling sites and mean values are plotted for each sampling event. Values greater than 15,000 ng/g are excluded for clarity.

4.3. Seawater

In 2025, petroleum hydrocarbons were found at low parts per trillion concentrations in all Port Valdez seawater samples (Figure 2, Valdez Marine Terminal/Saw Island (20.4 ± 8.7 ng/L), Gold Creek (6.7 ±1.26 ng/L), and Jackson Point (10.9 ± 1.7 ng/L)). These hydrocarbon concentrations represent the dissolved constituents (C-free) in the subsurface waters where the samplers were deployed for 30 days in the spring. They are not traditional total water concentrations, but in this report, the passive sampling device C-free concentrations are used as a proxy for seawater concentrations of PAHs. These dissolved concentrations represent the bioavailable fraction and can be directly associated with exposure levels for organisms in the water. Passive sampling devices have been successful at predicting the hydrocarbon bioaccumulation in edible tissue of clams (Minick et al 2019).

The typical LTEMP dissolved hydrocarbon pattern of dominating and heavily water-washed naphthalenes was present at all sites and in most replicates (Figure 8). Smaller, 2–3 ring PAHs comprised 97-99% of the sum concentrations, indicating the more readily water-

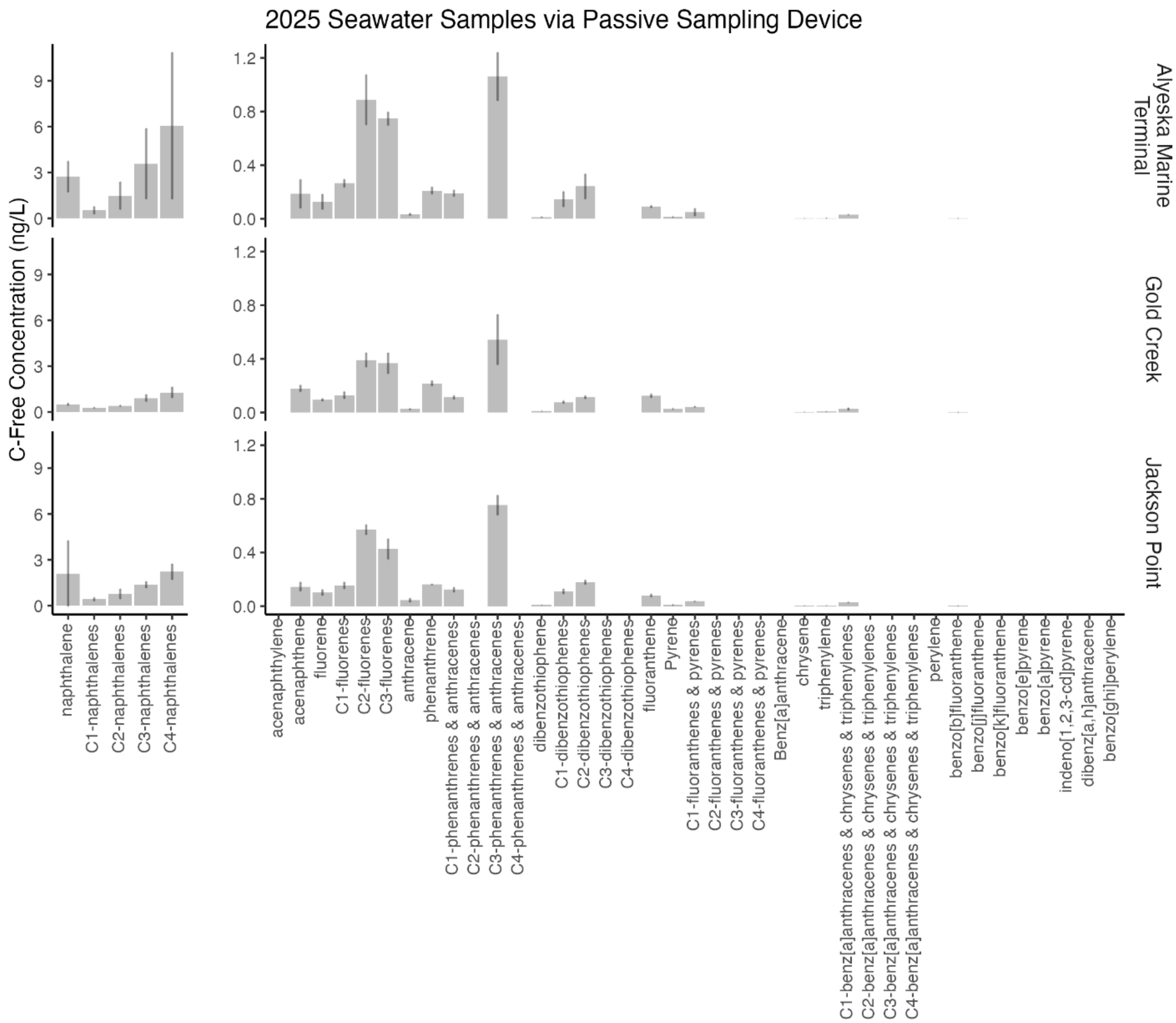

Figure 8. PAH profiles in seawater sampled via passive sampling devices placed at Valdez Marine Terminal, Gold Creek, and Jackson Point in 2025. Values represent mean ± standard deviation for the three replicates. Note the changes in scale between the Naphthalenes on the left and the other PAHs.

soluble fraction. Other PAHs detected at lower concentrations at all sites were fluorenes, fluoranthenes, dibenzothiophenes, phenanthrenes, and anthracenes.

Present dissolved PAH concentrations from the passive sampling devices are comparable to water concentrations at unoiled sites and sites with medium human activity around Prince William Sound (Short et al., 2008; Lindeberg et al., 2017). The present passive sampling device-derived water concentrations in Port Valdez were all at least two to three orders of magnitude below published water quality standards and those of polluted areas across the United States (EPA, 2002).

4.3.1. Seawater - Ecotoxicological Interpretations

Concentrations reported in the Port Valdez subsurface seawater derived by passive sampling devices are below those reported to cause adverse effects even in marine organisms' most sensitive life stages. The 2025 PAH concentrations in the parts per trillion range (i.e., one drop in 20 Olympic-sized swimming pools) are an order of magnitude lower than those reported to cause developmental and delayed effects in herring and salmon early life stages (Incardona et al., 2015). However, no analytical lower limit measured from water or tissues has been identified for developmental cardiac effects in herring (Incardona et al., 2023). Naphthalene, while present at greater concentrations than other PAHs, is of low toxicological concern at present concentrations.

Water quality guidelines set by the U.S. and Canada to represent the lowest observed acute effect concentration are not exceeded by any individual PAH or the sum PAHs (set at 300 ug/L). In 2025, water concentrations did not exceed conservative, protective individual PAH threshold concentrations set for Brazil, British Columbia, Canada, or the United Kingdom (Lourenço et al., 2023), nor the national seawater PAH benchmark comparison performed by Baldwin and colleagues (2024).

4.3.2. Seawater - Site-Specific Source Identification

Seawater primarily reflects petrogenic sources of hydrocarbons with few higher molecular weight PAHs as evidenced using diagnostic ratios. One observation is the prominent naphthalene peak with ascending alkylation, indicative of a water-washed and weathered petrogenic source in all samples. Several samples were also relatively high in the parent naphthalene compound, indicating a fresh hydrocarbon source. Weak pyrogenic signals are present and ratios indicate diesel emissions sources across all sites. Jackson Point seawater does have a slight signature of some pyrogenic sources compared to the other sites.

4.3.3. Seawater - Historical Perspective

2025 marked one of the lowest years on record for seawater hydrocarbon concentrations around the Valdez Marine Terminal and Gold Creek. Differences observed between 2024 and 2025 at the Gold Creek site suggest that a minor hydrocarbon release may have occurred in 2024, such as a small fuel spill from an anchored vessel, as uncharacteristically high concentrations were observed in 2024 and were not sustained. PAH concentrations in passive samplers have remained low since the 2016 inclusion of passive sampling device-derived water concentrations in LTEMP (Figure 9). A peak in PAH levels is observed at the terminal-adjacent site, Jackson Point, following the 2020 terminal spill, supporting the reactivity and reliability of the passive sampling devices. Passive sampler PAH profiles have also remained consistent, with high naphthalene spikes dominating, as noted in previous LTEMP reports (Payne & Driskell, 2021).

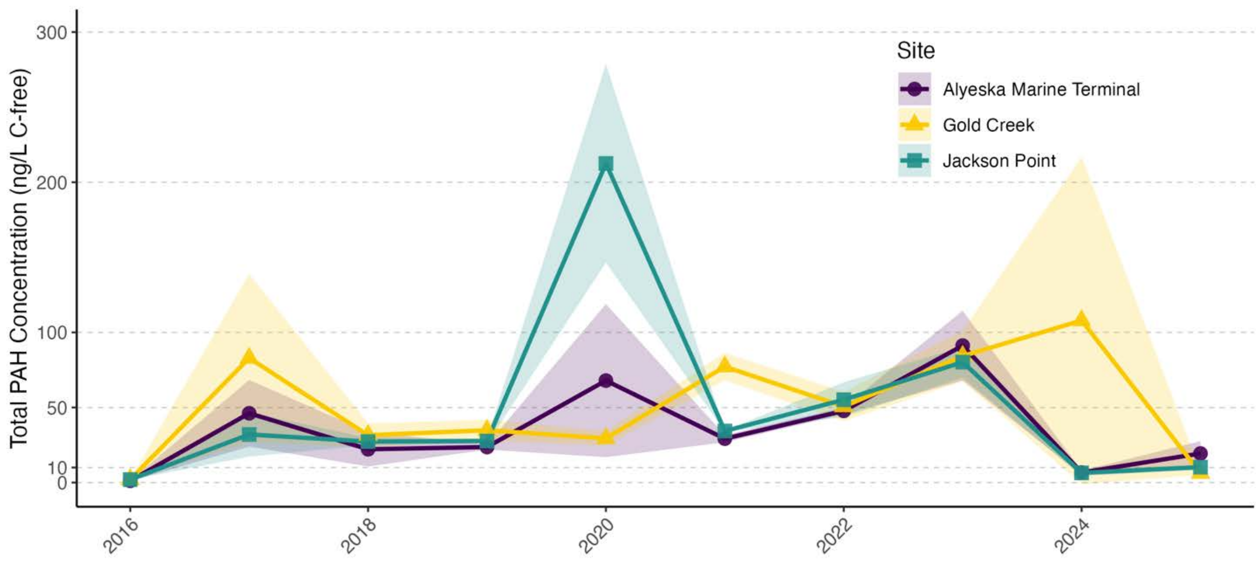

Figure 9. Sum PAH concentrations in seawater derived by passive sampling device at five sites for 2016–2025. Sites are distinguished by color and shape and plotted by mean ± 1 standard deviation. Note that 2016 values only include parent PAHs, no alkylated PAHs were quantified in 2016.

5. Holistic Interpretation

In 2025, we saw agreement on low-level PAHs at similar concentrations across the three standard LTEMP stations in Port Valdez (i.e., Gold Creek, Valdez Marine Terminal, and Jackson Point). While an increase in sum PAH concentrations in sediments was seen at the terminal, which was determined to be of ANS origin, levels are still predicted not to cause adverse effects to marine life. Mussel tissue and seawater PAH concentrations were similar across sites and consistently low at all LTEMP sites in 2025, whereas sediment PAH concentrations were higher and more variable at the terminal. Mussel PAH levels found at the Valdez Small Boat Harbor were higher than those of other stations, confirming this station's status as a pyrogenic, non-ANS positive control site. As each matrix measures a different section of the environmental hydrocarbon load, the differences between matrices likely reflect differences in the accumulation, degradation, elimination, and dispersion of hydrocarbons across the sites.

The ubiquity of hydrocarbons in the environment complicates tracing sources, understanding ecotoxic thresholds, and following dynamics over time and space. Environmental samples, like sediments, can accumulate multiple hydrocarbon sources over time, resulting in a mixed or unresolved profile. Organisms such as blue mussels can accumulate, eliminate, or alter hydrocarbon compounds, complicating the identification of the sources. Passive sampling devices are designed to complement the biological and toxicological interpretations by measuring just the dissolved compounds available to aquatic organisms (i.e., the bioavailable fraction) but are not well suited for hydrocarbon forensics. The forensic agreement between the 2025 samples is a mixed source, largely petrogenic signal. This is consistent with the forensic determinations made in the last 5 years. Again, strong pyrogenic and mixed sources contribute to blue mussel hydrocarbon profiles at the Valdez Small Boat Harbor.

The ecotoxicological risk to organisms from the hydrocarbon levels present in the sediments, mussel tissue, and dissolved in the water from 2025 was low. Previous work focusing on how low levels of hydrocarbon exposure can influence ecologically and commercially important fish species in Prince William Sound has found profound effects on heart development (Incardona et al., 2021). Recent herring research reveals that analytical chemistry with detection levels in the sub parts per billion level (ng/g) is not sensitive enough to distinguish between exposure and background concentrations in water or embryo tissue even when crude oil-induced effects on heart development and PAH-induced enzymatic response were detected (Incardona et al., 2023). Instead, enzymatic induction related to nominal crude oil exposure (e.g., CYP1A induction) is directly related to cardiac deformities in herring. It may provide a more sensitive assessment of injury at the low end of PAH exposure levels (Incardona et al., 2023).

6. Future Perspective

Frequent reanalysis of LTEMP's aims and methodology is necessary to maintain the utility of such a robust monitoring program even in its 32nd year. While maintaining the program's integrity with the three matrix approaches, efforts must be taken to ensure that future monitoring and reporting are conducted to guarantee comparability to previous analyses and utility for future projects. A review of contemporary hydrocarbon biomonitoring study designs confirms the validity of using multiple matrices, including intertidal mussels (Kasiotis & Emmanouil, 2015), sediments, and passive sampling devices with a suite of hydrocarbon (e.g., beyond the 16 EPA parent PAHs), petro-geochemical markers for more definitive forensic determination. These matrices are suitable for trend- and problem-oriented monitoring, the two main objectives of LTEMP (Beyer et al., 2017).

The following represents a list of potential future directions recommended to increase the reach, longevity, and importance of LTEMP work. Note that the 2025 suggestions do not directly address monitoring study design but rather invite comments from the wider public and scientific audience through increased dissemination.

Increase project visibility

1. **Draft a scientific manuscript**
Pursue scientific publishing for greater visibility and utilization of LTEMP data; following the January 2025 poster presentation at the Alaska Marine Science Symposium. Additional analysis would be included in this peer-reviewed manuscript, including investigating contaminant trends using environmental data and size and lipid content of mussels (Ek et al 2021).

2. **Archive data**
Continue to work with data librarians at the National Center for Ecological Analysis & Synthesis (NCEAS) and the Alaska Ocean Observing System (AOOS) for external data management and archival.

3. **Improve program dissemination**
Address broader community concern for local pollution issues using alternative dissemination methods (e.g., short explainer video, updates to the PWSRCAC LTEMP website, popular science articles, participating at community events like the Prince William Sound Natural History Symposium, attending and presenting at relevant conferences, creating educational content). Community needs identified through these outreach projects could be integrated with LTEMP data interpretation and future sampling programs.

7. Conclusion

In the 32nd year of the LTEMP run by PWSRCAC, concentration, source, and potential ecotoxicological effects of hydrocarbons were assessed in bulk marine subtidal sediments, Pacific blue mussels, and dissolved in the nearshore waters via passive sampling devices. The hydrocarbon fingerprints in the 2025 samples vary by site, with those at or near the Valdez Marine Terminal revealing ANS crude and its associated products as the primary hydrocarbon source. Hydrocarbons found in Pacific blue mussels from Gold Creek, and the Valdez Small Boat Harbor cannot be linked directly to the terminal operations. However, these samples revealed various sources, including petroleum and combusted petroleum products. Low potential environmental and toxicological risk is posed by hydrocarbons contributed by the terminal and tankers in 2025. Passive sampling devices continue to report low levels of bioavailable hydrocarbons in the water column within Port Valdez.

Since 1993, hydrocarbon concentrations in Prince William Sound have been generally low, with localized spikes corresponding to events like the April 2020 oil spill at the terminal. Following an all-time low in the mid-2010s, hydrocarbon concentrations in sediments and mussels have slowly increased across all sites. However, they are still below any threshold for adverse effects on aquatic life. The utility of the LTEMP in maintaining a robust baseline hydrocarbon database continues to be critical in light of rapid environmental change and continued petroleum pollution risk.

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