2018 SALISH SEA
TOXICS MONITORING SYNTHESIS

a selection of research

PSEMP

Puget Sound Ecosystem Monitoring Program


The Salish Sea
& Surrounding Basin
The Salish Sea extends from the north end of the Strait of Georgia to the south end of the Puget Sound and west to the mouth of the Strait of Juan de Fuca
Mt. Waddington
Monmouth Mountain
Desolation Sound
Squamish River
Basin Boundary
N. Gulf Islands
Strait of Georgia
Vancouver Island
Fraser River
S. Gulf Islands
Mt. Baker
Skagit River
San Juan Islands
Cape Flattery
Strait of Juan de Fuca
Glacier Peak
Pacific Ocean
Olympic Peninsula
Puget Sound
Hood Canal
Nisqually River
Mt. Rainier
N
0 50 100 km.
0 50 mi.
Data Sources:
SRTM (CGIAR-CSI), NOAA, Wa. DFW, Wa. DNR, BC Digital Atlas, ESRI
stefan freelan - 2009
http://staff.wwu.edu/stefan/SalishSea.htm

ACRONYMS AND ABBREVIATIONS

Terms

AVS . . . . . . Acid Volatile Sulfides
BB . . . . Bellingham Bay
BIBI . . . . . . benthic index of biotic integrity
BMP . . . . . . best management practices
BSM . . . . . . Bioretention soil media
CABS . . . . . compost-amended biofiltration swales
CB . . . . Commencement Bay
CEC . . . . . . Contaminants of Emerging Concern
CSO . . . . . . Combined Sewer Overflow
CTWP. . . . . creosote-treated wood pilings
DDT . . . . . . Dichlorodiphenyltrichloroethane
DEET . . . . . Diethyltoluamide
EDCs . . . . . Endocrine Disrupting Compounds
eDNA . . . . . environmental DNA
ELISA . . . . . enzyme-linked immunosorbent assays
FTIR . . . . . . Fourier Transform Infrared Spectrometer
GIS. . . . . . . geographic information system
GSI. . . . . . . green stormwater infrastructure
HCBD . . . . . Hexachlorobutadiene
HLB . . . . . . hydrophilic-lipophilic-balanced
HRMS . . . . . high resolution mass spectrometry
LDW. . . . . . Lower Duwamish Waterway
LID . . . . . . Low impact development
MP . . . . Microplastics
NGO. . . . . . non-governmental organization
OC . . . . Organic carbon
OPEO . . . . . octylphenol ethoxylates
PAH . . . . . . Polycyclic aromatic hydrocarbons
PB . . . . procedural blank
PBDE . . . . . Polybrominated diphenyl ethers
PBT . . . . . . Persistent Bioaccumulative and Toxic contaminants
PCA . . . . . . principal component analysis
PCB . . . . . . Polychlorinated biphenyls
PCP . . . . . . Pentachlorophenol
PEG . . . . . . polyethylene glycols
PES. . . . . . . Polyethersulfone
PFAS. . . . . . per- and poly-fluoroalkyl substances
PFOS . . . . . Perfluorooctane sulfonate
POCIS. . . . . Polar Organic Chemical Integrative Samplers
POPs. . . . . . Persistent Organic Pollutants
PPCP . . . . . Pharmaceuticals and Personal Care Products
PPG . . . . . . polypropylene glycols
RoR . . . . . . Run of the River dams
SMS . . . . . . Sediment Management Standards
SOG . . . . . . Strait of Georgia
SPMD . . . . . semi-permeable membrane devices
SQS . . . . . . Sediment Quality Standards
SRKW . . . . . Southern Resident killer whales
SSRIs. . . . . . selective serotonin reuptake inhibitors
SWMMWW . Stormwater Management Manual for Western WA
TCEP . . . . . tris-(2-chloroethyl) phosphate
TCP . . . . . . Toxics cleanup program
TEQ . . . . . . toxic equivalency quotient
TM. . . . . . . toxic metals
TOC . . . . . . Total organic carbon
TSS. . . . . . . total suspended solids
UGA . . . . . . Urban growth area
WAMSQS . . . Washington State marine sediment quality standards
WWTP . . . . Wastewater Treatment Plant

Programs and agencies

BBAMP . . . . Boundary Bay Ambient Monitoring Program
BWG. . . . . . Bioretention Work Group
CWA . . . . . Clean Water Act
DMMP . . . . Dredged Material Management Program
Ecology . . . . Washington State Department of Ecology
ENVVEST . . Environmental Investment project for Sinclair and Dyes
EPA . . . . . . U.S. Environmental Protection Agency
KC DNRP. . . King County Department of Natural Resources and Parks
KCEL . . . . . King County Environmental Lab
NBK . . . . . . Naval Base Kitsap
NMFS . . . . . National Marine Fisheries Service (NOAA)
NOAA . . . . National Oceanic and Atmospheric Administration
NPDES . . . . National Pollutant Discharge Elimination System
NWFSC. . . . Northwest Fisheries Science Center (NOAA)
ORCA . . . . . Ocean Research College Academy at Everett Community College
PNNL . . . . . Pacific Northwest National Laboratory
PSDDA . . . . Puget Sound Dredged Disposal Analysis program
PSNS & IMF . Puget Sound Naval Shipyard and Intermediate Maintenance Facility
PSSST . . . . . Puget Sound Stormwater Science Team
RSMP . . . . . Regional Stormwater Monitoring Program (currently called SAM)
SAM . . . . . . Stormwater Action Monitoring (previously called RSMP)
SFU . . . . . . Simon Fraser University
SPAWAR . . . Space and Naval Warfare Systems Command
TBiOS . . . . . WDFW's Toxics-focused Biological Observation System
UBC . . . . . . University of British Columbia
USFWS . . . . U.S. Fish and Wildlife Service
USGS . . . . . United States Geological Survey
UW . . . . . . University of Washington
UW CEE . . . UW Civil & Environmental Engineering
UWT CUW. . UW Tacoma Center for Urban Waters
UWT SIAS . . UW Tacoma School of Interdisciplinary Arts and Sciences
WDFW . . . . Washington Department of Fish and Wildlife
WDNR . . . . Washington Department of Natural Resources
WDOH . . . . Washington Department of Health
WSC . . . . . . Washington Stormwater Center
WSDA . . . . . Washington State Department of Agriculture
WSDOT. . . . Washington State Department of Transportation
WSU . . . . . . Washington State University

ACKNOWLEDGEMENT AND CREDITS

This document is the second of what will be a series of updates providing information on the status of toxics monitoring in Salish Sea. It represents a collaborative effort of investigators from over twenty agencies in the greater Salish Sea watershed. We appreciate the time and effort that was provided.

Contributing organizations

Disclaimer

The data and interpretations in the contributions were prepared by the associated authors and organizations based on their ongoing research and investigations. They do not necessarily reflect the views or policies of the editors or the editors' organizations. Support for some of this effort has been provided by the United States Environmental Protection Agency (EPA). As such, it is important to note that the content of this document does not necessarily reflect the views and policies of the EPA. Finally, the mention of trade names or commercial products should not be taken as an endorsement or recommendation. In addition, we would like to point out that this document is not a comprehensive synthesis of the entirety of the contaminant-related monitoring or research in the Salish Sea. The Puget Sound Ecosystem Monitoring Program Toxics Workgroup continues to strive to cast an ever-widening net to bring together as much of the region's toxics work as possible.

Puget Sound Ecosystem Monitoring Program (PSEMP)

This effort was organized through the Puget Sound Ecosystem Monitoring Program Toxics Workgroup. The Toxics Workgroup focuses on improving toxics-related monitoring in the region by encouraging coordination and collaboration, identifying priorities and gaps, and increasing the knowledge and understanding. The group meets bi-monthly.

More information can be found at: https://rebrand.ly/psemp-toxics

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Publication design: Kris Symer, Puget Sound Institute, University of Washington Tacoma.

Recommended citation

PSEMP Toxics Work Group. 2019. 2018 Salish Sea Toxics Monitoring Synthesis: A Selection of Research. C.A. James, R. Jordan, M. Langness, J. Lanksbury, D. Lester, S. O'Neill, K. Song, and C. Sullivan, eds. Puget Sound Ecosystem Monitoring Program. Tacoma, WA. https://www.eopugetsound.org/articles/2018-salish-sea-toxics-monitoring-synthesis

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INTRODUCTION

The first Toxics Monitoring Review was published by the PSEMP in 2016 with the intent of presenting an overview of toxics-related research and monitoring activities in the Salish Sea (PSEMP Toxics Workgroup, 2017). At that time, we realized the initial effort had not captured the full range of regional investigations, and that a follow up effort was warranted. Using the 2018 Salish Sea Ecosystem Conference as a central event, we decided to undertake a second review and synthesis, which is presented here.

As before, the primary objective is to provide a summary of toxics-related monitoring and research in a single document to 1) communicate the range of efforts currently underway, 2) provide a brief summary of findings to managers and policy makers, and 3) form a basis to develop an inventory of research needs and monitoring gaps.

This review presents a compilation of activities representing the work of over 50 groups in both the United States and Canada. We would like to note our appreciation to the contributors and applaud their dedication to the work.

SECTION 1: STATUS AND TRENDS

SECTION 2: RESEARCH

SECTION 3: MANAGEMENT

This review is organized into three broad categories: status and trends, research, and management. Section 1: "What is happening? (Status and Trends)" includes work that examines the presence, distribution, magnitude, and change through time of contaminants in the Salish Sea ecosystem. Section 2: "What is being learned? (Research)" includes investigations that assess why changes in contaminant levels may be occurring, as well as new methods that may allow us to improve our approaches to assess contaminants. Section 3: "What is being done about it? (Management)" describes efforts that address and remediate toxic contaminants in the environment.

While the range of contributions included in this document certainly is not comprehensive, the information has allowed us to identify some major points, which are highlighted below.

What is happening? (Status and trends)

There are numerous monitoring programs throughout the Salish Sea, and the primary focus of many contaminant monitoring programs is to provide a better understanding of the impacts of man-made chemicals on the environment, track their spatial distribution, and to assess if conditions are improving or declining. Environmental monitoring is adaptively managed; existing programs are modified as methods evolve and trends appear, while new ones are developed in response to changing conditions and the need to investigate new questions. This section provides a snapshot of the programs investigating the status and trends of contaminants throughout the Salish Sea.

Identifying the source of a particular contaminant (or contaminant class) is critical to designing an appropriate cleanup strategy or regulating the source. In some cases, the contaminant source may be known or suspected, and further analysis provides confirmation or improved resolution, as was the case of Hafner et al. in their evaluation of dioxin and furan data in Budd Inlet. In other situations, the source emerges from routine monitoring. This occurred in the work of Carey et al. in which they monitored polybrominated diphenyl ethers (PBDEs) in juvenile Chinook and found a likely source in the Snohomish River.

Several programs utilize various aquatic species to track how contaminants move through the food web. This information is important for measuring direct exposures and estimating the potential for harmful impacts. River otter scat contains persistent organic pollutants (POPs), which allowed Wainstein et al. to utilize a non-invasive monitoring method to track POP levels in these organisms. Higher in the food web, Lundin et al. monitored polycyclic aromatic hydrocarbons (PAHs) in southern resident killer whale scat, concluding that although PAHs were present, they were not at high enough levels to cause harm. Similar to Wainstein et al., this work is non-invasive and provides a mechanism to track PAH exposure, which in this case may have been associated with vessel exhaust, in an endangered species. Other species can provide information on conditions in localized environments, such as embayments or the nearshore. Lanksbury et al. used caged mussels as biomonitors to help identify sources of PAHs to Puget Sound, while demonstrating the efficacy of mussels as a monitoring tool. Mussel tissues from this study were also analyzed by James et al. specifically for Contaminants of Emerging Concern (CECs), and by Spanjer et al. for microplastics.

O'Rourke et al. performed a focused monitoring of fish, crab, and squid off the King County shoreline and found that while polychlorinated biphenyls (PCBs) were generally higher in fish from Elliott Bay, there were important localized differences. They further reported that for rockfish, contaminant burdens appear to increase with age. O'Neill et al. evaluated POP concentrations in resident (Blackmouth) Chinook salmon and found that PCB and PBDE concentrations were generally higher in fish caught in South Puget Sound and observed progressively decreasing levels moving north through the Strait of Juan de Fuca.

In another biomonitoring approach, Ocean Research College Academy students compared metal concentrations in seagrass and sediments from samples collected near Mukilteo and off Whidbey Island. They reported finding evidence of metal accumulation in eelgrass. Finally, Silverthorn et al. were interested in determining if run-of-the-river dams led to increased methylmercury accumulation in American dippers, which feed locally. They concluded that the potential for methylation may be somewhat enhanced in dam environments.

Within the region, several sediment monitoring programs assess chemical trends over time. Eash-Loucks et al. provided an update of King County's decade-long sediment monitoring program in the Puget Sound central basin. The Washington State Department of Ecology (Ecology) Sediment Chemistry Index has been in use for many years, providing a categorization methodology based on sediment monitoring results (Weakland et al.). The Washington State Stormwater Action Monitoring (SAM) program focused on nearshore sediment quality at sites within the Urban Growth boundary. Black et al. presented the first round of sediment chemistry results at 41 SAM sites for metals and organic compounds and concluded that while there are localized areas of contamination, Puget Sound nearshore sediments are relatively clean. Periodically, programs are assessed and evaluated for their effectiveness and to determine if any improvements can be made. Hightower provided an overview of Metro Vancouver's sediment monitoring program in Boundary Bay (British Columbia, Canada).

A suite of studies reported on conditions in regional freshwater lakes and streams, some of which can directly impact Puget Sound through contaminant transport. In the first of two presentations, Colton et al. reported on PCBs in juvenile Chinook and found that concentrations increased moving downstream through the Green-Duwamish system. They also reported on persistent, bioaccumulative, and toxic (PBT) contaminants in fish from Lake Sammamish and Lake Union, Washington, indicating that Lake Union fish were generally more contaminated, warranting a consumption advisory for PCBs and mercury. Mathieu and McCall focused on perfluorinated compounds in fish collected from freshwater lakes and found that: 1) samples from urban lakes had the highest concentrations, and 2) perfluorooctanesulfonic acid (PFOS) was the dominant compound. Nickelson reported on the assessment of pesticides in sediments of freshwater streams and found detectable levels in 30% of locations sampled. Bifenthrin was above assessment criteria at 14% of all sites. Finally, Sheibley et al. reported on biological monitoring approaches for evaluating condition in freshwater streams and showed that levels of zinc (Zn) in sediments were associated with poor conditions.

Continual improvement of monitoring techniques and analyses methods is essential to effectively track ecosystem status and recovery. Some examples include Johnston et al. and Strivens et al. who evaluated the utility of passive sampling devices to monitor a range of contaminants. James et al. have applied high resolution mass spectrometry techniques to broadly monitor organic contaminants in biota.

In addition to the commonly reported environmental contaminants, microplastics received the attention of several groups. Dimitrijevic et al. detected microplastics in mussels and continue to evaluate whether they are useful tools for microplastic monitoring. Masura et al. collected and analyzed water samples from the Puyallup River and found little evidence that wastewater treatment plants (WWTPs) were a source of microplastics to the environment. Bendell et al. and Spanjer et al. reported that microplastics were widespread in sediments collected throughout the Salish Sea with measureable levels present in every sample. Further, Bendell reported that both macro- and microplastics contained high levels of metals, suggesting they may be a vector for metals contamination to regional sediments.

As monitoring programs evolve, so do the methods and tools associated with them. Sources come to light and need to be addressed, new contaminants enter the equation, and more refined and appropriate techniques are developed. This section provides highlights of some of the current monitoring programs throughout the Salish Sea.

Section 2: What is being learned? (Research)

Human development in the Salish Sea region brings with it landscape changes that often lead to inputs of contaminants to marine and fresh waters. These pollutants originate from both nonpoint sources (i.e., runoff from impervious surfaces associated with paved areas and buildings, agricultural inputs and aerosols from car exhaust and wood smoke, etc.), and point sources (i.e., oil spills, industrial and municipal wastewater discharges, etc.). The papers highlighted in this section describe research on contaminants in both the biotic (animals) and abiotic (water and sediments) components of Salish Sea ecosystems. They include investigations of hydrocarbon (e.g., PAH) contamination from creosote, spilled oil, fossil fuel exhaust and wood smoke, studies on well-known persistent chemicals (i.e., PCBs, PBDEs, DDTs, and some metals), and investigations into new CECs found in stormwater runoff and WWTP effluent, including pharmaceuticals and personal care products (PPCPs). The 16 papers in this section are loosely organized into groups related to: elucidation of contaminants in stormwater runoff and their effects on salmon and forage fish, monitoring of CECs in fish, the application of abiotic and passive monitoring devices, assessment of contaminants in water and sediment, and uptake of contaminants by local biota.

Urban stormwater discharge negatively effects the health of the Salish Sea by polluting freshwater and marine aquatic environments, degrading habitat, and contributing to flooding. McIntyre et al. describe how urban stormwater runoff is lethal to adult Coho salmon, which display an acute urban runoff mortality syndrome following rain events in urban streams where they have returned to spawn. They describe hypoxia-like symptoms in exposed Coho but not chum salmon. In tandem, Kolodziej et al. are using high-resolution mass spectrometry to elucidate the chemical composition of urban stormwater runoff and have identified approximately 60 chemicals associated with Coho mortality, many of which are linked to tire-wear particle leachates. As a result, they suggest prioritizing tire-wear particles for detailed fate and toxicity assessments.

Harding et al. demonstrated how Pacific herring (a forage fish and keystone species) exposed to urban stormwater runoff suffer cardiac injury and reduced growth. They postulated that reduced cardiorespiratory fitness, likely a result of exposure to PAHs in stormwater, could result in delayed adverse outcomes for exposed herring. West et al. studied the effects of PAH exposure associated with creosote pilings on Pacific herring embryos and found that the PAH pattern in embryos was similar to the creosote source. Liedtke et al. investigated PCBs in Pacific sand lance, another important forage fish species. They found evidence of bioaccumulation, with larger individuals having higher PCB concentrations than smaller fish, and showed that Pacific sand lance exhibit maternal transfer of PCBs to their eggs.

CECs encompass a broad range of contaminants. They generally enter waterways through sewage discharges, and traces of some PPCPs have been detected in marine and fresh waters of the Salish Sea. Meador et al. investigated the status of CECs in Puget Sound basins that receive WWTP effluent and detected a number of CECs in WWTP effluent, estuary waters, and in juvenile Chinook and staghorn sculpin. They also showed that the exposed fish exhibited altered physiology, which may indicate adverse effects and an increased probability of mortality. Shultz et al. investigated the presence of selective serotonin reuptake inhibitors (SSRIs), a class of drugs typically used as antidepressants. They surveyed eight WWTP effluents for six SSRIs, and performed exposure experiments to assess uptake, metabolism, and effects on trout and English sole. They found that sertraline is extensively metabolized in fishes and is potentially the most harmful of the compounds tested. Using laboratory assays, Jain and Laetz investigated the toxicity of two cardiac-specific medications to embryonic zebrafish. They found that gemfibrozil (a cholesterol drug) may alter fish growth, development, and lipid metabolism.

The next series of papers covers the use of passive and noninvasive sampling methods. Johnston et al. assessed CECs using integrative passive sampling devices to obtain data on impacts from stormwater runoff. They found that this approach was cost-effective and allowed for continuous surveillance of receiving waters. The previously mentioned West et al. study used simple LDPE strip passive samplers as a useful proxy for herring embryos in the field. Hobbs et al. explored the use of organic biofilms as passive samplers to assess sources of toxics in rivers and streams. They found results from organic biofilms to be comparable to results measured in manufactured passive samplers (semi-permeable membrane devices, SPMDs), concluding that biofilms can be an effective tool. Lastly, Olsen and Shawn demonstrated how captive sea otter diet and feces can be tested with enzyme-linked immunosorbent assays (ELISA) kits as an initial monitoring and screening tool. They found that concentrations of PBDEs, PCBs, glyphosate, and pyrethroids were low in seafood diet items and fecal samples from Northern sea otters at the Seattle Aquarium.

The last five papers in this chapter included investigations of contaminants in water and sediment, and the links between water and sediment contamination and effects on aquatic biota. Sun et al. explored the biogeochemical cycling of PBDEs from WWTP effluent in the Strait of Georgia. They discovered that the level of bromination varied with depth, and suggested that as the effluent plume rises, the less-brominated PBDEs are released from sewage particles more rapidly, resulting in an enrichment of more brominated congeners at shallower depths. Kuang et al. studied dispersion and removal of silver and cadmium water in the Strait of Georgia and found that dissolved silver concentrations were lower than expected and WWTP effluent is not a significant point source of silver or cadmium to that water body. Takesue et al. conducted geochemical aging with radionuclides (i.e., beryllium and lead) to distinguish recent versus pre-existing deposition of sediments and contaminants (i.e., PAHs, PBDEs, and metals) in Bellingham and Commencement Bays. Duchet et al. explored the effects of neonicotinoids found in Puget Sound surface waters by exposing freshwater aquatic invertebrate communities to a mixture of neonicotinoids, finding alterations in community structure at low concentrations. Finally, Burd et al. explored the physical and geochemical effects of sediment on uptake of PBDEs into marine sediment feeders, as well as trophic transfer. They found PBDE levels in sediment feeder tissues were elevated near WWTP outfalls and that the variations were best explained by sediment acid volatile sulfide, PBDEs, organic lability, and input. While accumulation in sediment feeders was high, there was little transfer to their predators.

Section 3: What is being done about it? (Management)

There is considerable effort underway in the region to reduce or mitigate the adverse effects of contaminant exposure on Salish Sea biota. Within Puget Sound, recovery plans (referred to as Implementation Strategies (IS)) are currently being developed to reduce the flow of toxic contaminants to fish. As discussed in Bentley and James, the Toxics in Fish (TIF) IS will serve as a recovery plan for achieving the Toxics in Fish Vital Sign goals and targets (http://www.psp.wa.gov/vitalsigns/toxics_in_fish.php). The TIF IS is being developed within the EPA National Estuary Program to ensure that Puget Sound fish populations will not be harmed by exposure to toxic contaminants and are safe for consumption by predators and humans. The IS, to be completed in 2019, will provide funding guidelines to federal, state, and local agencies for project and program implementation. The strategies developed are also being used to inform a particularly high-profile effort by Washington State Governor Jay Inslee to recover Southern Resident Killer Whales (SRKWs). Governor Inslee directed the formation of a SRKW Task Force to identify, prioritize, and support implementation of an action plan to address threats to the recovery of these whales, including contaminants (https://www.governor.wa.gov/issues/issues/energy-environment/southern-resident-killer-whale-recovery-and-task-force). The SRKW Task Force has identified three major themes for addressing contaminants: pollution prevention, pollution removal and clean up, and pollution permitting and management. We have adopted these themes to organize the management-related submissions for the 2018 Toxics Synthesis.

Pollution prevention

The most effective strategy to reduce the adverse effects of contaminant inputs to the Salish Sea is to stop the flow of contaminants via chemical bans or phase-outs. One example of a recent phase-out effort is the Washington State proposal to ban the use of copper in antifouling paints on boat hulls, beginning in 2021. Hobbs et al. conducted a baseline study of copper concentrations in five Puget Sound marinas, including assessment of impacts to biota, in 2016 and 2017. They demonstrated that copper (Cu) accumulates inside study marinas to higher levels than outside marinas, and that enclosed marinas, where water is slower to flush, accumulated higher Cu levels than more open marinas. This information can be used for evaluating the progress of an eventual Cu phase out in marine antifouling paints.

Pollution removal and clean-up

Proper removal and clean-up of contaminant sources is critical to reducing releases and exposures. Stormwater is one of the major pathways by which chemicals released into the environment reach aquatic habitats of the Salish Sea. Thus, stormwater treatment is considered the next line of defense for reducing the adverse impacts of contaminants. Numerous stormwater treatment technologies are being evaluated throughout the region. Jayakaran et al. evaluated the efficacy of porous asphalt pavements, using a replicated test facility, comprising three cells constructed with conventional impervious asphalt and six with porous asphalt. Preliminary results suggest that porous asphalt systems provide considerable treatment of several key stormwater pollutants (i.e., over 95% of Total Suspended Sediments and over 80% of total phosphorous and orthophosphate) were removed compared to standard asphalt pavement systems. These results, while preliminary, suggest that porous asphalt systems are a useful tool in the green stormwater infrastructure toolbox to restore the natural pathways that stormwater takes from landscape to stream. Leonard et al. evaluated the chemical and biological performance of compost-amended biofiltration swales (CABS) for treatment of highway runoff. Based on initial results they demonstrated that CABS remove both metals and organic pollutants and enhance infiltration capacity. Moreover, fish embryos exposed to effluent from the laboratory CABS exhibited a reduction in toxicity compared to system influent.

Mitigation plans are being developed for stormwater hot spots. For example, Feist et al. detail how such plans can help address Coho urban runoff mortality syndrome through effective management. As presented in McIntrye et al., Puget Sound Coho returning to some urban streams experience high mortality rates, potentially related to stormwater runoff associated with roadways and traffic. Feist et al. discuss the development of predictive maps to identify hotspots of mortality syndrome across Puget Sound, a method that is already being utilized by various organizations and agencies for green stormwater infrastructure planning.

Abercrombie and McMillan discussed the importance of creosote-treated piling removal within known spawning areas for Pacific herring, such as those in Port Gamble. Effective piling removal reduces the potential for PAH releases to the environment and subsequent exposures. Ecology's Toxics Cleanup Program is focusing on complete removal of creosote-treated pilings as a source control measure at cleanup sites.

Contaminant inputs that reach the Salish Sea can accumulate in sediment depositional zones. To protect marine life, dredged materials are managed to limit transfer of contaminated sediments. Nakayama et al. summarized monitoring events designed to assess the effects of dredged material disposal at the Commencement Bay disposal site. The monitoring results confirmed that the site is performing as designed, provided important information for site management, and supported adaptive management. As the Commencement Bay site moves into its 30th year of operation, the Dredge Materials Management Program is evaluating lessons learned to inform refinements to the monitoring framework.

Pollution permitting and management

Monitoring and research are needed to better inform management actions. For example, developing source control measures for urban runoff requires a better understanding of sources and release rates. For example, Cu and Zn can be harmful to aquatic organisms. Bookter and Serdar estimated release of Cu and Zn in a western Washington urban sub-basin containing a mix of land uses. Literature values and GIS analysis were employed to identify primary sources, and release estimates are being verified with a focused sampling study.

Likewise, an understanding of contaminant risks to biota is necessary to inform management actions. Currently, data are inadequate to describe realistic exposure scenarios and potential effects for aquatic species exposed to complex mixtures of toxic chemicals. Baldwin et al. proposed land use analyses as a surrogate for identifying priority watersheds where contaminant exposures are more likely to pose a risk. This information can be used to create a "risk" index, and establish priority watersheds for monitoring and further study.

Monitoring programs are necessary to understand the effectiveness of management actions. For example, Song et al. described the how the SAM program is evaluating the overall hydrologic and water quality benefits of bioretention systems for stormwater treatment, while Hinman focused on optimizing the performance of bioretention media. Healy and Patmont discuss the status of the Hylebos Waterway remediation project, finding that long term monitoring demonstrated that more than 99% of clean up goals have been met. The Puget Sound Sediment Monitoring Program was recently redesigned, based on analyses of data from 28 years of sediment and benthos sampling. Dutch et al. discuss revisions that include expanded annual sampling and collection of a new suite of benthos and biogeochemistry parameters to assess climate change and nutrient loading. These changes will help assess nutrient enrichment and climate change pressures in Puget Sound.

Key messages

- **Chemical contamination continues to be widespread in the Salish Sea; however, there are localized variations in concentrations of key contaminants.**
- **Some contaminants impact the health and safe consumption of fish and shellfish, particularly benthic species from urbanized areas, and pelagic fish from throughout Puget Sound.**
- **Although Puget Sound nearshore sediments are relatively clean, mussel tissue monitoring shows higher contamination in urban centers.**
- **Contaminants in stormwater runoff negatively affect the health of salmon and forage fish species.**
- **Contaminants of emerging concern, including pharmaceuticals and personal care products, have been detected at elevated concentrations in Salish Sea waters, with exposed fish exhibiting altered physiology.**
- **Current, localized management and cleanup programs are underway and are being adapted according to monitoring results.**
- **New ecosystem scale management plans are being developed to address toxics contaminants in fish and southern resident killer whales.**

Dosewallips estuary.

Photo: Mariko Langness, WDFW TBiOS

Puget Sound mussel monitoring cage at Appletree Cove beach. Mussel cages were deployed for approximately three months in the winters of 2012/13, 2015/16, and 2017/18 throughout Washington State. Composites of mussels from each location were analyzed for a suite of chemicals including PAHs, PCBs, PBDEs, DDTs, other organochlorine pesticides, and metals (see submission by Lanksbury et al.); a subset was analyzed for CECs (see submission by James et al.).

Photo: David Toth, WDFW Volunteer (2018)

SECTION 1:
What is happening?
STATUS AND TRENDS

Using multivariate statistical tools to evaluate dioxin/furan congener profiles at Budd Inlet

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https://fortress.wa.gov/ecy/publications/SummaryPages/1609101.html
https://fortress.wa.gov/ecy/gsp/Sitepage.aspx?csid=2245

- **Chemometric analysis identified three sources as contributors to dioxin/furan congener profiles in Budd Inlet.**
- **The sources represent hog fuel boilers, pentachlorophenol (PCP) from historical wood treatment, and polychlorinated biphenyls (PCBs).**

Dioxin/furan contamination in sediment samples is generally representative of a variety of sources. Multivariate statistical methods (collectively referred to as chemometrics) are used to reduce the mixed profiles measured in the sediment samples into a small number of modeled congener profiles, which in turn can be linked to known sources. When incorporated with data visualization tools, these profiles can be spatially mapped to reveal patterns in source distribution.

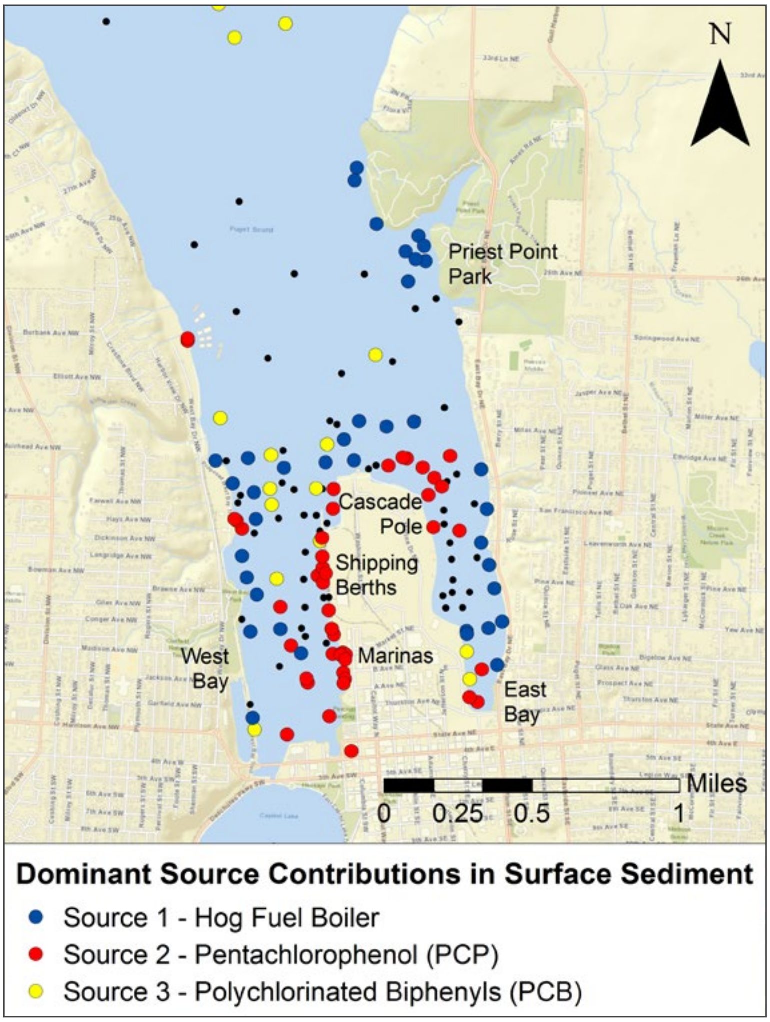
We used chemometric methods and visualization tools to evaluate the distributions of, and contributions from, various dioxin/furan congener profiles in sediments at three embayments in Puget Sound. One of these embayments was Budd Inlet, which is located in the south Sound area and is bordered by the City of Olympia, WA. At over 500 sediment samples, the dioxin/furan congener data set for Budd Inlet is among the largest in Puget Sound.

Chemometric analysis of this data set revealed a pattern of three unique dioxin/furan endmembers (congener profiles), contributing nearly 98 percent of the total variance across the Inlet. These three sources were well mixed throughout the surface sediment layer (0 to 1 foot) but showed considerable variability in the subsurface core intervals.

Source 1 correlated to hog fuel boiler emissions and ash. Nine documented boilers historically operated in Budd Inlet and would have been a diffuse source of dioxin/furans. As a result, Source 1 was not found at the same high contributions as Sources 2 and 3. In surface sediments, the fractional contribution of Source 1 was highest near Priest Point Park and the nearshore areas of the East and West Bays opposite the peninsula. Stormwater runoff was implicated as the primary source to surface sediments.

Source 2 correlated to wood treatment processes containing PCP. Two subsurface areas, one near at the north end of the shipping Berths, and one at the south end of the East Bay, had elevated contributions of Source 2 suggesting a direct pathway to sediments. Overwater structures were/are present at both locations. Contributions of Source 2 were highest in surface sediments near the Cascade Pole site, along the shipping Berths, and in the adjacent marinas. Stormwater runoff from former treated wood storage yards on the Port of Olympia peninsula were implicated as the primary source to surface sediments near the shipping Berths. Additional catch basin samples are needed from City of Olympia storm drains discharging to the marinas to determine if ongoing upland sources exist in this area.

Source 3 contained furan peaks representative of PCBs but included additional congener peaks that were not identified using the source library. The greatest contributions from Source 3 were collocated with those of Source 2 in subsurface cores near Berth 3 and at the south end of East Bay. In addition, Source 3 had minimal to no contribution in storm drain solids samples from both the City and Port drainages. For the above reasons, contamination from Source 3 was considered historical.



Location and source of PBDE exposure in juvenile Chinook salmon along their out-migrant pathway through the Snohomish River, WA

Andrea Carey[1], James West[1], Robert Fisk[1], Mariko Langness[1], Gina Ylitalo[2], Sandra O'Neill[1]

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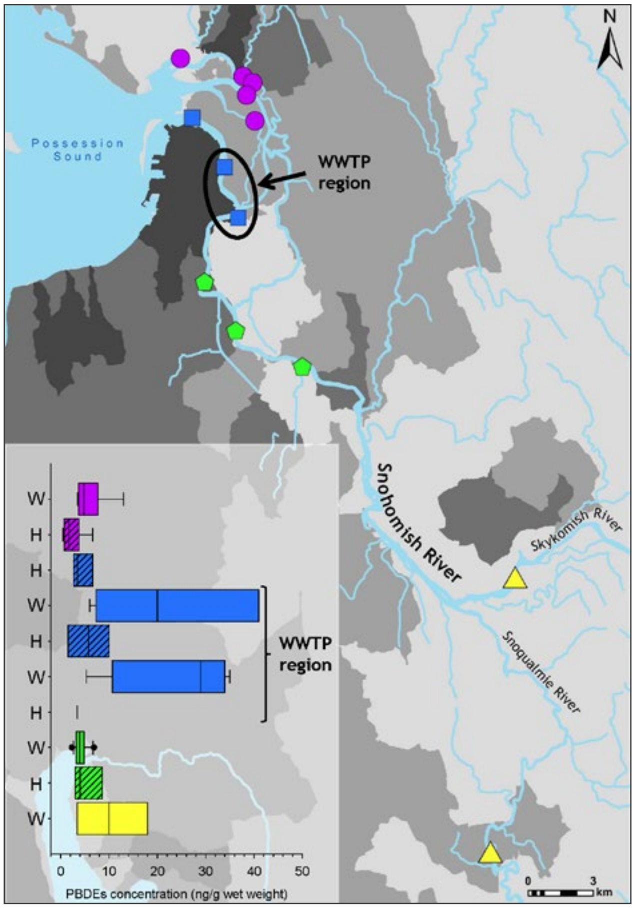
- **PBDE exposure in wild Chinook salmon emigrating from the Snohomish River is high enough to impair their health.**
- **A WWTP outfall and CSOs in the lower mainstem delta is the putative source of PBDEs.**

Polybrominated diphenyl ether (PBDE) flame retardant inputs to the Salish Sea and the Snohomish River in particular, may be impairing the health of juvenile Chinook salmon and reducing their early marine survival, possibly contributing to their decline and limiting their recovery. Previous studies documented that Chinook salmon migrating out of the Snohomish River had PBDE concentrations high enough to alter their immune response, increasing their susceptibility to naturally occurring diseases (O'Neill et al., 2015; Sloan et al., 2010). The objective for this study was to determine where in the Snohomish River system migrating Chinook salmon are exposed to and accumulate PBDEs, and to assess the source(s) so that corrective actions can be implemented.

We measured PBDEs and other contaminants in whole body samples of juvenile Chinook salmon collected from multiple locations along their out-migrant pathway (Figure). Salmon from the upstream tributaries of the Snoqualmie and Skykomish rivers, representing the cumulative exposure from all sources prior to entering the Snohomish River, were compared to salmon from subsequent downstream regions of the mainstem delta to assess the location of contaminant exposure and the source(s). Sites in the lower mainstem delta included some within close proximity to wastewater treatment plant (WWTP) outfalls. Contaminants were also measured in salmon sampled from distributary channels of the lower delta to evaluate the extent of PBDE exposure in fish migrating through regions other than the mainstem. Additionally, because wild (i.e., natural) origin Chinook salmon may use estuaries (including the delta) more extensively than hatchery origin Chinook (Levings et al., 1986; Rice et al., 2011), we compared contaminant levels by origin type.

Analyses of the PBDE concentrations (Figure) and body burdens (data not shown) revealed that wild origin Chinook salmon were primarily exposed to and accumulated high levels of PBDEs at two sites within the lower delta of the Snohomish River, both located in the immediate vicinity of a WWTP outfall and combined sewer overflows (CSOs). Approximately 73% of the natural origin samples of Chinook salmon from this region had PBDE levels high enough to alter their immune response and increase their disease susceptibility, based on laboratory exposure studies (Arkoosh et al., 2010, 2013). In contrast, none of the hatchery origin Chinook salmon from this entire watershed had PBDE levels high enough to alter their immune response. The longer estuarine rearing time by wild fish likely caused them to be exposed to harmful PBDE levels that could ultimately reduce their early marine survival. Additionally, wild Chinook salmon from the lower mainstem delta had a distinct contaminant pattern (data not shown), more indicative of wastewater inputs. We concluded that effluent from the WWTP and/or CSOs in the lower mainstem delta of the Snohomish River was the putative source, or pathway, for PBDE exposure in juvenile salmon migrating from that watershed. Identification of this location and the reputed source(s) of PBDEs will allow environmental managers to establish corrective actions to control the PBDE inputs. Ultimately, reductions in PBDE exposure could improve the health of Chinook salmon and enhance their marine survival.



A map depicting the Snohomish River system, juvenile Chinook salmon collection sites, and region where the wastewater treatment plant (WWTP) is located. The box plot shows the concentrations of PBDEs measured in the juvenile Chinook salmon which are color coded according to the region where they were collected and their origin type (W = Wild; H = Hatchery) is labeled on the y-axis. The regions are organized from the most upstream sites (bottom, yellow) to the most downstream sites (top, purple).

River otters of the Green-Duwamish: biomonitors of ecological health

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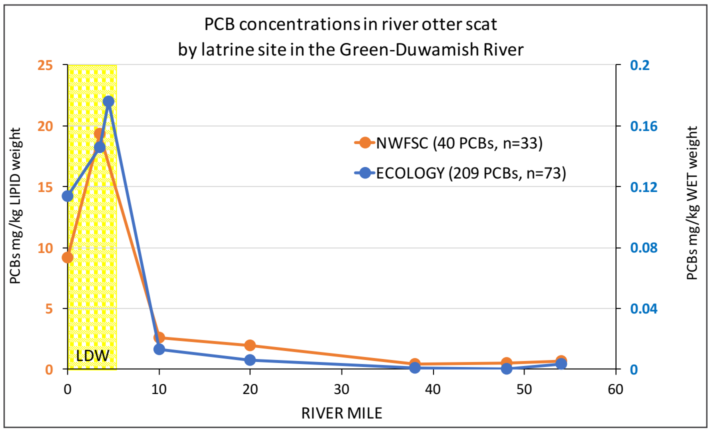
- **Scat samples suggest high levels of contaminants in river otters in the Lower Duwamish Waterway Superfund site, with levels declining upriver.**
- **Contaminants data provide a baseline and establish the value of otters as biomonitors in assessing ecological impacts of upcoming cleanup efforts.**

River otters (*Lontra canadensis*) are apex predators that play important roles in aquatic ecosystems (e.g., Ben-David et al., 1998; Cote et al., 2008; Larsen, 1984; Roemer et al., 2009). They prey primarily on fish and crustaceans, but are opportunistic predators with a diet ranging from insects to birds and mammals (see Boyle, 2006). They are vulnerable to biomagnification of persistent pollutants, and with relatively localized home ranges (Blundell, 2000; Bowyer et al., 1995), they are considered biomonitors of wildlife exposure to toxics and environmental health (Carpenter et al., 2014; Guertin et al., 2010). Empirical and modeling studies evaluating correlations between polychlorinated biphenyl (PCB) levels in river otter diet, feces and liver tissue have established scat as an accepted proxy for understanding toxicological significance (see Guertin et al., 2010). In summer and fall 2016, we collected 33 otter scats from sites along the Green-Duwamish River, ranging from river miles 0-54. River miles 0-5 represent the Lower Duwamish Waterway (LDW), a U.S. Superfund site slated for a 17-year remediation. Concentrations of PCBs at sites in the LDW were 9.1 and 19.3 mg/kg (geometric means, lipid weight) - above the reported threshold value of 9 mg/kg associated with adverse effects for river otters. By river mile 10, mean concentrations of PCBs decreased to 2.6 mg/kg, with remaining upriver sites ranging from 0.4-1.9 mg/kg. Polycyclic aromatic hydrocarbon (PAH) concentrations showed a similar pattern. The highest PAH levels (140 and 91 mg/kg, geometric means, wet weight) were measured in the LDW whereas levels upriver were 9.7-25 mg/kg. Based on preliminary genetics data from several sampling locations, we infer that otters remain in local river reaches, so scat contaminant levels likely reflect local environmental concentrations. Scat collected in 2017 and analyses for brominated flame retardants, organochlorine pesticides, stable isotopes, and genetics will provide additional depth and breadth to these results. These are the only empirical contaminants data available for a mammal or apex predator in the Green-Duwamish. They suggest that otters may be impacted by contaminant loads in the LDW; however, significant questions remain as to the potential individual health and population effects. The data also reveal that the contamination gradient along the Green-Duwamish is reflected in otters, indicating they are useful biomonitors of wildlife and food web exposure to contaminants, as well as watershed health in this system. The timing of this study provides an important baseline level of contamination in otters that may be of great value for assessing ecological impacts of long-term Duwamish Superfund site cleanup efforts.



Polychlorinated biphenyl (PCB) concentrations from river otter scat collected at latrine sites along the Green-Duwamish River, King County, WA. Values are geometric means. Samples analyzed at two separate laboratories, represented by two axes; methods vary – see axes titles. Yellow rectangle represents the Lower Duwamish Waterway Superfund site (river miles 0-5).

Game camera photo of river otters at a latrine site along the Green-Duwamish River, King County, WA. Photo: Michelle Wainstein

UNIVERSITY of WASHINGTON NOAA FISHERIES

Pre-oil spill baseline profiling for contaminants in Southern Resident killer whale fecal samples indicates possible exposure to vessel exhaust

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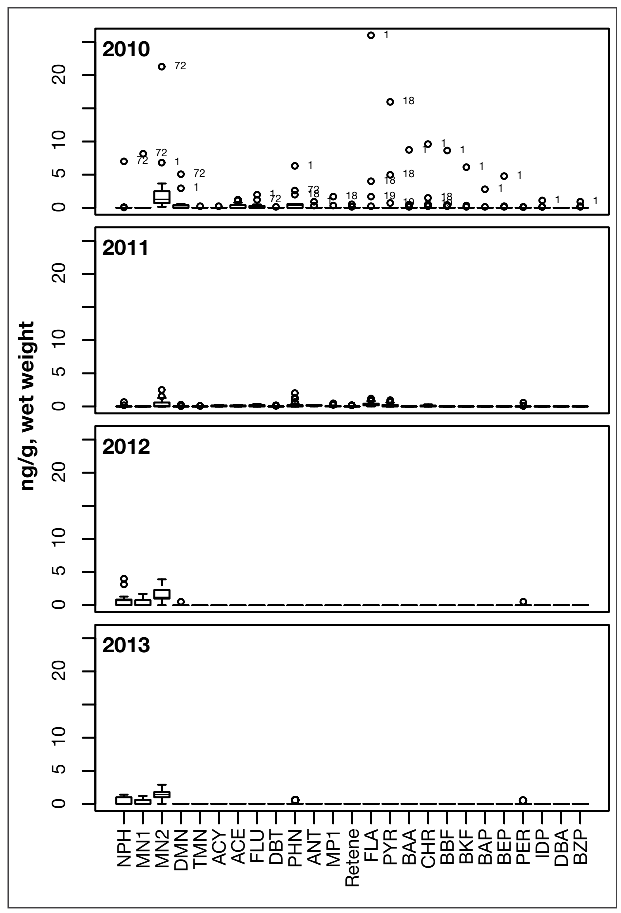
https://doi.org/10.1016/j.marpolbul.2018.09.015
https://www.nwfsc.noaa.gov/ http://conservationbiology.uw.edu/

- **PAHs are a common component of oil as well as combustion from vessel motors.**
- **Overall, concentrations of the measured PAHs were low in the whale fecal samples.**
- **Elevated PAH levels were measured prior to the revision of the Be Whale Wise guidelines increasing the mandated distance between vessels and whales.**

The inland marine waters of the Salish Sea are vulnerable to a catastrophic event such as an oil spill. More than 2 billion gallons of oil are transported quarterly in the state of Washington (Ecology 2017, 2018). Current shipping lanes transect areas designated as critical habitat for the Southern Resident killer whales (SRKWs), pipelines terminate at marine ports within this designated habitat, and the railways run along major marine waterways. The consequences of exposure to oil in marine mammals has been associated adverse physiological effects (lesions, disease, dysfunction, impairment), and population decline (Schwacke et al, 2013, Venn-Watson et al, 2015, Stimmelmayr et al, 2018, Kellar et al, 2017, De Guise et al, 2017, Matkin et al, 2008). A common component of oil is polycyclic aromatic hydrocarbons (PAHs), established as carcinogenic and mutagenic (ATSDR 2018) Combustion of fuel from boat motors is another source of PAHs, and an additional risk for the SRKWs because of the vessel traffic. The historical precedent of oil spill impacts on marine ecosystems has emphasized the importance of having pre-spill exposure data, particularly on wild cetaceans. The objective of this study was to measure PAH concentrations in fecal (scat) samples from this endangered killer whale population.

Fecal samples were collected from the water's surface May through October from 2010 to 2013. Samples were immediately centrifuged, decanted, and frozen, and later genotyped for individual identity (NOAA NWFSC), and analyzed for contaminant concentrations (NOAA NWFSC). Identities were matched with census data from the Center for Whale Research.

A total of 263 samples were collected, with 70 large enough for PAH contaminant analysis. Samples represented all pods, age-sex classes, and years. The results (see Figure 1) demonstrate the SRKWs are currently experiencing negligible exposure to the PAHs measured; with a few exceptions, all samples were below 10 ppb wet weight. This PAH baseline data, in conjunction with other health and population metrics on the SRKW population, will be invaluable to guide remediation goals and damage assessment evaluations in the event of an oil spill. An unexpected finding from this study was four samples, all collected in 2010, that had levels of PAHs above 10 ppb. Three of these samples contained a PAH profile produced through combustion. The Be Whale Wise guidelines (www.bewhalewise.org), increased the legal distance that boats must maintain from whales from 100 to 200 yards (yds) after 2010. The extent these whales were exposed to boat exhaust during 2010 when vessels were allowed to be in closer proximity to the whales is unknown. A previous estimate demonstrated the likely occurrence of unsafe vessel exhaust exposure in SRKWs based on the 2010 guidelines (Lachmuth et al, 2010) Also, following the implementation of the mandated 200 yd distance in 2011, no samples had PAHs at levels above 10 ppb. This suggests that whales may have experienced a decrease in exposure to combustion engine emissions following the updated vessel regulations.



Boxplots of 25 PAHs (ng/g, wet weight) measured in SRKW fecal samples, by year. Notations for 2010 denote sample number of four outliers, samples 1, 18, 19, and 72.

Figure footnote: naphthalene, NPH; 1-methylnaphthalene, MN1; 2-methylnaphthalene, MN2; 2,6-dimethylnaphthalene, DMN; 2,3,5-trimethyl naphthalene, TMN; acenaphthylene, ACY; acenaphthalene, ACE; fluorene, FLU; dibenzothiophene, DBT; phenanthrene, PHN; anthracene, ANT; 1-methylphenanthrene, MP1; fluoranthene, FLA; pyrene, PYR; retene (methyl isopropyl phenanthrene); benz[a]anthracene, BAA; chrysene + triphenylene (co-elution), CHR; benzo[b]fluoranthene, BBF; benzo[j]fluoranthene + benzo[k]fluoranthene (co-elution), BKF; benzo[e]pyrene, BEP; benzo[a]pyrene, BAP; perylene, PER; indeno[1,2,3-cd] pyrene, IDP; and dibenz[a,h]anthracene, BZP.

Using transplanted mussels (*Mytilus trossulus*) to monitor and track PAH contaminants in the Puget Sound nearshore

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https://wdfw.wa.gov/conservation/research/projects/marine_toxics/

- **PAH pollutants are entering the nearshore food web of the Puget Sound, especially along shorelines adjacent to highly urbanized areas (e.g. Seattle).**
- **Total PAH concentration in mussels increases with the percent of impervious surface (a proxy for urban development) in watersheds adjacent to the shoreline.**
- **Transplanted mussels can be a useful tool to help identify different sources of PAHs to Puget Sound shorelines.**

Stormwater delivers a diverse range of contaminants to receiving waters in Puget Sound, including toxic polycyclic aromatic hydrocarbons (PAHs). Understanding the sources and extent of PAH contamination in the nearshore is critical to managing the health of Puget Sound's marine ecosystems. In the winter of 2012/13, the Washington Department of Fish and Wildlife's Toxics-focused Biological Observing System (TBiOS) team conducted a large-scale, active biomonitoring study using native bay mussels (*Mytilus trossulus*) transplanted from a local aquaculture source (Penn Cove, WA) to characterize the extent and magnitude of nearshore contamination in the Puget Sound.

Because of the success of that study, TBiOS now conducts mussel surveys on a biennial basis, with three completed to date (winters of 2012/13, 2015/16, and 2017/18). Puget Sound mussel monitoring is a collaborative effort, coordinated by TBiOS and funded primarily through the Stormwater Action Monitoring program (40 sites), with a number of other state, county, tribal, and local partners and stakeholders funding additional sites (30~50) each survey. Citizen science volunteers support the program by deploying and retrieving the mussels in anti-predator cages. Monitoring sites cover a broad range of land-use types and mussel soft tissue composites from each site are analyzed for a range of organic contaminants (e.g. PAHs, PCBs, PBDEs, DDTs) and metals.

Here we report on PAHs from the 2012/13 and 2015/16 surveys. PAHs were detected at all of the monitoring sites and were the most abundant organic contaminants measured. Total PAH concentrations ranged from 29 (2013) to 7,350 ng/g dry weight (2016) and were highest in the most urbanized areas of Puget Sound, especially in Elliott and Salmon Bay (Seattle). Eagle Harbor (Bainbridge Island), Commencement Bay (Tacoma), and several other locations also had elevated total PAHs. There was a strong positive correlation between PAH concentration and the percent of impervious surface in watersheds adjacent to the shoreline (Figure 1). Impervious surface, used here as a proxy for urban development, is strongly linked to stormwater contamination.

We used principal component analysis (PCA) to explore the pattern of PAHs in mussels from sites with at least 50% detected values in both years and calculated the ratio of alkylated-phenanthrene/phenanthrene, a forensic tool used in source tracking, in each sample. The PCA indicated that two broad groups of mussel sites were dominated either by parent PAHs or by alkylated homologs of PAHs (Figure

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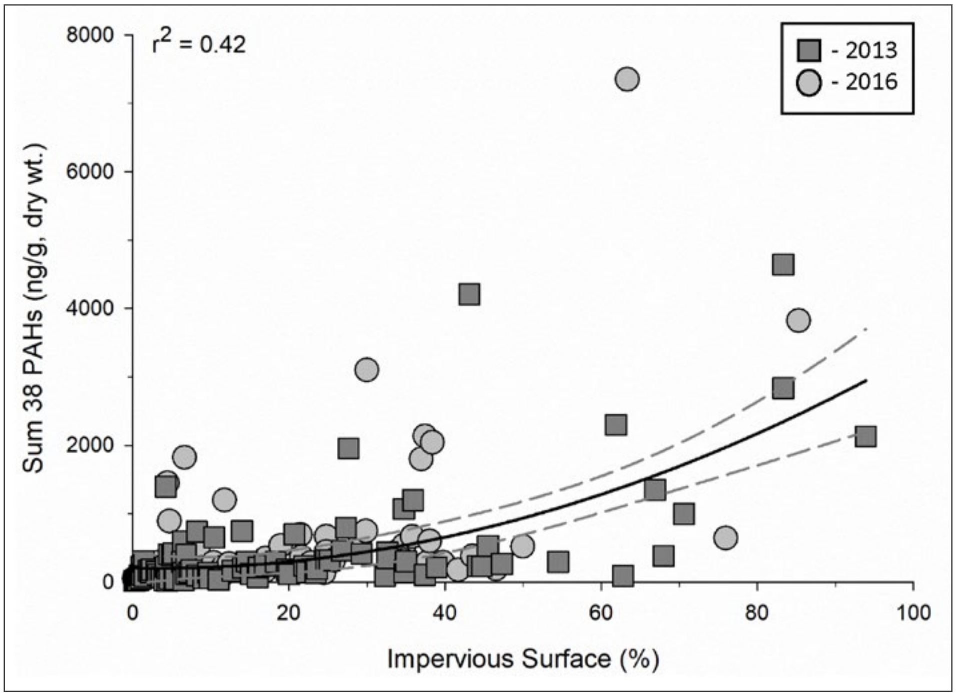

Figure 1. The concentration of $\sum_{38}$PAHs increased with percent impervious surface in nearshore watersheds (stepwise multiple linear regression of log-transformed $\sum_{38}$PAHs versus Impervious Surface; $p<0.0001$, $r^2 = 0.42$). Circles/squares represent transplanted mussel sites; solid black line is the predicted regression curve; dotted lines are the 95% confidence intervals.

[CONTINUED]

2, PC1 axis). A pyrogenic signature (more parent PAHs) dominated the two groups on the right, with combustion of biomass (e.g. wood burning) and automobile exhaust likely the major sources of PAHs. A petrogenic signature (more alkylated homologs) dominated the group on the left, suggesting those locations are exposed to higher amounts of unburned diesel, gasoline, motor oil, or hydraulic fluids. The findings from these surveys indicate PAH contaminants are entering the nearshore food web of the greater Puget Sound, especially along shorelines adjacent to highly urbanized areas, and demonstrate how transplanted mussels might be useful in identifying sources of PAHs along the shorelines of Puget Sound.

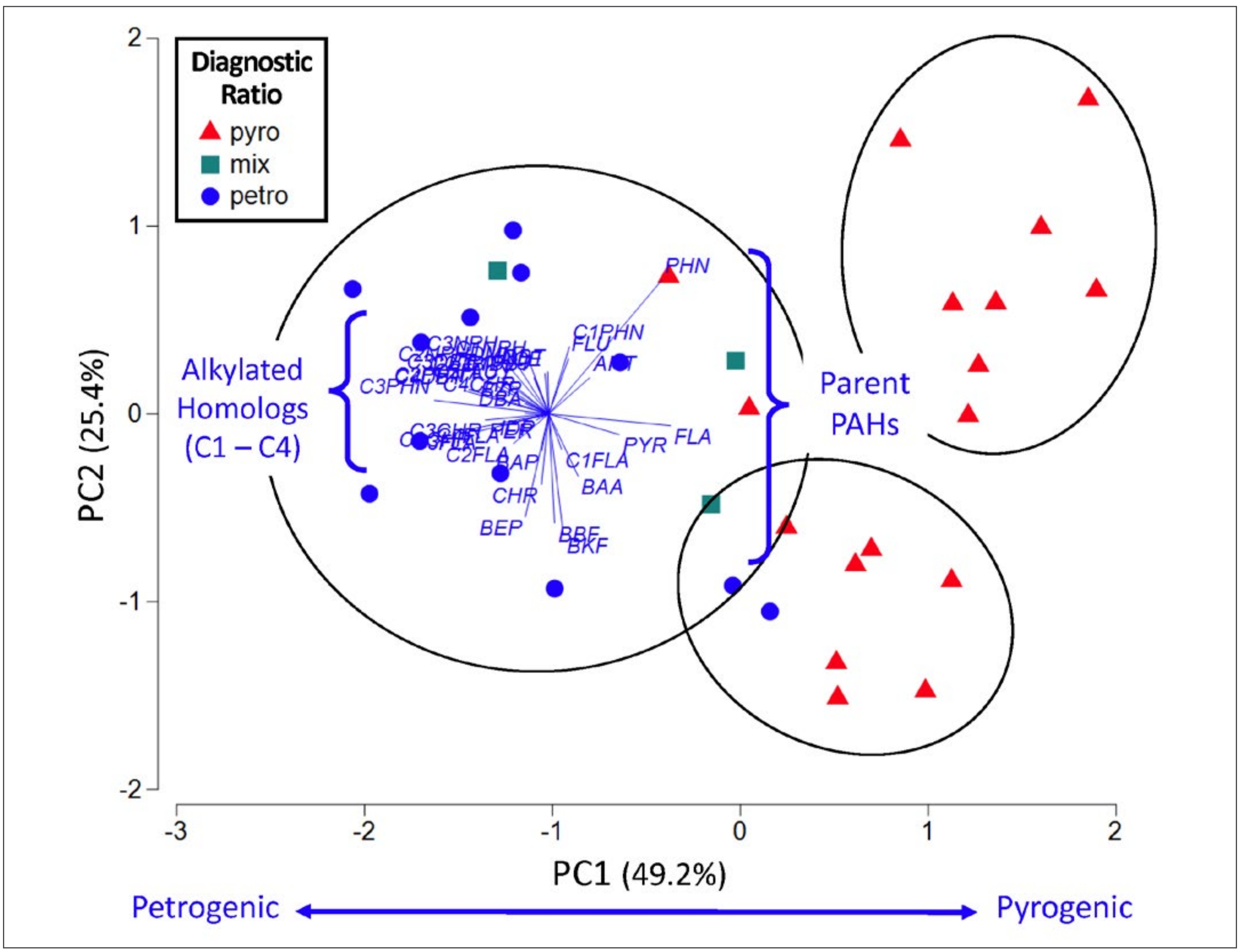

Figure 2. Principal component analysis of 37 PAHs in mussels from 32 sites with at least 50% detected PAHs in 2012/13 and 2015/16 surveys. PAH vectors are shown in blue; % variation explained by each principal component axis indicated in parenthesis. Ratio of alkylated-phenanthrene/phenanthrene in mussel sites were pyrogenic (red triangles), mixed (green squares), or petrogenic (blue circles).

Contaminants of emerging concern in Bay Mussels throughout the Salish Sea

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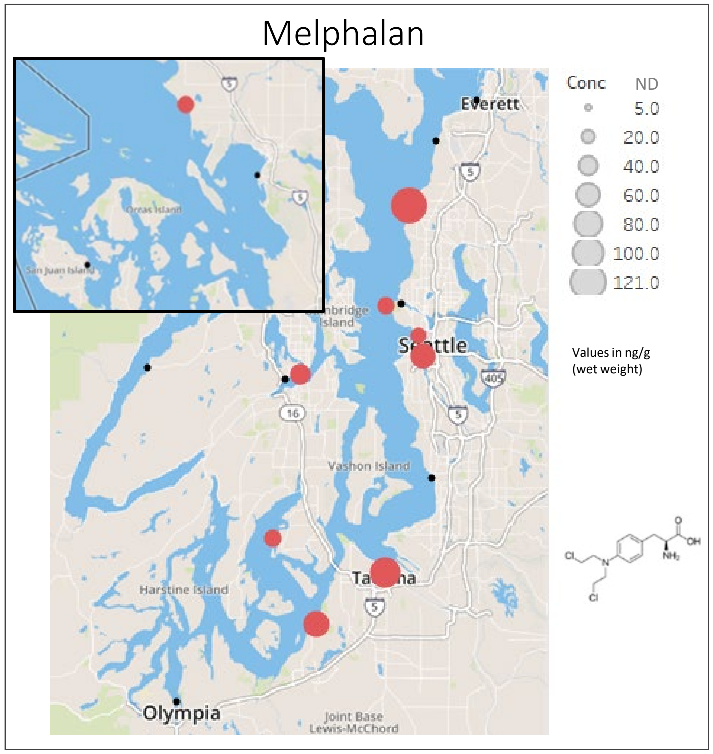
- **Transplanted mussels were deployed at 18 locations in Puget Sound and analyzed for CECs.**
- **Results indicated a wide range of exposure to low levels of medications and antibiotics, some at levels of biological concern.**

Monitoring of bay mussels (*Mytilus trossulus*) has been an important part of WDFW's Toxics-focused Biological Observing System (TBiOS) in the Puget Sound. Traditional monitoring has focused on a suite of priority compounds including PAHs, PCBs, PBDEs, and metals. In order to expand the range of compounds investigated, we undertook a pilot program in 2016 to analyze a select set of tissue samples for contaminants of emerging concern (CECs), utilizing two distinct analytical approaches. One set was analyzed by targeted methods focusing on a suite of over 200 pharmaceuticals, personal care products, and endocrine disrupting compounds. The results supported the notion of widespread exposure of marine organisms to trace levels of organic contaminants, including compounds such as the antidepressant sertraline, and the antibiotic virginiamycin. The synthetic opioid oxycodone was present in tissue samples collected from three sites, including one Elliot Bay and two near the Bremerton Shipyard. The chemotherapy drug melphalan was present in samples from 9 of 18 locations. Melphalan has been shown to induce DNA damage in exposed haemocytes of Zebra mussels (*Dreissena polymorpha*; Buschini et al. 2003), and so its presence may be of biological concern. Results also clearly demonstrated the importance of analytical considerations such as matrix effects, variable limits of detection, and quality assurance criteria when comparing data across an ecosystem.

A second set of tissue samples were analyzed by high resolution mass spectrometry (HRMS) in order to gain a broader understanding of exposures without focusing on a pre-defined list of analytes. This non-targeted approach utilized accurate mass, isotopic ratios, and retention time information for the identification of a wide range of unique compounds for follow up analysis. Additional criteria, such as differential occurrence patterns, potential for biological interactions, and/or compound properties (e.g., halogenation), are then applied to identify a subset for focused identification. In this instance a candidate list of approximately 175 unique compounds, was selected for identification based on common occurrence across samples and presence in existing accurate mass databases and libraries. Multiple compounds were identified, including synthetic hormones such as drospirenone, again supporting the notion of a wide range of CEC exposures in the nearshore of Puget Sound.



Summary of melphalan concentrations in transplanted mussel tissues deployed in various locations in Puget Sound. Concentrations are in ng/g tissue (wet weight). ND – not present at concentrations above the detection limit. The detection limits ranged from 16.8 to 82.4 ng/g tissue.

WDFW volunteer deploying mussel cage at North Avenue Park, Anacortes on the night of October 2015. Photo: Brenda Cunningham, WDFW Volunteer

Nearshore sediment microplastic monitoring for the Stormwater Action Monitoring (SAM) program, Puget Sound, Western Washington

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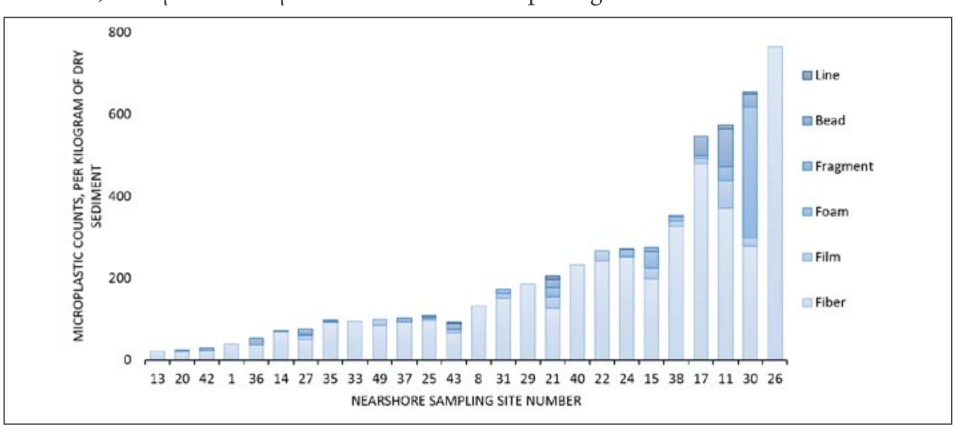
Plastic pollution is a well-recognized issue afflicting water bodies worldwide. Plastics smaller than 5 mm commonly referred to as microplastics are of concern as their near ubiquitous occurrence in water, sediment, and biota poses a potential danger to biota through ingestion (Jovanović 2017) and as a potential vector for contaminant transfer (Hartmann et al. 2017). Currently, little is known about the distribution of these microplastics in Puget Sound Sediment. To address this gap, USGS scientists conducted a pilot project to determine the occurrence of microplastics in marine sediment samples collected as part of Washington State Department of Ecology's Stormwater Action Monitoring Program (SAM). Sampling location were chosen to represent a range of nearshore land use, urbanization, and sediment drift characteristics. Collection coincided with contaminant chemical characterization for which field and laboratory methods, sampling location details, and full results are detailed in Black et al. (2018).

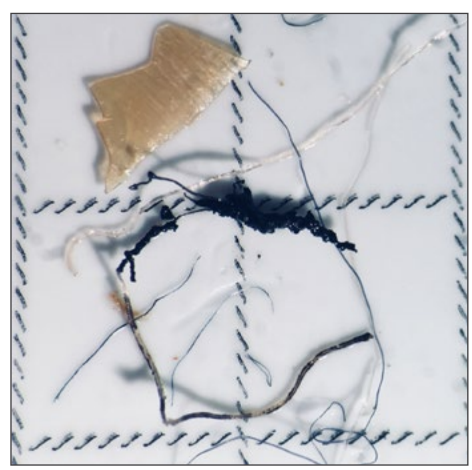
Microplastics were detected in sediments from all 25 sampled nearshore locations. Microplastics are separated into two size fractions, 355µm-1000 µm and >1000 µm, and sorted by type (e.g., Fiber, Films, or Fragments). Total microplastic concentrations ranged from 22 to 654 pieces per kilogram of dry sediment. Fibers were the most commonly found and were 270 percent more abundant than any other type. Smaller sized plastics, 355 µm -1000 µm, were 300 percent more abundant than larger pieces. No statistical differences were observed among sampling locations, non-fiber pieces were higher in lower-energy drift cells (those characterized as "non") versus higher energy drift cells. The median densities of both large and small fibers were higher in "non" drift cells, yet fiber densities in active drift cells were more variable. As with chemical concentrations found concurrent in nearshore sediment, the number of plastic particles in sediment was poorly related to land cover. These findings should be evaluated with care, given the preliminary nature of microplastic sample collection and laboratory analysis methods.

Microplastics are composed of numerous types of polymers of different shapes, sizes and densities. These features could have a profound effect on transport and deposition in aquatic environments. Thus it was not surprising to find a broad distribution of microplastic densities among the sites examined in this study. Previous studies have shown that microplastics in sediments tend to settle out more readily in areas of low energy such as bays and harbors (Vianello et al., 2013). Although the median densities of plastics, particularly non-fibers, at sites located in drift cells with no movement were often slightly higher than at sites in actively moving drift cells, the difference was not significant. Microplastic fibers tended to have the greatest range in densities in drift cells characterized as moving from Left to Right or Right to Left, whereas non-fibers consistently had greater density variations in drift cells with no movement. These contradictory results seem to highlight the potential variability in microplastic transport based on the shape of microplastics in Puget Sound.

- **Microplastic pollution in Puget Sound nearshore sediment is ubiquitous, found in all 25 samples analyzed.**
- **Microplastic fibers, such as polyester from clothing, was 300 percent more common than other types of microplastics found.**



Microplastic counts in nearshore sediment from the Puget Sound collected as part of the Stormwater Action Monitoring program. Counts are per kilogram of sediment (dry-weight). Categories of plastics are based on visual assessment. Site numbers correspond to locations sampled during 2016; location details can be found in Black et al. 2018 (https://doi.org/10.3133/sir20185076).



An assortment of microplastics in a nearshore sediment sample. Photo: Spanjer, Andrew

Spatial comparison of PBTs in marine fish and invertebrates from King County waters

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http://green2.kingcounty.gov/ScienceLibrary/?&CategoryID=17

- **Observed small spatial scale differences in concentrations of PCBs and PBDEs in Elliott Bay.**
- **Mercury decreased in squid between 1997 and 2016.**

In 2014, King County initiated a long-term marine tissue contaminant monitoring program. Fillet and whole-body fish and invertebrate tissue chemistry data from this program are used to track changes over time to assess management actions and evaluate the risk of adverse effects to aquatic life and humans from fish consumption (King County, 2016). The program monitors species on a rotating basis: Dungeness and Red rock crabs every 4 years, English sole and rockfish (brown, copper, and quillback) every two years. In addition, market squid were monitored once in 2016. The program plans to begin monitoring forage fish in 2020. Sampling locations include Elliott Bay and central Puget Sound sites within King County waters.

Spatial differences in polychlorinated biphenyls (PCB) concentrations in crab, English sole and rockfish were observed; however, a spatial difference in polybrominated diphenyl ethers (PBDEs) concentrations was only observed for English sole. In general, PCB concentrations in all crab and fish species were higher in Elliott Bay compared to other King County locations. However, even within Elliott Bay, distinct spatial differences in PCB and PBDE concentrations were observed for English sole over a relatively short distance (Figure 1).

PCBs were not detected in English sole fillet tissue at the Alki location even though some of the highest concentrations were detected in fish collected nearby along the Seattle Waterfront. Average PBDE concentrations in English sole were similar at all stations except for higher mean concentrations detected in fish collected along the Seattle Waterfront.

Differences in contaminant accumulation in crab tissue types were observed between muscle tissue and the hepatopancreas. Mercury concentrations were higher in crab muscle tissue compared to the hepatopancreas. PCB and PBDE concentrations were higher in the hepatopancreas relative to levels detected in muscle tissue. Contaminant levels in Dungeness crab were similar to those observed in 2012 by the Washington Department of Fish and Wildlife (WDFW) (Carey et al. 2014) for their Puget Sound-wide assessment of contaminants in Dungeness crab.

Concentrations of mercury, PCBs and PBDEs in rockfish (whole body) were more closely correlated with age (as measured by otoliths) than location (R2 = 0.76 – 0.85). This finding was similar to WDFW's results that were based on a larger Puget Sound wide data set (Niewolny et al. 2014).

While recreational fishers frequently collect squid from public piers in King County, little data were available to assess potential human health concerns associated with squid consumption. Historical squid tissue data were limited to samples collected by King County in 1997 and analyzed for metals, PCBs, tributyltins, and base-neutral-acid extractable compounds. In 2016, PCBs and PBDEs were detected at relatively low concentrations in squid tissue. Mercury concentrations in squid tissue in 2016 were lower than levels detected in 1997, and below Washington Department of Health's methylmercury human health screening level for high fish consumers (Figure 2).

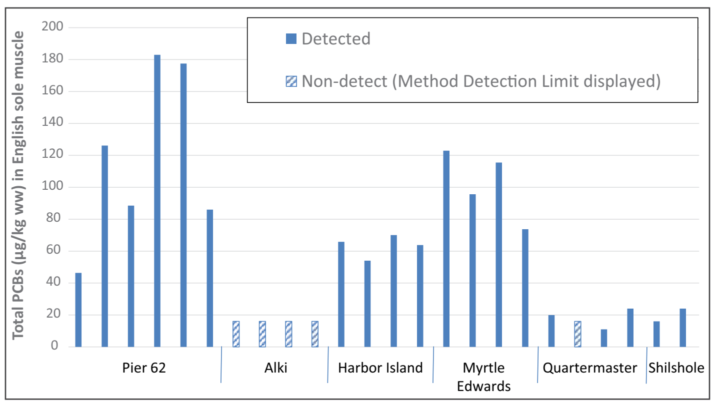

Figure 1: PCBs (µg/kg ww) in English sole muscle composite samples.

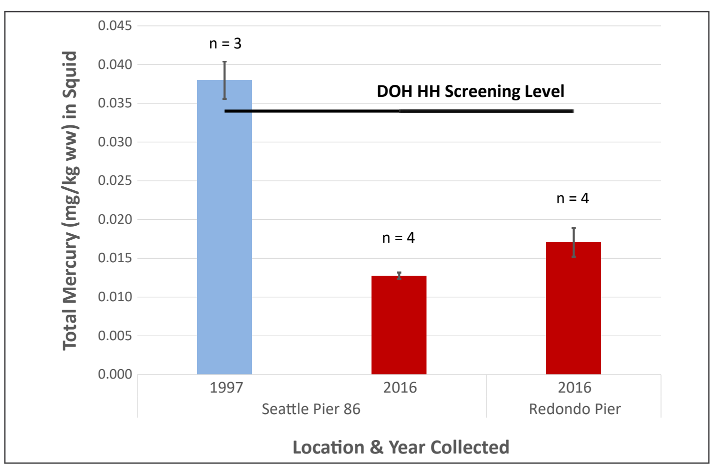

Figure 2: Mercury concentrations (mg/kg ww) in cleaned squid between 1997 and 2016.

Contaminants reveal spatial segregation of sub-adult Chinook salmon residing and feeding in Puget Sound

Washington Department of FISH and WILDLIFE

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https://wdfw.wa.gov/conservation/research/projects/marine_toxics/

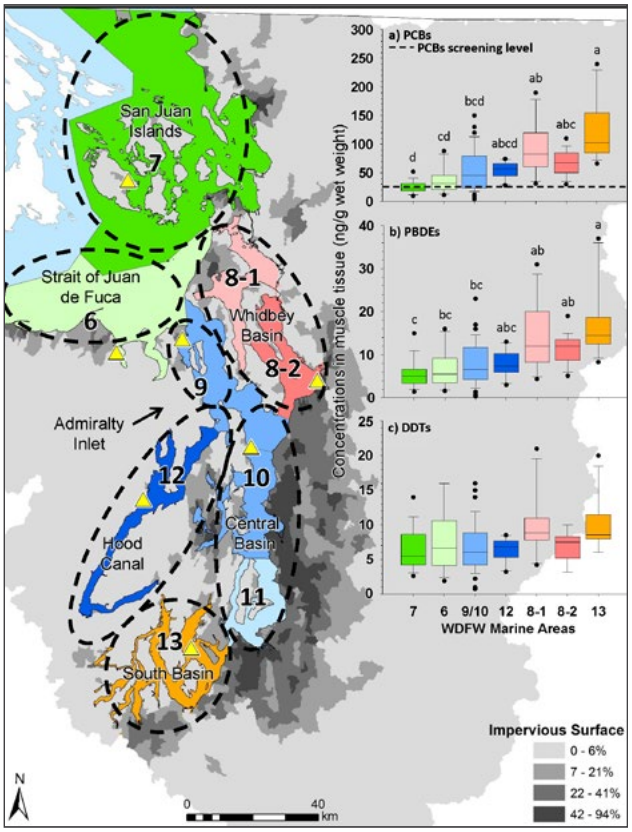
- **Polychlorinated biphenyls (PCBs) in resident Chinook salmon exceeded the DOH screening level for human consumption in all Puget Sound basins and were highest in South Basin.**
- **Chinook salmon have distinct contaminant patterns associated with catch locations, indicating segregated populations with limited feeding distributions.**

Adult salmon accumulate most of their body burdens of persistent organic pollutants (POPs) while feeding in marine habitats, where they also acquire most of their body mass. Although the majority of Chinook salmon originating from Puget Sound migrate to the Pacific Ocean to feed and grow, approximately one third reside in the Salish Sea for much of their marine rearing phase (Chamberlin et al., 2011; O'Neill & West, 2009). Here, they are exposed to POPs through their diet, including Pacific herring and other pelagic fishes, which are highly contaminated in Puget Sound (West et al., 2008, 2011). Resident Chinook salmon are targeted by recreational anglers, potentially putting these fishermen at increased risk of contaminant exposure. In addition, Chinook are the primary food source of the Southern Resident Killer Whales (SRKWs), and thus a major source of toxic chemicals to these endangered whales (Cullon et al., 2009; Mongillo et al., 2016; O'Neill & West, 2009). The objectives of this study were to determine whether contaminant concentrations in resident Chinook varied among marine basins and whether anglers targeting these salmon are at risk of contaminant exposure.

We measured POPs in resident Chinook salmon collected from various WDFW Marine Areas (MAs), roughly representative of Puget Sound basins, in the late fall, winter, and spring of 2016 and 2017, outside the typical migration timing for ocean-returning adults. Chinook samples were donated by anglers participating in fishing derbies or collected from a test fishery. Skinless muscle tissue was collected from behind the fish's head and analyzed for PCBs, polybrominated diphenyl ethers (PBDEs), and dichlorodiphenyltrichloroethanes (DDTs).

Contaminant concentrations and patterns in Chinook salmon varied by marine basin: PCBs and PBDEs were lowest in fish caught in the Strait of Juan de Fuca (SJF) and the San Juan Islands (SJIs) (MAs 6 & 7), intermediate in fish caught further into Puget Sound, south and east of Admiralty Inlet (MAs 9/10, 12, 8-1, 8-2,) and highest in fish caught in the South Basin (MA 13), furthest from the ocean (Figure). Concentrations of DDTs did not vary significantly among basins. Additionally, Chinook had distinct contaminant fingerprints associated with their catch locations (data not shown), indicating segregated populations with limited marine feeding distributions. Our results are consistent with acoustic telemetry studies that documented a high degree of basin fidelity with limited movements between resident Chinook caught and tagged in the SJIs and the Central Basin (Arostegui et al., 2017; Kagley et al., 2017).

People (and SRKWs and other top-level predators) consuming resident Chinook salmon caught in the SJIs and the SJF will be exposed to lower PCB and PBDE levels than those consuming fish from other areas of Puget Sound. However, concentrations of PCBs in virtually all fish from all basins exceeded the Washington Department of Health's (DOH) PCB screening value for human health (23 ng/g). In contrast, PBDEs and DDTs in fish in all basins were well below the human health screening values. Data from this study will be used by DOH to provide basin-specific fish consumption advice to protect human health in Puget Sound.



Concentrations of a) PCBs, b) PBDEs and c) DDTs (ng/g wet weight) measured in muscle tissue from Chinook salmon collected in eight WDFW Marine Areas (MAs). Similar letters signify MAs with no significant difference (p > 0.05). Puget Sound basins are circled with a dotted line and yellow triangles indicate where the Chinook salmon were landed during the fishing derbies and test fishery.

Spatial comparison of heavy metal concentrations in sediment and eelgrass within Possession Sound

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- **Sediment and eelgrass at Mount Baker Terminal had higher concentrations of arsenic, copper, lead, and zinc than at South Whidbey Island, possibly a result anthropogenic activity.**
- **Copper, arsenic, and zinc concentrations were higher in eelgrass blades compared to adjacent sediment, suggesting eelgrass bioaccumulates these metals.**

The Ocean Research College Academy (ORCA) is a dual enrollment program at Everett Community College where high school juniors and seniors experience innovative, interdisciplinary and student-centered learning. A longitudinal study modeled after Puget Sound Partnership's State of the Sound Report was conducted by students and began in 2004.

Possession Sound is located in the North Whidbey Basin of Puget Sound, between Snohomish County and Whidbey Island near the cities of Everett and Mukilteo. The largest freshwater influence to Possession Sound is the Snohomish River, and naturally occurring and anthropogenic processes transport heavy metals into the watershed. While some trace metals may play a role in the marine ecosystem at low concentrations, others can be detrimental at higher concentrations. Eelgrass (Zostera marina) is found in sand and silt substrates in shallow marine waters and is a critical nursery habitat for juvenile fish, shellfish, and other marine organisms. However, heavy metals contained in the sediment may bioaccumulate in eelgrass, and copper, zinc, and lead are known to inhibit eelgrass growth and productivity (Lyngby and Brix, 1984). In addition, eelgrass blades may be accumulating metals over time from other sources besides sediment, such as the water column.

In order to investigate trace metals in eelgrass compared to sediment, eelgrass and adjacent sediment samples were collected using a Ponar sediment grab from two locations in Possession Sound (Figure 1) between the years 2015 and 2018. The Mount Baker Terminal (MBT) sample site is located near the Mukilteo Ferry and the Boeing shipping pier, near the densely populated city of Mukilteo. The Whidbey sample site is located off the sparsely populated shores of southeast Whidbey Island. Samples were processed by the Everett Environmental Lab for determination of arsenic, copper, lead, and zinc concentrations according to EPA protocols (EPA-3050B).

Mean concentrations of zinc, arsenic, copper, and lead were higher at the MBT site than at the Whidbey site (Figure 2), which suggests some heavy metals originate upstream in the Snohomish River and are carried into the Sound. Increased human activity surrounding Mount Baker Terminal could also contribute to the higher concentrations of heavy metals there. Decreased levels of anthropogenic activity near the Whidbey site may explain the lower overall heavy metal concentrations at that site.

Mean concentrations of zinc, arsenic, and copper were higher in eelgrass blades than in adjacent sediment, while mean lead concentrations were lower in eelgrass blades than in adjacent sediment (Figure 2). The higher mean concentrations of zinc, arsenic, and copper in eelgrass indicates bioaccumulation of metals, possibly through adsorption or absorption of dissolved metals in the surrounding water column, in addition to uptake of metals from the sediment. Lower lead concentrations in eelgrass than in the adjacent sediment implies that lead is not readily bioaccumulated in eelgrass blades, or that lead has different settling rates as compared to the other metals. To explore these trends, additional studies are underway to analyze heavy metal concentrations within the water column of Possession Sound.

Figure 1: Map of Possession Sound showing the two sample collection sites Mount Baker Terminal (MBT) and southeast Whidbey Island (Whidbey).

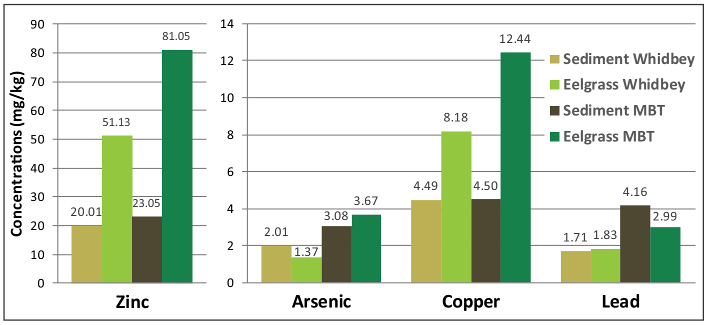

Figure 2: Mean concentrations of zinc, arsenic, copper, and lead in eelgrass and sediment from Whidbey and Mount Baker Terminal (MBT) sites in 2015-2018. Heavy metals were higher overall in eelgrass compared to sediment, this trend was most strongly supported by zinc and copper.

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Ecotoxicological costs and benefits of run-of-river hydroelectric dams

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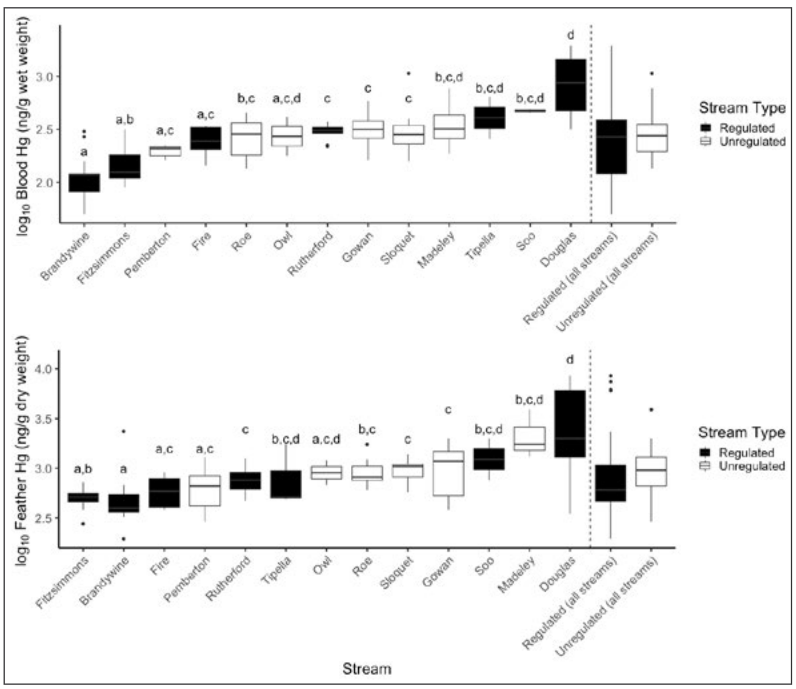
- **American dippers inhabiting densely forested mountain streams experienced high mercury exposure compared to passerines from other uncontaminated sites in western North America.**
- **Biogeochemical conditions in reservoirs of some regulated streams may be contributing to methylmercury production.**

Run-of-river (RoR) dams are a common energy production alternative on mountain streams throughout the world, but their ecotoxicological impacts remain poorly understood (Anderson et al., 2015; Gibeau et al., 2016). The formation of methylmercury, a vertebrate neurotoxin and teratogen, has been documented in reservoirs of large hydroelectric projects (Rosenberg et al., 1997) and beaver dams (Roy et al., 2009), and now in the small reservoirs above RoR dams, locally known as "headponds". The American dipper (Cinclus mexicanus) river bird shares the steep mountain stream habitat sited for RoR developments and is a well-described indicator of water quality, making it an ideal species for studying potential eco-hydrological impacts related to altered river flow regimes. In 2014 and 2015, we monitored American dipper populations at stream sites with and without RoR dams across three watersheds (Squamish, Lillooet, and Harrison) in the Coast Mountain Range of British Columbia. We determined that high elevation, RoR-regulated streams provide stable year-round habitat for the American dipper (Silverthorn et al., 2018). Mountain stream reaches modified by flow abstraction may offer an opportunity for altitudinal migrant dippers to exploit a consistent food resource closer to their high elevation breeding territory, enabling them to take on a "resident strategy" that is more typical of low elevation salmon-bearing rivers (Morrissey et al., 2004). We also used stable isotopes (δ13C, δ15N, δ34S) to reconstruct American dipper diets and trace methylmercury bioaccumulation in their tissues. Assimilated diets were comparable among regulated and unregulated streams, dominated by benthic macroinvertebrates and resident freshwater fish, with negligible contributions from anadromous Pacific salmon (Silverthorn et al., 2017). Although invertebrates at unregulated streams were isotopically similar along their gradient, dippers and invertebrates sampled below dams on regulated streams had 34S-depleted tissues, suggesting increased activity of sulfate-reducing bacteria and more Hg methylation below the dams. While there was no model support for an effect of river regulation on dipper blood (417.6 ± 74.1 S.E. ng/g ww at regulated streams, 340.7 ± 42.7 S.E. ng/g ww at unregulated streams) or feather mercury concentrations (1564 .6 ± 367.2 S.E. ng/g dw regulated, 1149.0 ± 152.1 S.E. ng/g dw unregulated), one recently regulated stream (Douglas Creek, commissioned in 2009) supported dippers with mercury concentrations of potential toxicity concern (up to 1824.6 ng/g ww in whole blood and 8459.5 ng/g dw in feathers). Relative to other passerines across western North America, dippers in the densely forested mountain streams of coastal British Columbia experienced high mercury exposure, regardless of stream type (regulated or unregulated). Elevated mercury in dippers is likely attributable to the birds' relatively high trophic position and high regional inorganic mercury deposition; however, biogeochemical conditions in reservoirs of some regulated streams may be contributing to methylmercury production. The long-term consequences of year-round occupancy and foraging in headponds requires further investigation, as RoR dams have the potential to increase methylmercury production in slow-flowing stream reaches that already experience high inorganic mercury deposition.



American dipper whole blood Hg (log_{10} ng/g ww, n=53 samples from regulated and 39 samples from unregulated streams) and feather Hg (log_{10} ng/g dw, n=59 samples from regulated and 38 samples from unregulated streams) concentrations at regulated and unregulated streams. Streams sharing a common letter were not significantly different in Hg concentration (p-value > 0.05 from post-hoc Tukey test)

Evaluation of 2017 Central Basin ambient subtidal sediment chemistry monitoring results

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1. KC DNRP

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- **2017 subtidal sediments at ambient stations in Puget Sound's Central Basin met most State Sediment Quality Standards with the exception of mercury and benzoic acid.**
- **Benthic macroinvertebrate community analysis was added in 2017 and will allow for a more holistic assessment of sediment quality changes over time.**

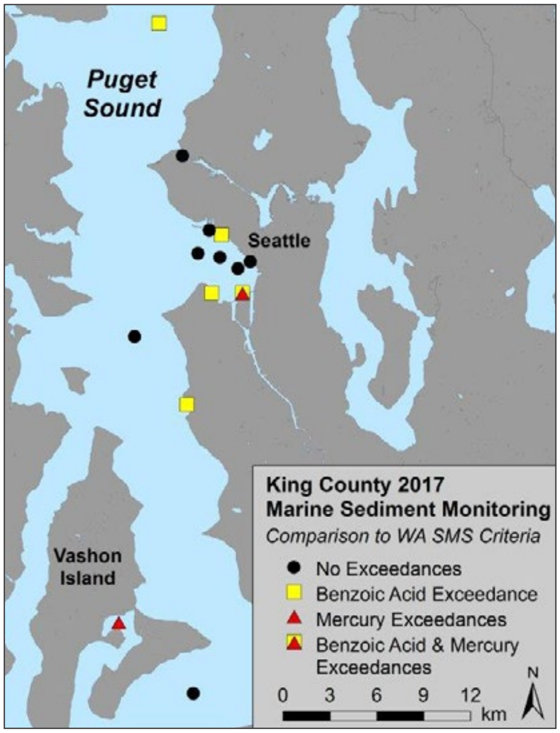
The primary goal of King County's marine ambient sediment monitoring program is to collect data of known quality in order to effectively characterize marine sediments within the County's jurisdiction. The County has been collecting sediment chemistry data from subtidal monitoring stations for several decades, with the most recent program iteration starting in 2007. The current program includes a total of 14 stations. Six of the stations are sampled every five years and located in either deep depositional areas or small shallow water embayments within Puget Sound's Central Basin. The remaining eight stations are located in Elliott Bay, and are sampled every two years. These data allow for the evaluation of spatial and temporal changes in sediment quality within King County's marine waters.

All 14 stations were sampled in June 2017 for conventional parameters (total solids, organic carbon, total sulfides, ammonia nitrogen, and grain size), sediment chemistry (including all WA Sediment Management Standard [SMS] priority chemicals), and triplicate benthic infauna samples. Sediment chemistry samples included the top 2 cm of sediment in order to collect the most recently deposited material. Although the SMS are based on the full biologically active zone (10 cm), the 2 cm samples are nonetheless compared to SMS to evaluate sediment quality.

In 2017, 7 of the 14 stations had no exceedances of the SMS. In Elliott Bay as well as the other Central Basin stations, benzoic acid was the most commonly exceeded SMS with exceedances at five stations including three in Elliott Bay. Additionally, two stations, located in near Harbor Island in Elliott Bay and in Quartermaster Harbor, exceeded the SMS for mercury (see figure). Mercury SMS exceedances are common, particularly in Elliott Bay, due to a combination of historical contamination as well as ongoing sources. While exceedances of benzoic acid in the Central Basin are not uncommon, they are typically not persistent at any one station. Benzoic acid has natural as well as man-made sources and is a precursor to many manufactured chemicals. Previous monitoring results indicate that while concentrations may be high during one sampling event, it is unlikely that exceedances will be encountered during the following event. No other SMS were exceeded in the ambient surface sediments.

In conjunction with sediment chemistry data, benthic infauna sampling was added to the ambient monitoring program at all stations starting in 2017. While the results have not been discussed here, the inclusion of benthic infauna community data in this and future sampling events will allow for a more comprehensive assessment of sediment quality changes within Puget Sound's Central Basin.

King County's Field Science Unit collecting marine sediment samples in Elliott Bay. Photo: Wendy Eash-Loucks



Map of King County's 2017 ambient sediment chemistry results in Puget Sound's Central Basin. Symbols indicate whether Washington Sediment Quality Standards (SMS) were exceeded at each station.

Legacy priority pollutants in sediments of the southern Salish Sea

DEPARTMENT OF ECOLOGY State of Washington

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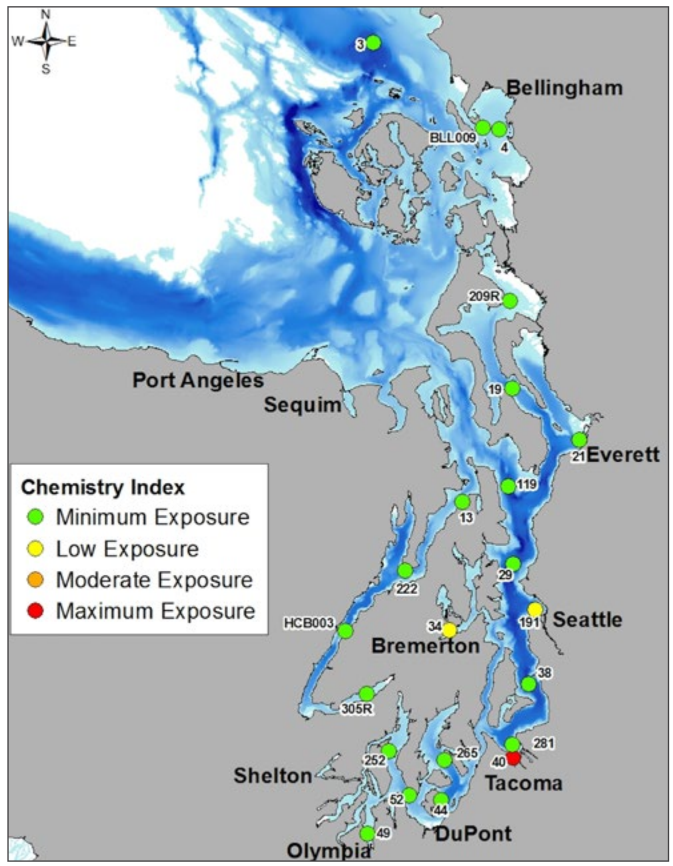
- **Ecology's Sediment Chemistry Index indicates overall minimum exposure to legacy priority pollutants.**

The Washington State Department of Ecology (Ecology) conducts long-term monitoring of marine sediment condition throughout Puget Sound. Sediment condition is evaluated annually with calculated indices based on outcomes of laboratory analyses, including determination of potentially toxic chemical concentrations. In 2016, Ecology analyzed for 90 priority chemicals in the top 2 to 3 cm of sediment at 22 locations.

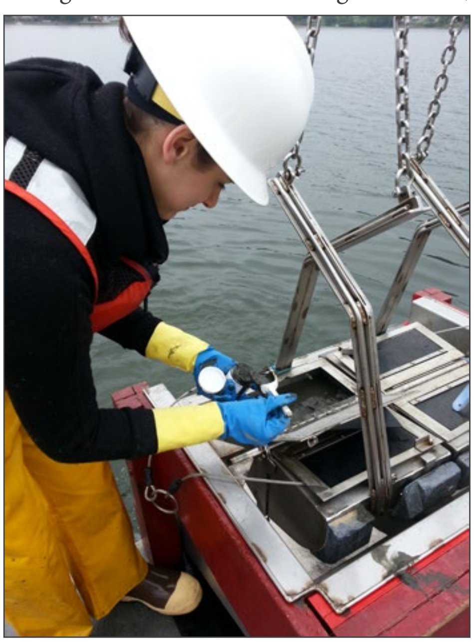
Many of the individual chemicals measured were not present at concentrations above the reporting limit of the analytical methods. Chemical classes that were detected at least 89% of the time included metals and polycyclic aromatic hydrocarbons (PAHs). Chemical classes that were detected less than 20% of the time included polybrominated diphenylethers (PBDEs), polychlorinated biphenyls (PCBs), and phthalates. Several of the chemicals had concentrations higher than (not meeting) their respective WA State Sediment Quality Standards (SQS; Ecology, 2013). One or more of the SQSs were not met at two sites: mercury exceeded the standard in Sinclair Inlet (Station 34); and several PAHs exceeded their respective standards in Commencement Bay (Station 40), including total high molecular weight PAHs, phenanthrene, indeno(1,2,3-cd)pyrene, fluoranthene, dibenzo(a,h) anthracene, benzo(g,h,i)perylene, and benzo(a)pyrene.



Spatial patterns of Chemistry Index categories based on 2016 sampling.

The Chemistry Index is a multi-chemical index that is used to estimate the exposure of benthic invertebrates to complex mixtures of potentially toxic chemicals that may accumulate in Puget Sound sediments. The values are based on the ratio of measured chemical concentrations to their respective SQSs. Index values are used to categorize sediments as having minimum, low, moderate, or maximum exposure to these chemicals (Long et al., 2012).

The Chemistry Index indicated that the vast majority, 19 of 22, of the monitoring locations had minimum exposure to chemicals of concern (Figure 1). Two sites, one in Sinclair Inlet and one in Elliott Bay, had low exposure. One site in Commencement Bay had high exposure. The 2016 results were consistent with previous findings summarized in Weakland et al., 2017, 2018; Partridge et al., 2018.



Collection of Puget Sound sediments. Photos: WA State Department of Ecology's Marine Sediment Monitoring Team

Nearshore sediment monitoring for the Stormwater Action Monitoring (SAM) program, Puget Sound, Western Washington

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https://doi.org/10.3133/sir20185076
https://ecology.wa.gov/sam https://www.usgs.gov/centers/wa-water

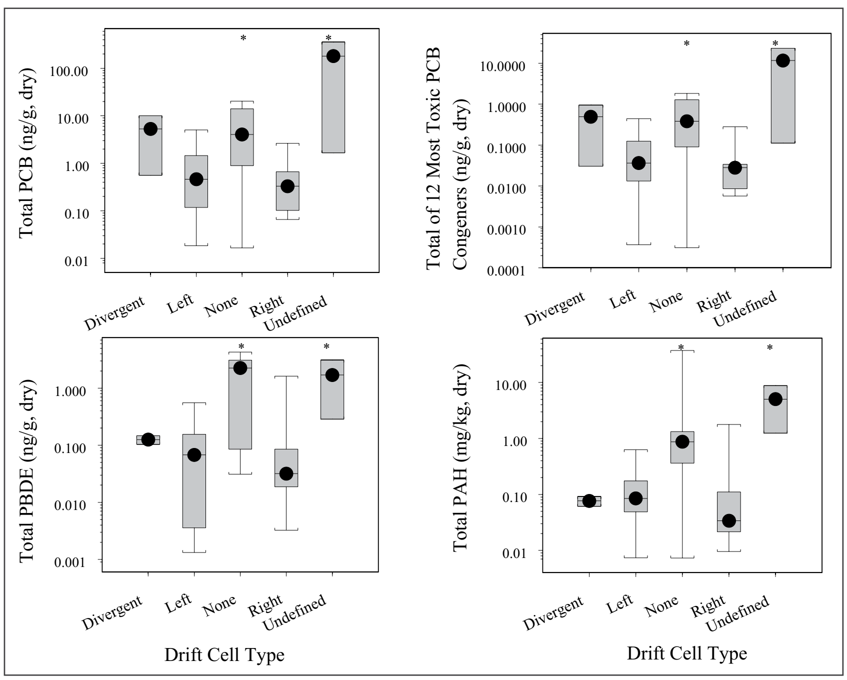
- **Chemical concentrations of metals and organics in nearshore sediments adjacent to Urban Growth Areas are generally low.**
- **Nearshore sediment chemical concentrations are significantly related to Puget Sound Drift Cells.**

Chemicals such as metals and organics (polychlorinated biphenyl [PCBs], polybrominated diphenyl ethers [PBDEs], polycyclic aromatic hydrocarbons [PAHs], and phthalates) continue to enter Puget Sound from point sources, combined sewer outfalls, and non-point sources. Runoff during storm events has been identified as a major source of contamination entering Puget Sound and has been implicated in the degradation of nearshore habitats and biota. Metals, organic chemicals, and other pollutants are known to accumulate in sediments such as those present along the shoreline of Puget Sound. As part of the Stormwater Work Group of Puget Sound's strategy to address sediment conditions in the nearshore, a regional monitoring program was designed to inform requirements for municipal stormwater permits issued by the Washington State Department of Ecology (Ecology). The monitoring program is referred to as the Stormwater Action Monitoring (SAM).

The focus of the initial monitoring effort was to characterize the status, spatial extent, and quality of Puget Sound sediment chemicals in nearshore sediment adjacent to Urban Growth Areas (UGAs). Sampling sites were selected using a spatially balanced probabilistic Generalized Random Tessellation Stratified (GRTS) sampling design. A benefit of the GRTS sampling design is that it allows one to extrapolate from a small number of sampled nearshore sites to the entire UGA nearshore shoreline of Puget Sound.

A total of 41 randomly selected sites were sampled in late summer of 2016. All sampling sites were located at 6 feet below the Mean Lower Low Water line. The top 2–3 centimeters of sediment were collected using a box corer and sieved to 2 millimeters and analyzed for PCBs, PBDEs, PAHs, phthalates, metals, total organic carbon, and grain size. Multiple statistical approaches were used to examine relations between chemical concentrations and land cover within the watersheds adjacent to sampling sites. The influence of marine hydrodynamic factors on nearshore sediment chemical concentrations was evaluated by assigning each site to one of five nearshore drift cell types based on its location. Each drift cell represents a long-term directional transport of sediment from its source to its depositional zone.

The nearshore sediment chemical concentrations for organics and metals were low, and in most cases less than criteria. The concentrations of some PAHs were greater than criteria, but these exceedances were limited to one or two sites. Based on study findings, 96% of the 1,344 km of UGA Puget Sound shoreline have PAH sediment concentrations less than criteria, while PCBs and PBDEs concentrations are less than criteria at more than 98% of the UGA shoreline. For metals, 100 percent of the nearshore sediment had concentrations less than criteria. While measured watershed attributes adjacent to the sampling sites were weakly related to chemical concentrations, concentrations were significantly related to drift cell types. Sediment chemical concentrations were significantly higher in drift cells with limited sediment movement compared to those with higher sediment transport energy. The results of this study will help Ecology refine municipal stormwater permit requirements as well as help other agencies develop nearshore and marine monitoring and restoration programs.



Box plots summarizing nearshore sediment chemistry concentrations by drift cell type. Divergent: drift cells with divergent flow, Left: drift cells flowing left to right looking at the shore, None: low energy drift cells with no specific flow direction, Right: cells flowing right to left looking at the shore, Undefined: cells with undefined flow (for this study, these cells were low energy). *: significantly higher concentrations.

Boundary Bay Ambient Monitoring Program - program assessment

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- **The program has met its objectives but would be improved by modifying some program components.**
- **Most monitoring results met provincial Ministry of Environment objectives and guidelines in this program cycle.**

The Boundary Bay Ambient Monitoring Program (BBAMP), one of four ambient monitoring programs conducted by Metro Vancouver Regional District, is unique in that Boundary Bay does not directly receive effluent from any of Metro Vancouver's wastewater treatment plants. However, Boundary Bay is ecologically significant and is subject to occasional sewer overflows and stormwater discharges. Initiated in 2009, BBAMP aims to provide baseline environmental quality data, characterize changes in water quality parameters, identify any changes in parameters that might indicate environmental changes, and act as a measure of performance for Metro Vancouver's Integrated Liquid Waste and Resource Management Plan.

After completing a full 5-year cycle, a program review and assessment was conducted in 2016-2017 on data generated between 2009 and 2015. The purpose of the assessment was to summarize the results of the water, sediment and biota studies as they relate to each other, critically review the program and provide recommendations for future monitoring. The assessment examined both catchments and the bay, however the focus here is the Boundary Bay marine receiving environment.

Program Assessment Key Findings:

Marine Water Quality. Analysis generally included physical and general parameters, nutrients, enteric bacteria, and total metals.

- Majority of results met the Boundary Bay Water Quality Objectives and BC Water Quality Guidelines.
- Dissolved oxygen was below guidelines at most sites, but consistent with levels in marine coastal waters.
- Some fecal coliform level exceedances occurred at two of the 11 sampling sites.
- Limited organics analysis was conducted, but all results were lower than the analytical detection limits and guidelines.
- Water is well mixed with no significant difference observed at the two depths measured, between-sites or temporally.
- When clustered, results for some parameters were higher in near-field than far-field sampling sites (near-field sites are closer to shore and shallow).
- Results from wet season sampling were higher than dry period sampling for all sites.

Sediment Monitoring. Analysis included sediment texture, fecal coliforms, metals, acid volatile sulfides and simultaneously extractable metals, polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides and polychlorinated biphenyls (PCBs).

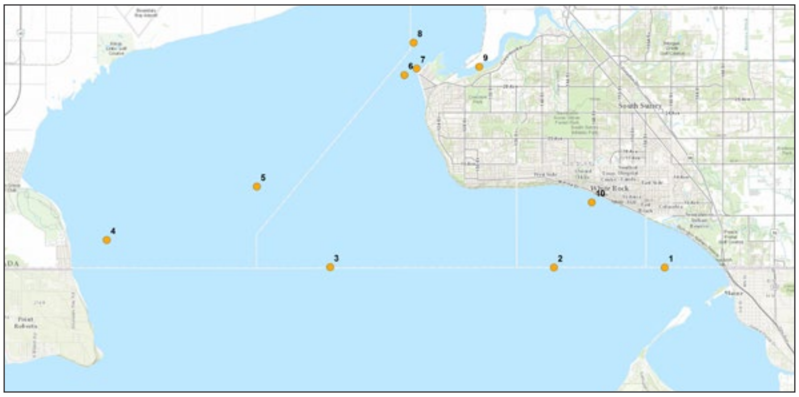
- Most measured substances met objectives or guidelines.
- The concentrations of metals and organics are highly dependent upon sediment particle size.
- Only one site had fine sediment with higher results for several parameters.

Biota Monitoring. Mussel tissue analysis included moisture, lipids, metals, PAHs, PCBs, polybrominated diphenyl ethers (PBDEs) and organochlorine pesticides.

- Caged mussels had high survival rates.
- Tissue concentrations for containments met guidelines.
- At near-field sites, contaminant concentrations were higher in caged mussel tissues and lipid content.
- Macro benthos showed a high degree of variation, but likely due to natural variability.

Program Assessment Recommendations:

- Dry season water sampling can be eliminated and sampling sites reduced.
- Sediment component is the least valuable and should be re-evaluated in the context of the bay's geomorphology and physical oceanography.
- Caged mussel study should be repeated at 5-year intervals and data interpreted on an eco-toxicological concentration response perspective, and compared with the US Mussel Watch database.
- Benthic community characterization should be re-interpreted against data from similar areas in the Salish Sea.



Map of Boundary Bay Ambient Monitoring Program marine water column sampling sites.

PCBs in Green-Duwamish juvenile Chinook

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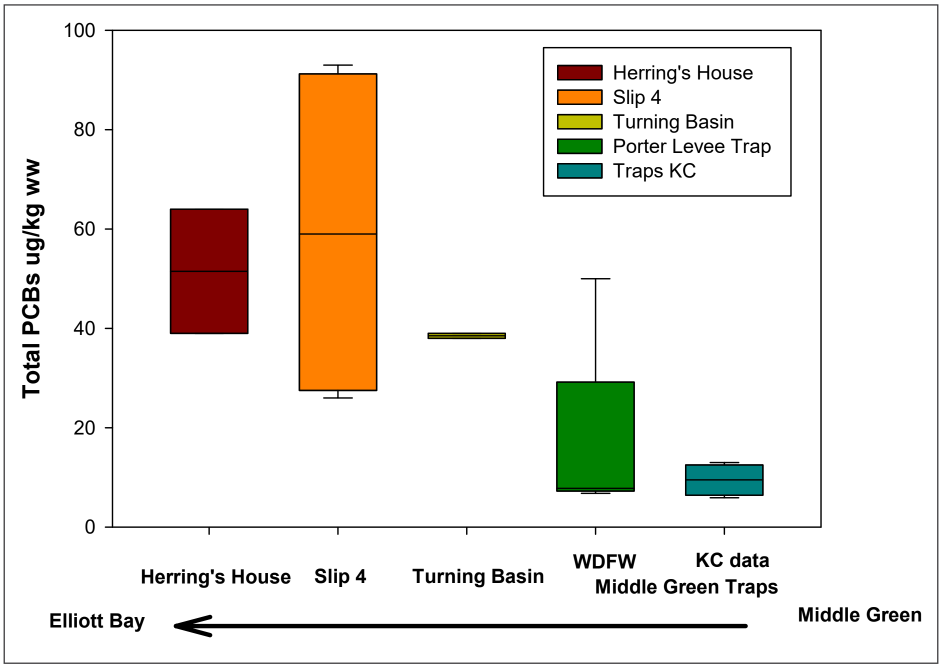
- **Total PCB Aroclor concentrations for juvenile Chinook samples collected from two Middle Green River traps and analyzed by King County were low (6-13 ug/kg) and within the range found by WDFW in fish from their Middle Green River screw trap.**
- **PCB concentrations in juvenile Chinook collected from the Lower Duwamish River and Green River show that concentrations increase with distance downstream.**

Polychlorinated biphenyls (PCBs) and other persistent bioaccumulative contaminants are known to accumulate in fish residing in the Lower Duwamish River. However, existing sediment chemistry data also suggest contaminant concentrations in the Lower Green River sub-basin may be high enough to impact aquatic life. Juvenile Chinook salmon spend variable lengths of time in different reaches of the Green-Duwamish system before entering Puget Sound. Recent publications on Green-Duwamish juvenile Chinook body burden and adult return rates (Meador, 2014; O'Neill pers. comm., 2018; O'Neill et al., 2015) suggest Chinook salmon health and survival may be impacted by exposure to PCBs or other contaminants in the Green-Duwamish River. Understanding the relative contributions of Lower Green River and the Lower Duwamish River to overall contaminant exposure for juvenile Chinook will indicate if there is a need to address contaminant sources upstream of the Lower Duwamish River to improve juvenile Chinook health and survival.

In 2013, King County initiated a long-term tissue monitoring program for three major lakes (lakes Sammamish, Washington, and Union) and two major rivers (Green and Cedar rivers). Each waterbody is monitored every 5 years. In 2017, King County collected fish from the Lower and Middle Green River and obtained juvenile Chinook from a Washington Department of Fish and Wildlife (WDFW) smolt trap and a Muckleshoot screw trap in the Middle Green River. One whole body composite sample of hatchery and three composite samples of wild juvenile Chinook were analyzed for PCB Aroclors. All but one of the wild composite samples were also analyzed for PCB homologues. Total PCB concentrations based on Aroclors were higher than those based on homologues. The Total PCB Aroclor concentrations for these four samples were low (6-13 ug/kg) and within the range found by WDFW in Chinook collected from their Middle Green River screw trap (O'Neill pers. comm., 2018). Juvenile Chinook concentrations collected to date from the Lower Duwamish River and Green River show PCB concentrations increase with distance downstream.



Total PCB Aroclor concentrations in juvenile Chinook. Data: WDFW and King County

PBTs in freshwater fish of the Lake Washington watershed

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1. KC DNRP

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- **A fish advisory based on PCB levels in smallmouth bass from Lake Union is justified. Total PCBs are at levels of concern for human health.**
- **A fish advisory is not necessary for total PBDEs since measured concentrations in fish from the three major lakes were below levels of concern for human health.**

In 2013, King County initiated a long-term freshwater tissue contaminant monitoring program for three major lakes (lakes Sammamish, Washington, and Union) and two major rivers (Green and Cedar rivers). The program collects samples from one waterbody every 5 years. Fillet and whole-body fish and invertebrate tissue chemistry data from this program are used to track changes over time to assess management actions and evaluate the risk of adverse effects to aquatic life and humans from fish consumption. All samples are composites of tissue from 3-5 fish.

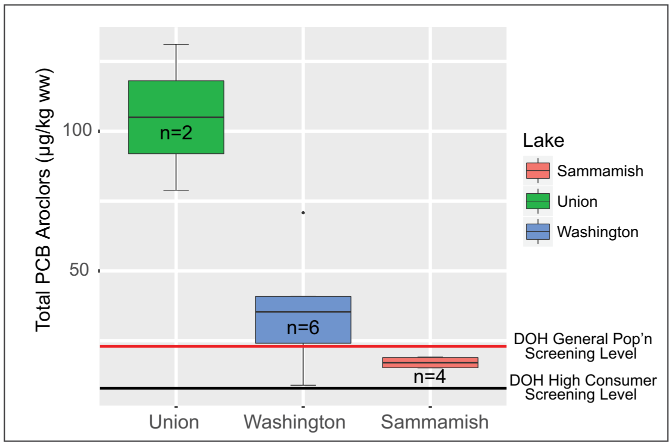
As of 2017, King County completed tissue monitoring from all three major lakes. Lake Washington was sampled in 2014 and lakes Sammamish and Union were sampled in 2015 and 2016, respectively. A variety of species were collected across the lakes, but smallmouth bass and yellow perch were most consistently captured, and provide high and mid-trophic level metrics of bioaccumulation, respectively. Concentrations of persistent bioaccumulative toxic (PBT) contaminants in fillet tissues were usually highest in Lake Union, and lowest in Lake Sammamish.

Total polychlorinated biphenyl (PCB) concentrations in smallmouth bass fillets from lakes Washington and Union were above the Washington Department of Health (WDOH) general population screening level for fish consumption. There is a state-issued fish consumption advisory for PCBs on smallmouth bass, but Lake Union fish appear to be more contaminated and may also warrant an advisory. Total DDT levels in smallmouth bass from all three lakes were below WDOH screening levels, but above the Clean Water Act (CWA) Section 303(d) tissue level cancer endpoint. Based on the Washington Department of Ecology Water Quality Assessment Policy 1-11 revisions, the lakes would be considered impaired for DDT. Polybrominated diphenyl ether (PBDE) concentrations in smallmouth bass and yellow perch were four times below WDOH screening levels. Mercury concentrations in smallmouth bass and yellow perch were above the WDOH general population screening level which is consistent with the state-wide fish consumption advisory for mercury.

Overall, the King County fish tissue monitoring results indicate:

- Total PCB concentrations in smallmouth bass from Lake Union are at levels of concern for human health.
- Total PBDE concentrations are below levels of concern for human health in all three major lakes; a fish advisory is not necessary at this time.
- Total DDT concentrations in smallmouth bass could justify CWA 303(d) impairment listing for Lake Union.

Three major lakes sampled by King County in the Lake Washington watershed.



Concentrations of PCBs in smallmouth bass from Lakes Union, Washington and Sammamish compared to Washington Department of Health (WDOH) screening values.

2016 Survey of per- and poly-fluoroalkyl substances (PFASs) in Washington rivers and lakes

DEPARTMENT OF ECOLOGY State of Washington

Callie Mathieu[1], Melissa McCall[1]

1. Ecology

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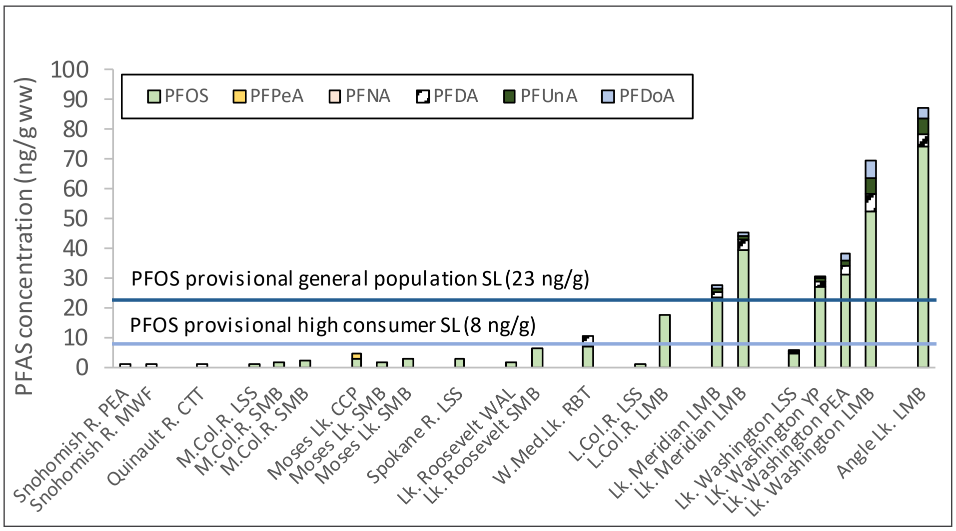
https://ecology.wa.gov/toxicsstudies

- **PFASs were detected in less than half of surface waters tested, but frequently detected in WWTP effluent, freshwater fish, and osprey eggs.**
- **Urban lakes had a relatively high percent contribution of PFOS in surface waters and contained the highest PFOS concentrations in biota.**

Per- and poly-fluoroalkyl substances (PFASs) are a group of man-made chemicals used in many industrial and consumer products, such as water-, stain-, and oil-repelling coatings, and firefighting foams. In 2008, the Washington State Department of Ecology (Ecology) found low levels, but widespread occurrence, of PFASs in Washington State freshwater systems (Furl & Meredith, 2010). Ecology conducted a follow-up study in 2016 to characterize current environmental levels of PFAS contaminants following shifts in manufacturing (Mathieu & McCall, 2017). Across the state, Ecology collected surface water from 15 freshwater sites, effluent from 5 wastewater treatment plants (WWTPs), freshwater fish from 11 sites, and osprey eggs from 3 sites for analysis of a suite of PFAS compounds.

PFASs were detected in 43% of surface water samples, 100% of WWTP effluents, 86% of fish fillet samples, 100% of fish liver samples, and 100% of osprey eggs. PFAS concentrations and detection frequencies in all matrices sampled were consistent with those recently reported for other nonpoint source waterbodies in North America and Europe (MDEQ, 2015; Zang et al., 2016; Eriksson et al., 2016) and 1-2 orders of magnitude lower than waterbodies known to be impacted by firefighting foam use or PFAS manufacturing facilities (Anderson et al., 2016; MDEQ, 2015; Newton et al., 2017; Lanza, 2016; Gewurtz, 2014).

Of the waterbodies sampled for this study, PFASs were predominantly detected in surface water collected from urban lakes (Angle Lake, Meridian Lake, and Lake Washington), and waterbodies receiving WWTP effluent (West Medical Lake and South Fork Palouse River). Surface waters from the urban lakes displayed distinct compound profiles from the WWTP-impacted waterbodies. Urban lakes contained a higher relative percent contribution of perfluorooctane sulfonate (PFOS), while the WWTP-impacted waterbodies were dominated by perfluoropentanoic acid (PFPeA), perfluorooctanoic acid (PFOA), and perfluorohexanoic acid (PFHxA). PFASs were generally not detected in surface water of rivers draining to the Salish Sea (Nooksack River, Puyallup River, and Snohomish River) or other ambient river sites in Washington.



PFAS concentrations (ng/g ww) measured in freshwater fish fillet samples collected in Washington State in 2016. Each bar represents one 3-5 fish composite of skin-on fillet tissue. Only detected compounds are presented in the graph. Perfluorobutanoic acid, perfluorohexanoic acid, perfluoroheptanoic acid, perfluorooctanoic acid, perfluorobutane sulfonate, and perfluorohexane sulfonate were analyzed but not present above the limit of quantitation. PFOS = perfluorooctane sulfonate, PFPeA = perfluoropentanoic acid, PFNA = perfluorononanoic acid, PFDA = perfluorodecanoic acid, PFUnA = perfluoroundecanoic acid; PFDoA = perfluorodecanoic acid, R. = River, Lk. = Lake, M. Col. = Mid-Columbia, W. Med. = West Medical, L. Col. = Lower Columbia, LSS = largescale sucker, SMB = smallmouth bass, CCP = common carp, WAL = walleye, RBT = rainbow trout, LMB = largemouth bass, YP = yellow perch, PEA = peamouth. DOH SL = WA Department of Health Screening Level; this is a provisional screening level that applies to PFOS only, which may trigger a fish consumption advisory after risk management and risk communication issues are considered by DOH toxicologists in assessing a waterbody for fish consumption.

Fillet and liver tissues of freshwater fish collected from the urban lakes contained the highest PFAS concentrations statewide (Figure 1). The highest osprey egg concentration was found at Lake Washington, as well. PFOS was the dominant compound found in all biota samples, making up 60-100% of the total PFAS burden. Other long-chain PFASs were frequently detected in biota samples at lower levels, while short-chain PFASs were rarely detected in fish or osprey eggs. Additional testing of fish tissue in urban waterbodies is planned for 2018 to assess the waterbodies for fish consumption advisories.

Pilot study of pesticides in Washington State stream sediment

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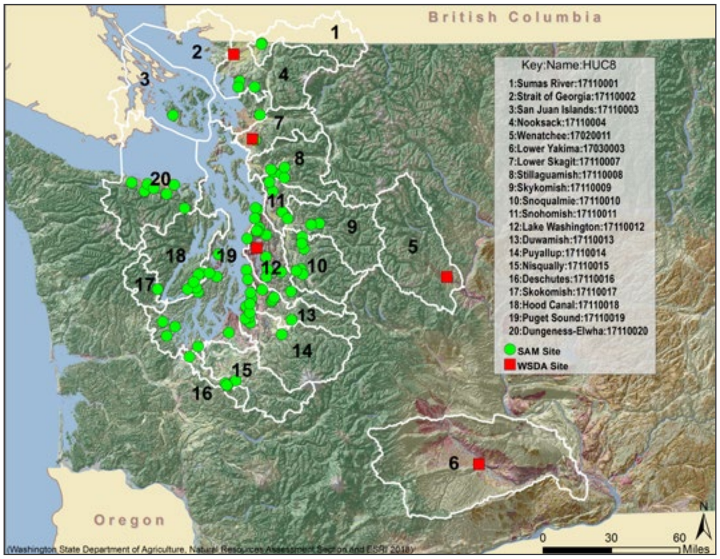
- **This partnership between several agencies allowed for a large scale sampling effort targeted towards pesticides in Washington State sediments.**
- **Bifenthrin, DDT and DDT degradates were the most commonly detected pesticides in this pilot study.**

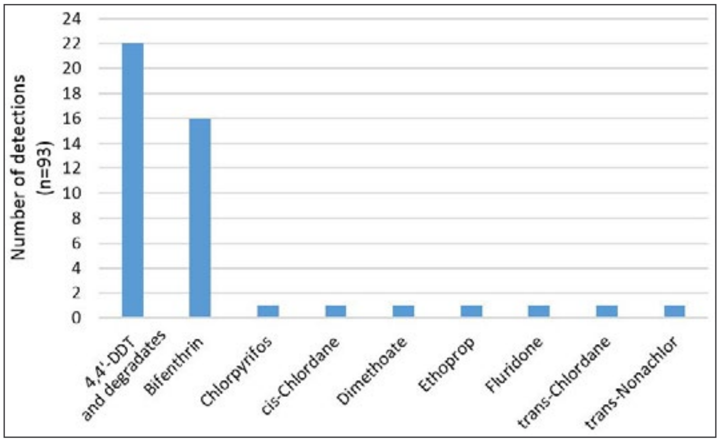
The Washington State Department of Agriculture (WSDA) has been implementing an ambient surface water monitoring program in agricultural and urban areas since 2003. The program has grown to include 14 sites and tests for over 100 pesticides during the growing season (March-October). The program's goal is to assess the frequency and magnitude of pesticide detections in surface waters.

In 2015 WSDA decided to assess the presence and magnitude of pesticides specifically in sediment, which has not previously been part of the ambient surface water monitoring program. It is well documented in the literature that chemicals will partition between matrices, and, especially if hydrophobic in nature, will accumulate in bottom sediment (Di Toro et al., 1991). This is especially a concern for endangered salmon species and their dependence on invertebrate communities as a source of food (Groot & Margolis, 1991).Through cooperation with the Manchester Environmental Laboratory, Stormwater Action Monitoring program, the Washington State Department of Ecology, the United States Geological Survey and the King County Environmental Laboratory sediment was collected at a total of 86 sites and analyzed for 126 current use and legacy pesticide compounds and total organic carbon. Sampling took place between April 6 and October 2, 2015.

Of the 93 samples collected, 12 unique compounds were detected in 28 of the samples. The current use insecticide bifenthrin, the legacy pesticide DDT and its degradates DDD and DDE were the most commonly detected, accounting for 36% and 49% of the total detections, respectively. Bifenthrin, a pyrethroid insecticide, was found at or above assessment criteria in 13 of the 16 samples in which it was detected. Detections above assessment criteria are considered toxic to benthic invertebrates. Reporting limits ranged from 12 µg/kg DW (dry weight) to 110 µg/ kg DW for different analytes, but also varied between analytical batches. Although there was an overall low frequency of detections, this study suggests bifenthrin toxicity in sediment is a concern. Collaboration and coordination with the agencies involved with this pilot study and other interested parties for future sediment monitoring is recommended.



WA state map of WSDA sampling locations (red) and Stormwater Action Monitoring sites (green) with Hydrologic Accounting Unit (8-digit HUC) boundaries.



Frequency of detected pesticides in Washington State freshwater stream sediments.

At left: Marion Drain near Granger, WA. A sampling location for the Pesticides in Washington State Sediments Pilot Study. Photo: Abigail Nickelson

Assessing biological condition in small streams of the Puget Sound lowlands through collaborative regional monitoring

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https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Stormwater-monitoring/Stormwater-Action-Monitoring/SAM-status-and-trends/Puget-lowland-streams

- **Biological condition, represented by an index of biotic integrity, was poorer in streams within the urban growth areas of Puget Sound.**
- **The most important stressor on poor biological condition were related to watershed and riparian canopy cover.**

Stormwater runoff from urban and urbanizing areas is a major cause of habitat and water quality degradation in small streams. Local jurisdictions throughout Puget Sound are increasing their efforts to manage stormwater to reduce flow volumes and pollutants. The long-term goal of this study is to monitor how stream health changes over time in urban, urbanizing, and rural areas of the Puget Lowlands. In 2015, the Stormwater Action Monitoring (SAM) program evaluated the current condition of wadeable streams within urban growth areas (UGAs) and outside UGAs representing a range of urban development conditions and impacts of stormwater runoff on small streams. This is the first regional evaluation of stream health with a focus on areas covered by the municipal stormwater permits. The study questions for this first round of sampling are:

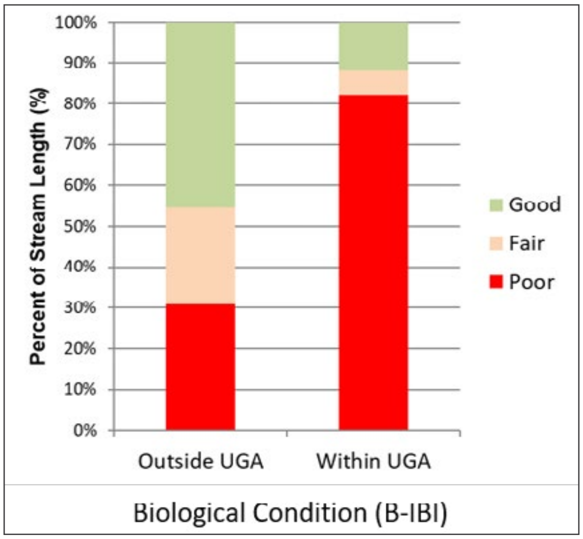
- What is the status of Puget Lowland ecoregion stream health within and outside UGAs?
- What percent of wadeable streams are in "poor" and "good" condition within and outside UGAs in comparison to least-disturbed reference site conditions in the region?
- What are the major natural and human stressors impacting stream health?

Stream health was evaluated using biological measures, water and sediment chemistry, and physical habitat conditions in streams and watersheds. A benthic invertebrate index of biotic integrity (B-IBI) was used as a comprehensive indicator of stream biological health. Nearly all of the stream health indicators (B-IBI, algae, water and sediment chemistry, habitat and landscape cover) were negatively influenced by urban development. While 69% of the stream length outside Urban Growth Areas (UGAs) was in good to fair conditions for B-IBI, 82% of the length within UGAs was in poor condition (Figure 1).

Key stressors associated with poor B-IBI scores were landscape-scale watershed characteristics, physical habitat, nutrients, sediment zinc, and stream substrate characteristics. Watershed and riparian canopy cover were found to be the most important stressors to B-IBI at the regional scale. This suggests that canopy cover protection and recovery (reducing impervious surface) could lead to substantial improvements in B-IBI scores.

Regional scale monitoring with spatially balanced sampling is a cost-effective way to evaluate unbiased status and trends in the ecoregion. SAM will continue to gather long-term status and trend data in the region. Over time this monitoring will tell us whether our overall management strategies, including stormwater management, are improving stream health.

A USGS hydrologist sampling water quality on Wapato Creek. Photo: Craig Senter, USGS



Percentage of total Puget Sound Lowland Ecoregion wadeable stream length in good, fair, and poor condition inside and outside of Urban Growth Areas (UGAs).

Diffusive gradient in thin-films: time integrated passive sampling for trace metals in receiving waters of Puget Sound

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https://marine.pnnl.gov/

- **Cd, Cu and Ni C_{DGT} capture linearity from 1 to 14 days displayed $R^2 > 0.987$, indicating high resolution.**
- **The ability to conduct constant surveillance of labile metals greatly improves the assessment of potential ecological effects from exposure.**

The Puget Sound Naval Shipyard (PSNS) & Intermediate Maintenance Facility at Naval Base Kitsap conducts an ambient monitoring program that measures trace metals and toxicity in the receiving waters of Sinclair and Dyes Inlets, Puget Sound. The ambient monitoring program provides an approach to assessing water quality in receiving waters and tracks progress in achieving water quality goals. The program recently added a new type of sampling called diffusive gradient in thin-film (DGT) to provide a time-integrated measurement of the bioavailable fraction of selected trace metals. This passive sampling allows for integrated capture as opposed to 1) grab sampling, which captures a single point in time, or 2) an auto-sampler setup, which is cost prohibitive when monitoring across large areas. The utilization of DGTs allows for the measurement of trace metal concentrations via chelation of labile metals (free and weakly complexed species), which more effectively represents the concentration of bioavailable metals and, therefore, more accurately represents the potential for biological effects compared to traditional dissolved metal analysis.

Field campaigns to record labile (C_{DGT}) Cd, Cu, Ni, Pb, and Zn concentrations have layered deployments in a manner that allows for response linearity to be defined for deployment times ranging from 24 hours to 14 days in areas with low to moderate ambient concentrations, and also in a manner that allows for capture of stormwater related pulses.

Uptake linearity and reproducibility by DGT for the program's three priority analytes Cu, Pb, and Zn displayed a range of results. In situ monitoring of Cu showed acceptable field reproducibility at 24 hours integrated C_{DGT} (14±17% as RPD; *n*=16), and uptake linearity of R^2=0.988 (Figure 1) over 1-14 day test periods. C_{DGT} Cu includes only weakly complexed Cu-DOC; providing an in situ correction for bioavailability due to DOC toxicity buffering. Ambient levels in the monitoring area averaged 6ng L^{-1} C_{DGT} Pb. While trend capture has been demonstrated at these levels using 72 hour deployments, 24 hour quantification was variable due to proximity of background concentrations on the DGT material; due to the time-integrated nature of this device an inverse relationship exists between DGT background levels and deployment time. Zn quantification via C_{DGT} displayed moderate variability at ≤7 days deployment at the low levels investigated. This is likely due to DGT resin binding selectivity, Zn-DOC kinetics, and proximity to sources. Cd and Ni performance were comparable to that of Cu. Condensing these results, balance between metals of concern and level of quantification must be considered when selecting DGT exposure periods.

The storm event C_{DGT} pulse capture studies in receiving waters at PSNS demonstrated successful quantification of Cu, which is shown in Figure 2. This figure also demonstrates non-saturation of resin after 50 days of deployment.

Research is demonstrating the value of integrating DGT sampling into ambient and stormwater monitoring programs. However, additional research is needed to understand the quantification limits, reproducibility, and representativeness of these measurements prior to incorporating into regulatory programs. Overall, DGT is expected to be an unparalleled tool for quantification of labile trace metals.

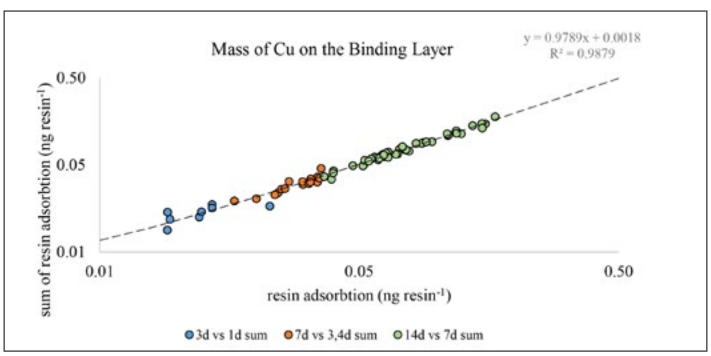

Figure 1. Analyte sensitivity when moving from 14 day to 1 day deployment time (*n* 1-day = 24; *n* 3 & 4-day = 32, *n* 14-day = 46, and *n* 7-day = 92). This comparison was made via overlaid deployments, where 3 and 4 day deployments were overlaid by a corresponding 7 day deployment; and consecutive 1 day deployments were overlaid by a 3 day deployment.

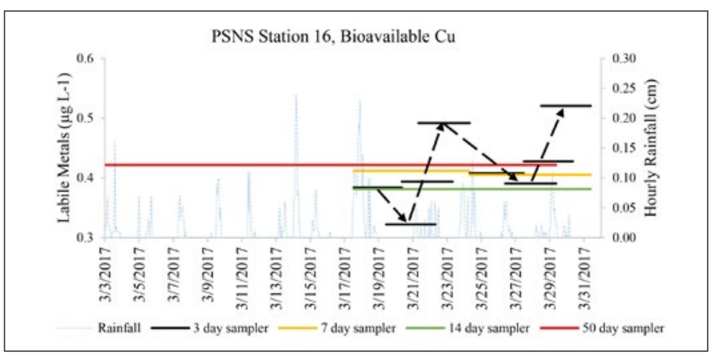

Figure 2. C_{DGT} Cu trend capture at PSNS field station PS16 during the spring of 2017; 72 hour deployments were staggered to capture stormwater related pulses (dashed black lines indicate pulse-induced shifts), in comparison to longer integrations.

Ambient monitoring to inform the protection of beneficial uses and achieve water quality goals in Sinclair and Dyes inlets, Puget Sound, WA

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- **Monitoring Program is focused on tracking environmental quality in the inlets that can be used to identify problems and evaluate effectiveness of corrective actions.**
- **Ambient monitoring and toxicity testing indicates improving effluent quality, that receiving waters are not toxic, though biota indicate some areas are elevated with PAHs, PCBs, Hg, and Cu.**

Currently discharge limits enforced under the Clean Water Act are focused on meeting water quality standards at the end of the pipe and environmental performance is measured based on meeting the discharge limits; but meeting discharge limits has very little to do with achieving water quality goals for coastal and estuarine ecosystems. Therefore, an effective monitoring and assessment program is needed to assess continuous process improvement, evaluate the ecological conditions, and provide metrics that can inform effective management of coastal and estuarine water quality.

As part of an integrated Environmental Investment (ENVVEST) project for Sinclair and Dyes Inlets (ENVVEST 2006; Johnston et al. 2009) a network of monitoring stations was established to characterize environmental conditions, assess potential impacts, and establish environmental quality trends within the Inlets. Water, sediment, and biota monitoring locations were selected that were co-located near suspected sources (industrial, waste water, and stormwater outfalls; marinas, stream mouths, and other sources) or were representative of ambient marine and nearshore conditions. Water column stations and effluents from industrial outfalls were sampled seasonally for trace metals (Cd, Cr, Cu, Hg, Pb, and Zn) using analytical procedures appropriate for seawater (Strivens, Brandenberger and Johnston, 2018), conventional parameters (salinity, dissolved and total organic carbon, total and suspended solids, dissolved O_2, pH, turbidity, NO_2+NO_3, NH_4, N, and P), and toxicity. Effluent and water column toxicity tests included mysid shrimp (*Americamysis bahia*) 96 hr survival, sand dollar (*Dendraster excentricus*) or purple sea urchin (*Strongylocentrotus*

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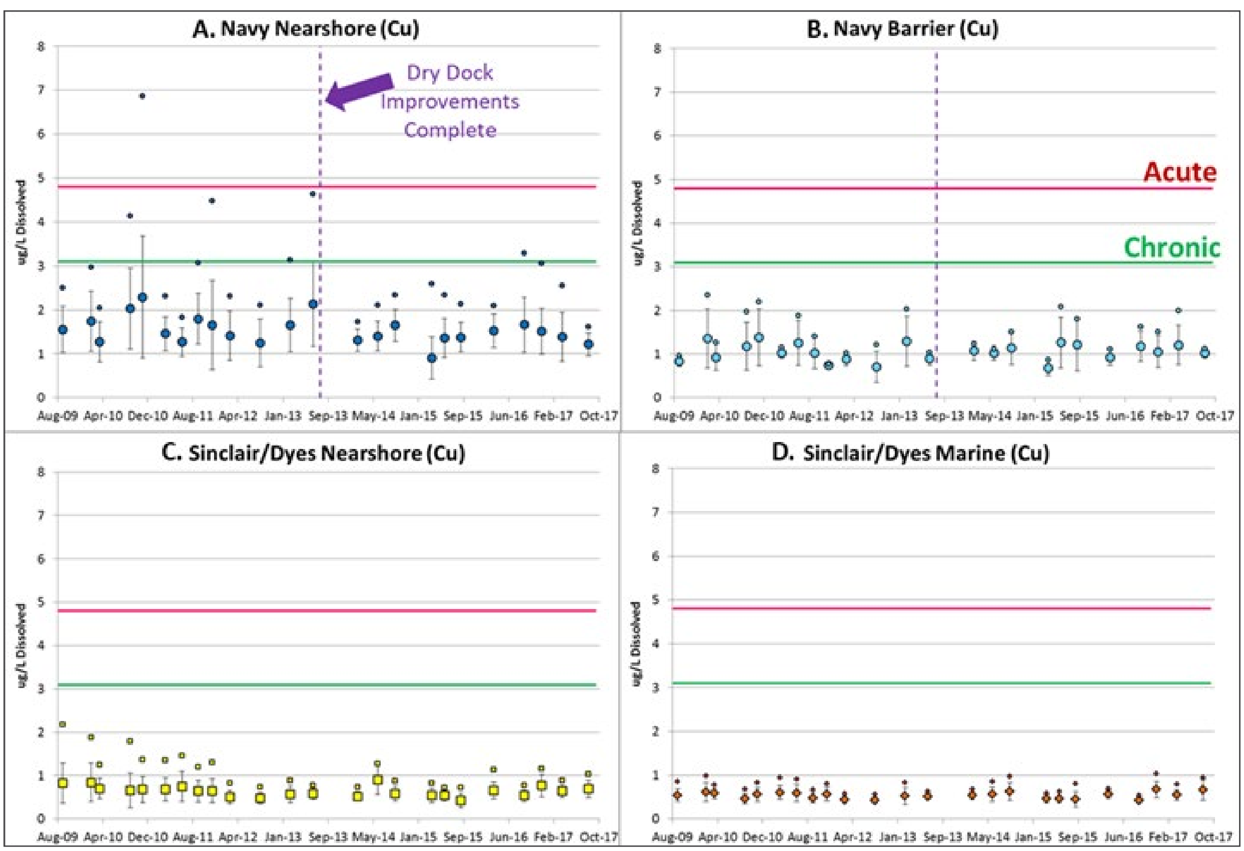

Figure 1. Concentrations of dissolved Cu (filtered through 0.45 µm filter) measured for seasonal sampling events within nearshore areas of the naval base (A. Navy Nearshore, n=13 stations), at the edge of the Navy security barrier (B. Navy Barrier, n=4), nearshore stations within Sinclair and Dyes Inlets (C. Sinclair/Dyes Nearshore, n=10-12), and marine stations located in the main channels of the Inlets (D. Sinclair/Dyes Marine, n=6-8). The data points show the mean (large symbol), standard deviation (error bars), and maximum concentration (small dot) of Cu measured for each sampling event. The water quality standards for acute (red line) and chronic (green line) exposure to Cu and the date dry dock BMPs were completed (purple dashed line) are also shown.

[CONTINUED]

purpuratus) 96 hr embryo development, QwikLite – dinoflagellate (*Pyrocystis lunula*) 24 hr bioluminescence response, mussel larvae (*Mytilus* sp.) 48 hr larvae survival and development, and kelp (*Macrocystis pyrifera*) 48 hr growth and germination. Additionally, indigenous mussels (*Mytilis* spp.) were sampled biennially for contaminant residues of metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), lipid content, and stable isotopes of C and N. The mussel data were compared to benchmarks of ecological effects (Johnston et al. 2007, Applied Biomonitoring 2009), samples obtained from a local seafood market harvested from Penn Cove on Whidbey Island (PKPLPC), and data from the national mussel watch status and trends monitoring program (Kimbrough et al. 2008).

Results from 2009-2016 showed that dissolved metals nearly always met water quality standards and that water quality in Navy nearshore areas appeared to improve after best management practices (BMPs) for industrial process improvements (US Navy 2012) were completed in Sept. 2013 (Figure 1). In general, toxicity from exposure to whole effluent samples was not observed and ambient water samples were not toxic to test organisms, except during the presence of algal blooms, which showed that toxicity was highly correlated with the abundance of the toxic algae *Gymnodinium splendens* (Rosen et al. 2009). Overall, mussel tissue residues were below benchmarks at most locations (Figure 2), however there were locations that had elevated levels of PAHs, PCBs, Hg, and Cu. Results from the monitoring provide metrics that are being used to assess progress toward meeting environmental quality goals for the watershed.

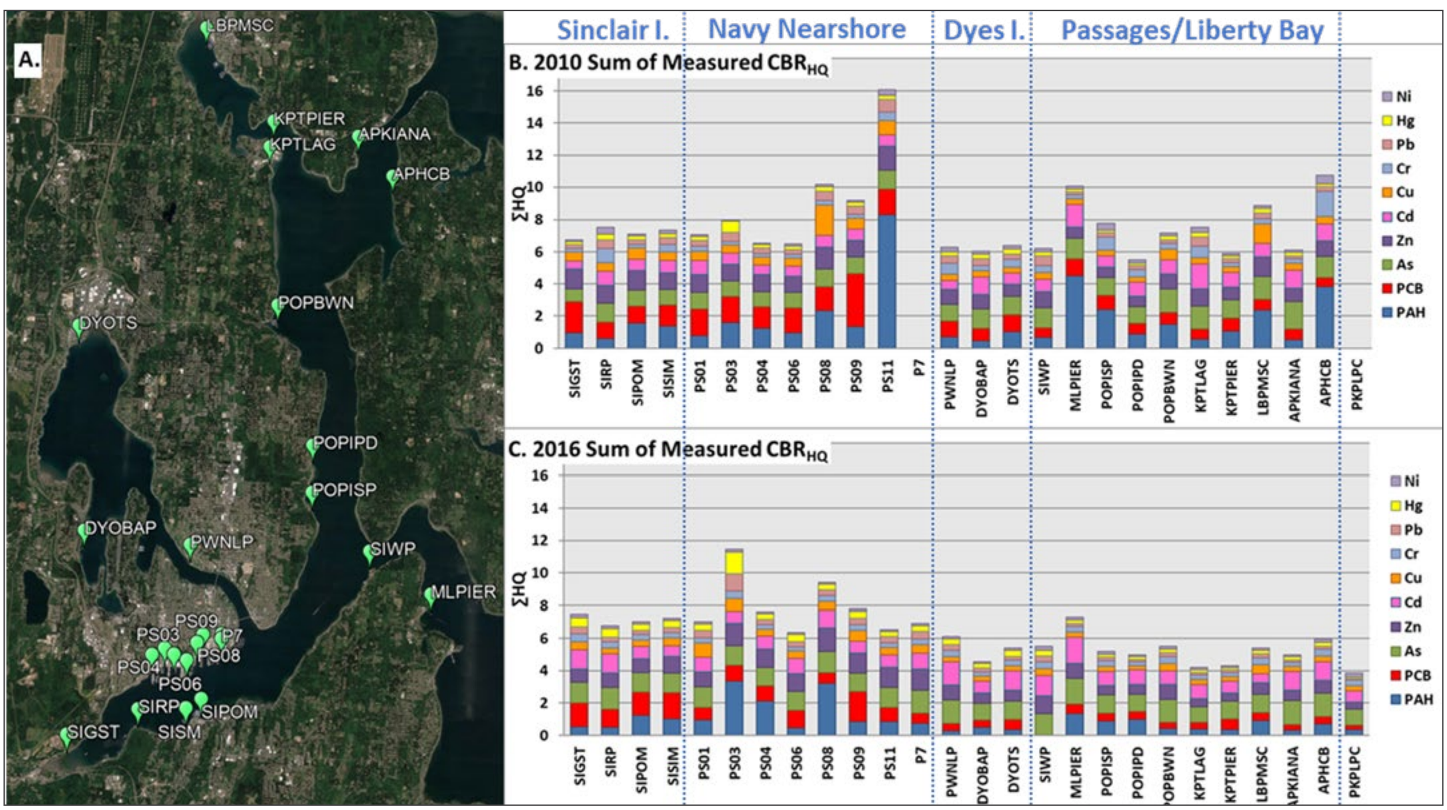

Figure 2. ENVVEST mussel watch sampling stations within Sinclair/Dyes Inlets and passages (A) and the sum of the Critical Body Residue (CBR) Hazard Quotient (HQ) determined from mussel (*Mytilus* spp.) tissue residue concentrations sampled in 2010 (B) and 2016 (C). The CBR is the concentration of a chemical in mussel tissues below which effects to mussel growth, reproduction, and survival are not expected (Johnston et al. 2007, Applied Biomonitoring 2009). The $\sum HQ = \sum C_i/CBR_i$, where C_i is the mussel tissue concentration of chemical *i*, CBR_i is the low effect dose for chemical *i*, and *i* = 10 (Ni, Hg, Pb, Cr, Cu, Cd, Zn, As, total PCBs, and the sum of 46 parent and alkylated PAHs). $HQ_i>1$ suggest some risk due to the presence of chemical *i*.

Macro and microplastics in the Salish Sea; are shellfish the canaries of our seas?

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- **Given the ubiquitous nature of macro and microplastics within our coastal ecosystems and the ability of shellfish to ingest these contaminants, plastics could be the greatest challenge as yet posed to both wild and farmed shellfish.**

Two recent studies from the Ecotoxicology Research in the Department of Biological Sciences, Simon Fraser University reported on possible additional stressors associated with plastics within coastal ecosystems.

The first study (Munier and Bendell 2018) showed that macro and microplastics collected from beaches within Burrard Inlet contained high levels of metals which could be a source of trace metal contamination to these coastal beaches. The second study (Kazmurik et al. 2018) determined the abundance and distribution of microplastics within 5 sediment size fractions (>5000 µm, 1000-5000 µm, 250-1000 µm, 0.63-250 µm and < 0.63 µm) for 16 sites within Lambert Channel and Baynes Sound, British Columbia, Three types of microplastics were recovered, micropellets, microfibers and microfragments. Microplastics were found at all sampling locations indicating widespread contamination of this region with these particles. Micropellets occurred in the greatest number (up to 25328/kg dry sediment) whereas microfibers and microfragments occurred in similar amounts and were much less in number as compared to micropellets (100-300/kg dry sediment). Micropellets have been shown to accumulate metals from the aquatic environment, hence in addition to the traditional geochemical components such as silt and organic matter, microplastics need too be considered as a sediment component that can influence trace metal geochemistry and thereby bioavailability. Of concern, oysters have been shown to ingest micropellets. Oysters exposed to micropellets have also been shown to be less fit with respect to reproduction and overall health. The high occurrence of microplastics within this region will have negative consequences on Canada's oyster farming industry and sets an example of the challenges that other shellfish growing regions of the world may be facing.

The west coast of BC has been home to a healthy shellfish aquaculture industry since the turn of the century. However, recent years has seen the industry facing the challenges presented by 70 years of human activity, the era of the Anthropocene. As shellfish both wild and farmed rely on clean cool waters rich in algae, any impact that alters these conditions will have consequences on shellfish health. And it is not one singular event, but rather the ocean environment serves to integrate all that we have done and are doing to our planet. Ocean acidification, a warming ocean, increased incidences of harmful algae blooms (HABS) and their associated shellfish borne diseases, increased incidences of viral infections, increased incidences of severe storm events, and now, the presence of microplastics which are being ingested by shellfish could combine to overcome an already struggling industry. Perhaps of greater concern, all that occurs for farmed shellfish will also be experienced by wild shellfish, a key species in marine ecosystems. Hence, shellfish serve as our canaries, showing us ahead of time, what might possibly be in store for our ocean ecosystems.

Shellfish; the canaries of our seas.

Are British Columbia blue mussels (*Mytilus edulis*) good indicators of microplastic pollution within the marine environment?

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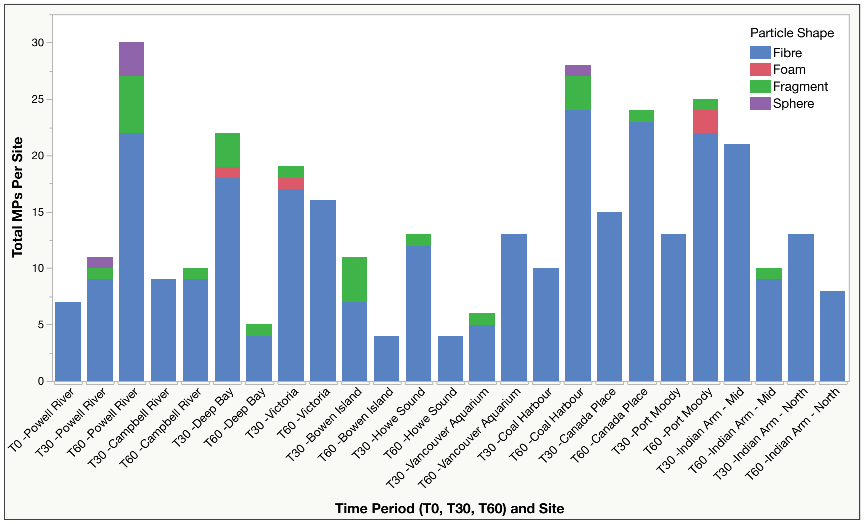
Blue mussels (*Mytilus* spp.) are an ecologically important species often referred to as "ecosystem engineers" due to the complex 3D habitats they create in coastal environments (Harley et al., 2006). Individuals are filter feeders, meaning they are exposed to a myriad of marine pollutants daily, and are used globally to assess ocean pollution through the International Mussel Watch program (Farrington et al., 2016). Plastic polymers <5mm in diameter, known as microplastics (MPs), are a newly established contaminant (Browne, Galloway, & Thompson, 2007) that may threaten the health of marine organisms. The objectives of our study were two-fold; 1) to determine MP abundances in British Columbia blue mussels as a function of space and time and 2) to determine if the blue mussel is a good indicator of marine MP pollution.

Mussels were provided by an aquaculture farm from Powell River, British Columbia. Individuals were from the same population and of similar size. A field program was conducted in winter 2017 (January – March) before spawning. Individuals (~5,000) were suspended at 1m depth (primarily floating structures) in lantern nets at 11 locations. Mussels were placed in lantern nets (n = 450) and left to filter insitu for 60 days. On Day 30, half of the mussels were collected from each site and the other half were collected on Day 60. Samples were frozen for MP analysis (-20°C).

To determine MP abundance within the shell cavity of each mussel, individuals were thawed, weighed and measured (to determine body condition index). Soft tissue was removed, placed into a 250 mL flask and digested using 0.4 ml of the Corolase enzyme (adapted Catarino et al. (2016)). The digestate was filtered through a 20µm filter paper (polycarbonate) and examined for MPs using visual microscopy. A random subsample of 'Suspect MPs' (10 – 15%) was sent to the Fourier Transform Infrared Spectrometer (FTIR) to determine polymer type. In total 200 mussels were digested for the study (8 mussels per site per time period). One procedural blank (PB) in every batch of 8 mussels was used to monitor for laboratory contamination.

- **Microplastics are present within the shell cavity of blue mussels located within the Strait of Georgia.**
- **In total, 378 'Suspect MPs' were identified in 179 blue mussels using visual microscopy. Final results will be corrected for contamination (using procedural blank data) and false positives using the information obtained after a random subsample of particles are examined by FTIR to determine polymer type.**

As of July 2018, a total of 378 'Suspect MPs' in 179 mussels have been identified which varied both spatially and temporally (Figure 1). The finalized dataset will consist of particle abundances (per individual mussel and per site) that have been confirmed as plastic using FTIR analysis and corrected for PB contamination. Polymer identification is required to account for false positives and negatives made during visual ID. Preliminary data indicates fibers as the dominant particle type, which is consistent with results reported within the northeastern Pacific Ocean (Desforges, Galbraith, Dangerfield, & Ross, 2014).



A total of 378 'Suspect Microplastics' were identified by visual microscopy in 179 mussels, as shown by site and deployment period (T0 = day 0, T30 = day 30 and T60 = day 60). 5-8 mussels were sampled per site/time period, except n = 1 for T60-Bowen Island.

Ocean Wise research biologist Julie Dimitrijevic places blue mussels (*Mytilus edulis*) in lantern nets. Photo: Ocean Wise

Exploration of microplastics in the lower Puyallup River watershed

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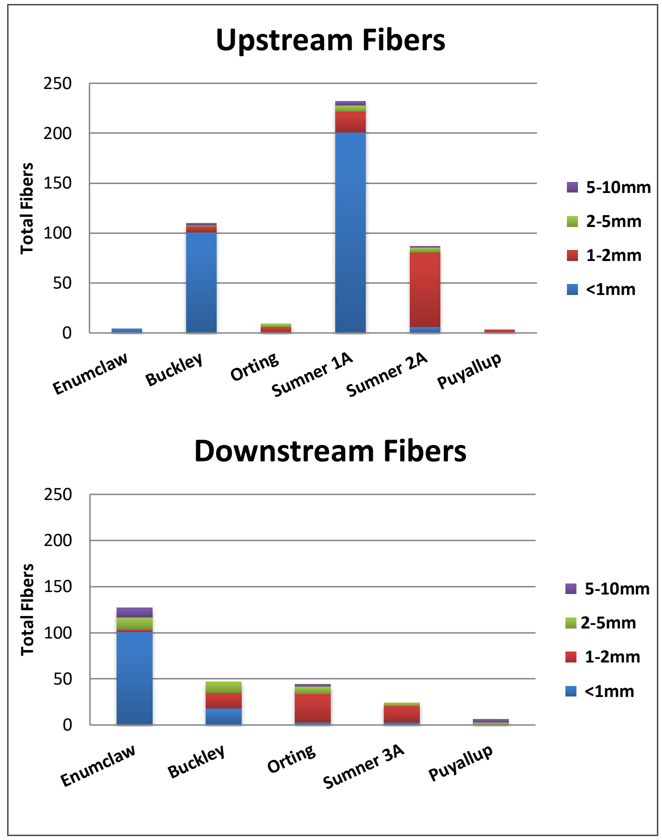
https://www.tacoma.uw.edu/center-urban-waters/sources-and-distribution-marine-microplastics

- **Microplastic fibers were found both upstream and downstream of wastewater treatments plants along the lower Puyallup River Watershed.**

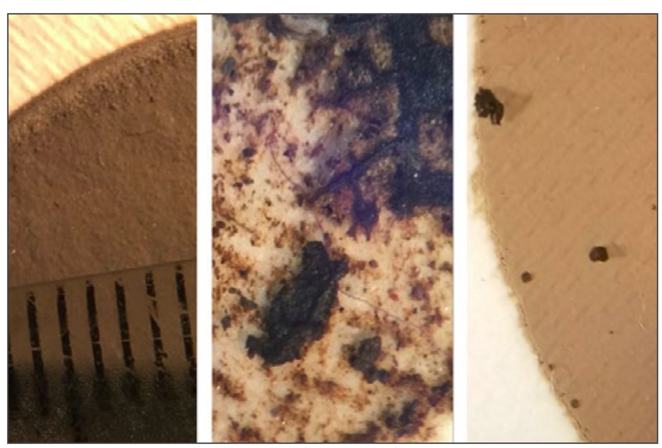
Microplastics are polymers less than 5mm and they vary in shape, color, chemical composition, and density. Manufactured plastics are primary microplastics that include pellets, fibers, and microbeads. Secondary microplastics are plastics fragmented through photodegradation and/or mechanical weathering. Research has documented microplastics in high densities (e.g., 100,000 items per m^3) in marine environments, but little work has been conducted in riverine environments. Our study focused on the Puyallup River Watershed, specifically wastewater treatment plants, as the potential source for microplastic to the Puget Sound. The Puyallup River and main tributaries, the White and Carbon Rivers, drain a watershed of approximately 2700 square kilometers and flow from several glaciers located on Mount Rainier, including the Puyallup and Tahoma Glaciers. Samples were collected monthly from August to November, both upstream and downstream of municipal wastewater treatment plants, from five cities (Enumclaw, Buckley, Orting, Sumner, and Puyallup) in the lower reaches of the Puyallup River Watershed. One liter whole water samples dyed with Rose Bengal stain were filtered and identified under a dissecting microscope. Fibers, fragments, foams, and films were identified, characterized and quantified. Overall, Sumner had to highest number of plastics at 384 and least near Puyallup at 10 for the months sampled. 78-fragments, 1-foam and 1-film were found, yet the majority of materials were fibers. The concentration of fibers, ranged from 0 to 204 fibers/L, with an average of 22-fibers/L in each sample collected. A t-Test ($p = 0.5946$) revealed that there was no statistical difference between the mean number of fibers downstream than the mean number of fibers upstream, and therefore does not support the hypothesis that wastewater treatment plants are the source of microplastic fibers in this watershed. Fibers within the watershed are hypothesized to be from aerial or runoff origins, with continued research needed to support. Polymers in surface waters of the Puyallup River Watershed do exist and are a minor source of plastics in the Puget Sound.

Note: This project was initially funded by the Center for Urban Waters through the Student Summer Internships in the summer of 2017.

Puyallup River just outside Puyallup, WA with Mt. Rainier in background. Photo: J. Masura



Total microplastics fibers found along the Lower Puyallup River Watershed (a) upstream and (b) downstream wastewater treatment plants.



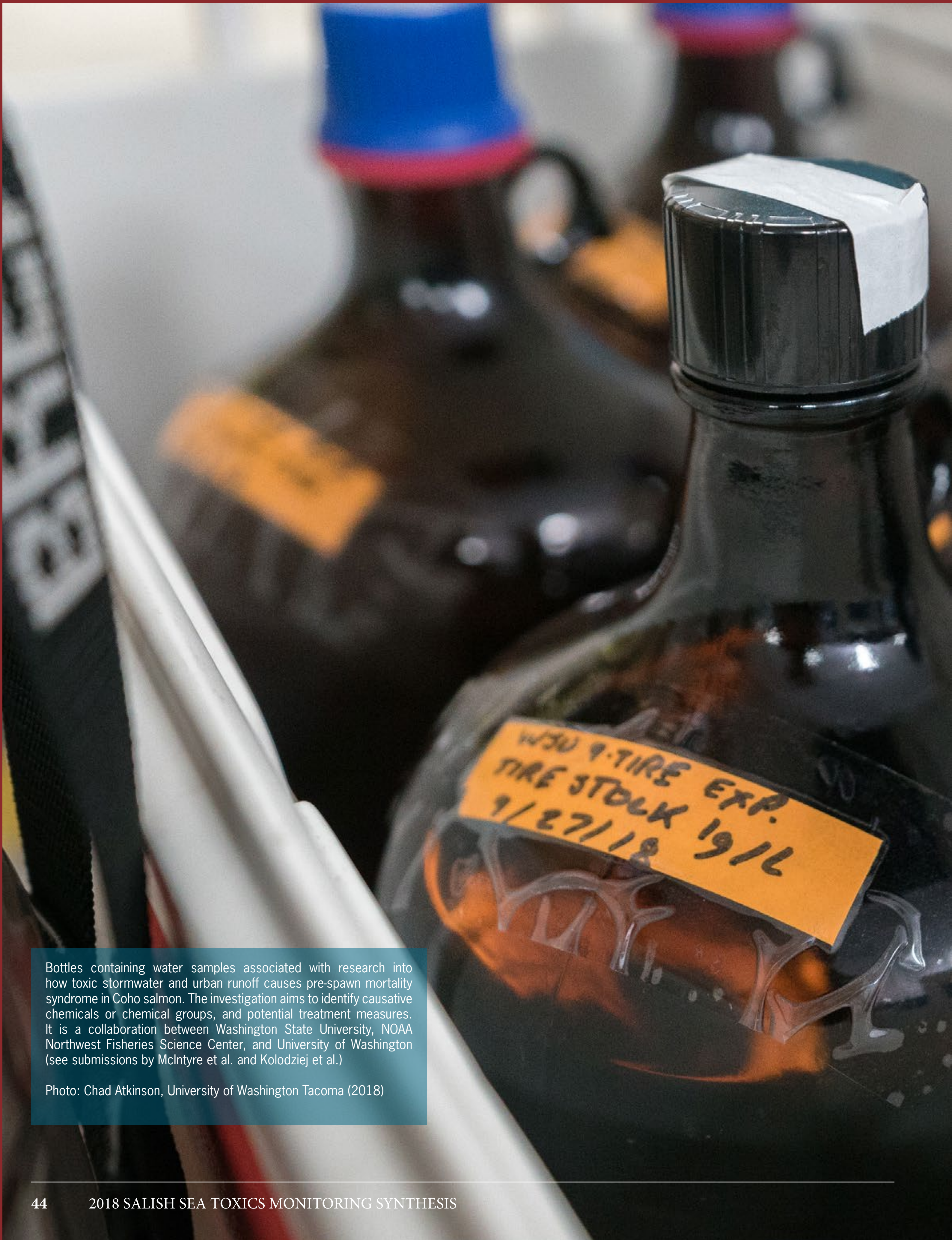
Microplastic fibers at 10x magnification. Note clear and purple fibers. Photo: Shannon Black

Volunteer team for Mussel Watch deployment at Little Squalicum Creek.

Photo: Jennifer Lanksbury, WDFW TBiOS

English sole blood sampling.

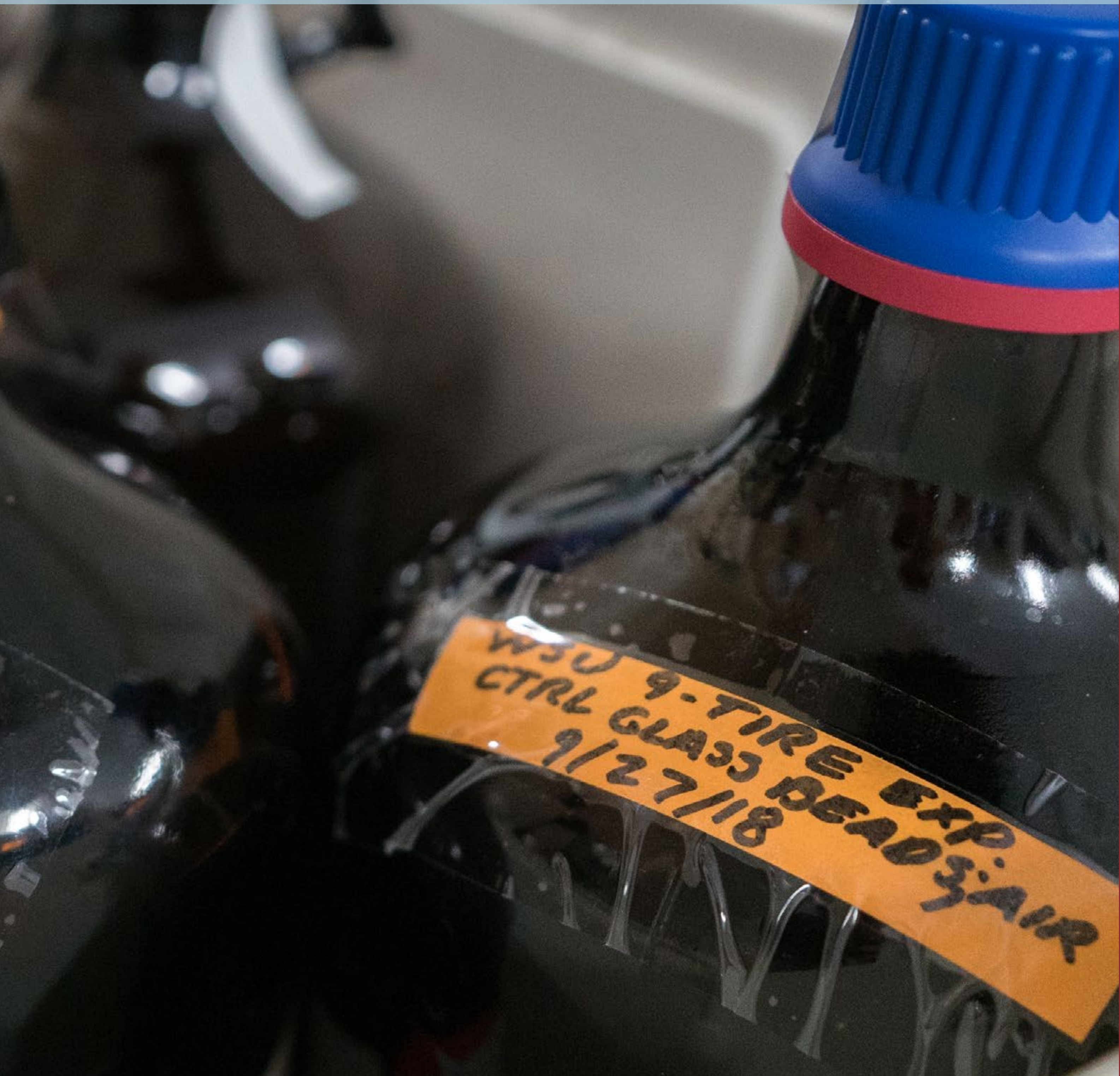
Photo: Connie Sullivan



Bottles containing water samples associated with research into how toxic stormwater and urban runoff causes pre-spawn mortality syndrome in Coho salmon. The investigation aims to identify causative chemicals or chemical groups, and potential treatment measures. It is a collaboration between Washington State University, NOAA Northwest Fisheries Science Center, and University of Washington (see submissions by McIntyre et al. and Kolodziej et al.)

Photo: Chad Atkinson, University of Washington Tacoma (2018)

SECTION 2:
What is being learned?
RESEARCH



Interspecies variation in the susceptibility of adult Pacific salmon to toxic urban stormwater runoff

Puget Sound Stormwater Science Team

Jenifer McIntyre[1], James Cameron[2], Jessica Lundin[2], Michelle Chow[3], Jay Davis[4], John Incardona[2], Nat Scholz[2]

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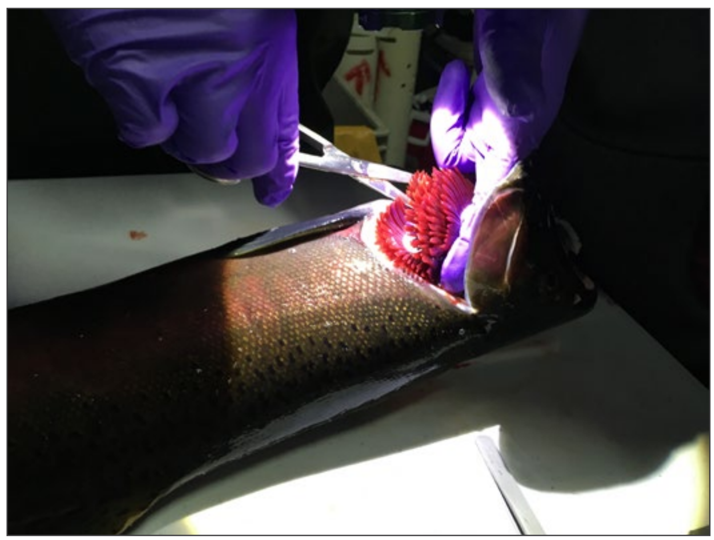
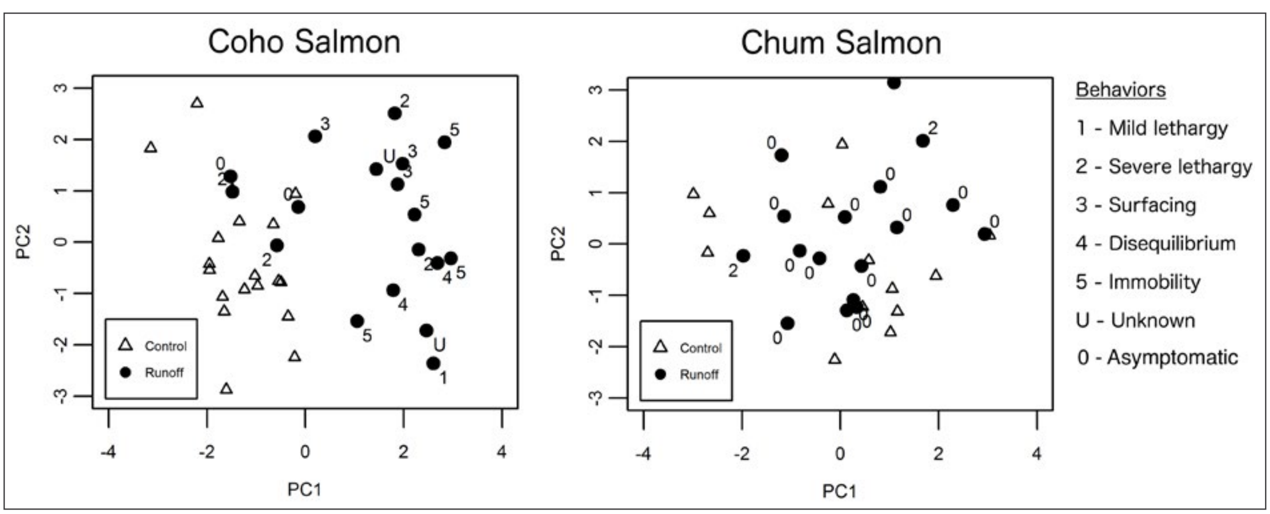
https://doi.org/10.1016/j.envpol.2018.03.012

- **Urban stormwater runoff is acutely lethal to coho but not chum salmon.**

Coho salmon (*Oncorhynchus kisutch*) are extremely sensitive to urban stormwater runoff, with spawners displaying an acute 'urban runoff mortality syndrome' following rain events during the fall spawning season (Scholz et al., 2011). By exposing coho salmon directly to road runoff we have been studying this phenomenon with controlled experimentation (Spromberg et al., 2016). In the journal Environmental Pollution, we recently reported on an experiment designed to test the relative sensitivity to urban runoff of a closely related species - chum salmon (*O. keta*) (McIntyre et al., 2018). Coho and chum salmon returning to spawn at the Suquamish Tribe Grovers Creek Hatchery were co-exposed to urban runoff collected from an on-ramp to SR 520 in Seattle. Exposures took place in PVC tubes placed in HDPE tanks containing aerated well water or urban runoff. When runoff-exposed fish became symptomatic, they were euthanized and an arterial blood sample was taken. Control-exposed fish were sacrificed at similar times as runoff-exposed fish. Blood samples were analyzed for pCO_2, hematocrit, plasma ions, pH, lactate, and glucose using a handheld blood analyzer (iSTAT). The experiment was repeated using runoff from six rain events. Coho exposed to runoff showed a variety of behaviors ranging from lethargy to immobility, with a median exposure time of 2.8 h. In contrast, chum exposed to runoff did not appear to become sick, even with a median exposure time of 5.8 h. Principle component analysis of the suite of blood parameters showed a significant effect of treatment in coho spawners, but not in chum spawners (figure). Specifically, for most coho in most storms, we saw an increase in hematocrit and lactate and a decrease in plasma Na and pH. These changes were not present in chum spawners exposed to runoff. These changes in coho behavior and blood are consistent with hypoxia although further testing is required to determine whether the hypoxia is due to an inability of the gills to permeate oxygen, dysfunction in oxygen transport, or interference with the ability of coho tissues to utilize oxygen. It is unknown at this time why coho spawners are sensitive to runoff while chum spawners are not. For the conservation of salmon in the Puget Sound region and beyond, it is important that we understand which Pacific salmonids have a sensitivity to runoff that puts them at risk from increased development in the region.



Sampling tissues from coho salmon. Photo: Jen McIntyre



Principle component analysis for coho and chum blood parameters. Treatment was a significant predictor of variability in coho blood parameters (PC1) but not chum blood parameters.

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Using high-resolution mass spectrometry to identify high-priority organic contaminants in urban stormwater

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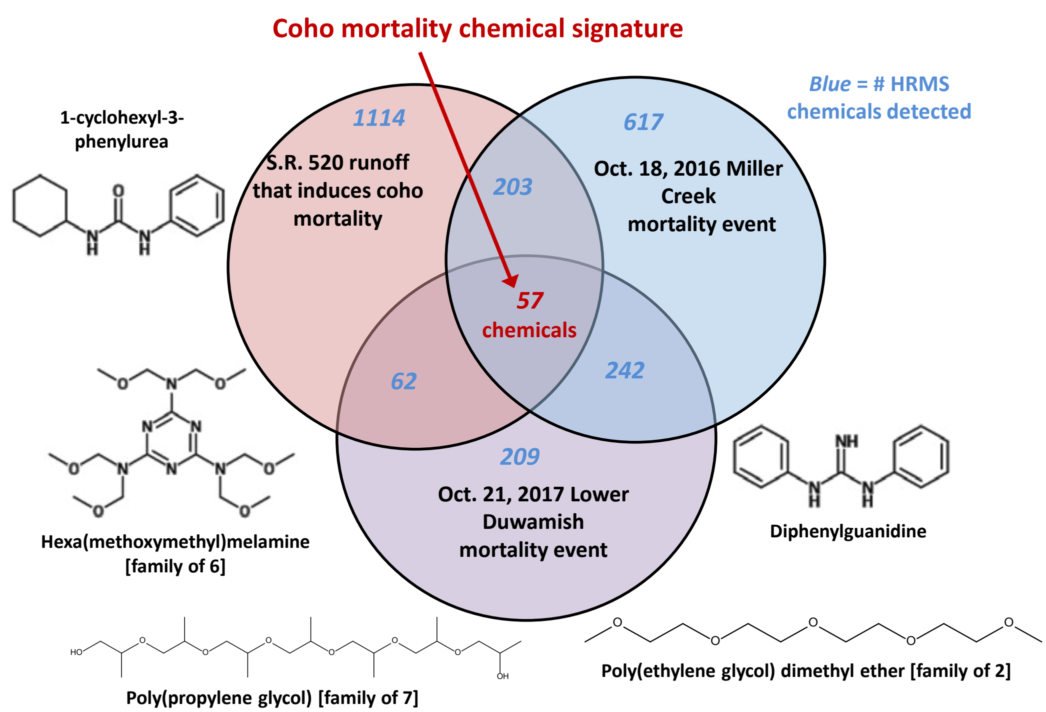
- **Using high-resolution mass spectrometry, we detected about 60 chemicals closely associated with adult coho salmon mortality after exposure to urban stormwater.**

Non-point source pollution such as stormwater runoff contributes to poor surface water quality in urbanized areas throughout the United States. Despite the importance of stormwater as a diffuse source of organic contaminants, its chemical composition remains poorly defined relative to other major contaminant sources to aquatic environments (Du et al. 2017). Currently, we have an especially limited understanding of which chemicals in stormwater are most responsible for observed impacts on aquatic organisms, such as acute toxicity in coho salmon and sublethal/developmental toxicity endpoints in fish and invertebrates. Critically, biological indicators suggest that chemical constituents other than metals, polyaromatic hydrocarbons, and other "conventional" stormwater pollutants are important drivers of toxicity in affected receiving waters and may also need attention via stormwater management. Using high-resolution mass spectrometry, we first applied non-target and suspect screening analyses to chemically characterize roadway runoff and stormwater-impacted receiving waters (Du et al. 2017). Next, we worked with laboratory exposures (e.g., roadway runoff exposures) and stormwater impacted field systems (e.g., collecting samples during mortality events) to identify a chemical signature (i.e., those chemicals always present) corresponding to the coho salmon stormwater mortality phenomenon (Peter et al. 2018). Several groups of novel organic contaminants were identified in stormwater runoff and were notably prominent in the coho mortality signature (Figure 1). Detected chemical classes included polyethylene glycols (PEGs), octylphenol ethoxylates (OPEOs), polypropylene glycols (PPGs), and two groups of nitrogen-containing compounds derived primarily from tire rubbers. Notably, a family of (methoxymethyl)melamine compounds, previously unreported in North American surface waters, were detected in road runoff and urban creeks at low µg/L concentrations. Hierarchical cluster analysis was applied to the chemical data to evaluate the relationship of motor vehicle-derived contaminant sources (previously associated with coho mortality incidence) to the observed coho mortality chemical signature. These analyses indicated that tire wear particle leachates were most similar to waters that induced coho mortality, relative to other vehicular sources (e.g., motor oil, antifreeze), indicating that tire wear particles are an under-appreciated source of contaminants to urban watersheds and should be prioritized for detailed fate and toxicity assessment (Peter et al. 2018).



Venn diagram demonstrating the chemical signature (highlighted in red at center), associated with stormwater-exposed coho salmon mortality showing overlap of chemical features detected by high-resolution mass spectrometry in: 1) arterial road runoff that was lethal to adult coho salmon; 2) Miller Creek on October 18, 2016; and 3) the Lower Duwamish on October 21, 2018. The Miller Creek and Duwamish samples were collected concurrent with observations of symptomatic adult coho salmon. Figure reproduced from Peter et al. (2018).

Cardiac injury and reduced growth in Pacific herring exposed to urban stormwater runoff

Puget Sound Stormwater Science Team

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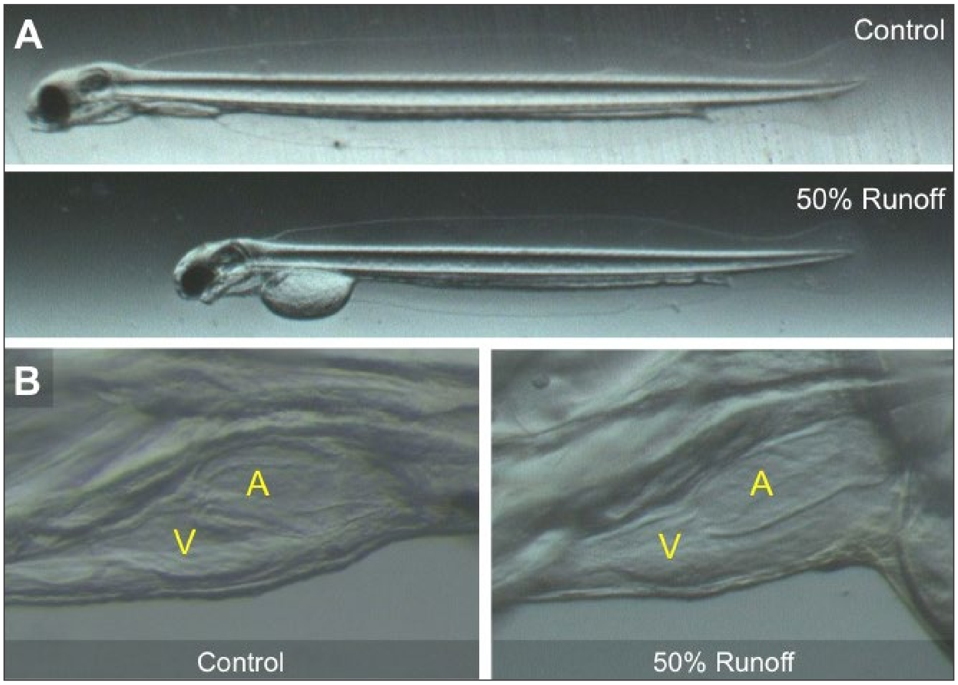
- **Stormwater exposed herring embryos exhibited cardiac injury consistent with PAH exposure.**
- **Stormwater runoff has the potential to cause delayed adverse outcomes for exposed herring.**

Pacific herring (*Clupea pallasii*) are a keystone species in Puget Sound. Like many forage fish species, they spawn adhesive eggs on intertidal and shallow subtidal substrates placing sensitive life history stages (embryos and larvae) in close proximity to land-based non-point source pollution such as urban stormwater runoff. Untreated urban runoff is chemically complex and highly toxic to aquatic life, including freshwater fish and invertebrates (McIntyre et al. 2015; Spromberg et al. 2016). However, very little is known about the impacts of urban runoff on nearshore marine fish. To examine the impacts of stormwater runoff on forage fish embryonic development, we exposed herring embryos to 0, 12, 25, or 50% stormwater runoff for 6 days beginning just prior to the onset of a visible heartbeat (5 dpf) through hatching (11 dpf). At the end of the exposure, water and tissue samples were collected for chemical and molecular analyses, and hatched larvae were imaged for morphological analyses.

Chemical analyses revealed that stormwater runoff contained a complex mixture of metals, polycyclic aromatic hydrocarbons (PAHs), and nutrients, as has been shown in previous studies (McIntyre et al. 2014). Stormwater runoff contained high levels of dissolved copper and nickel and a broad range of PAHs including naphthalenes, phenanthrenes, chrysenes, fluoranthenes, and pyrene. Total PAH concentrations in embryos were positively correlated with stormwater runoff concentration and contained similar percent PAH compositions as stormwater runoff.

Mean hatching occurred 12 days post fertilization for all treatment tanks and there was no significant difference in hatching rates across treatments. Preliminary results indicate that stormwater exposures caused significant reductions in larval length in embryos exposed to 50% stormwater runoff. In addition, herring exposed to stormwater runoff exhibited cardiac injury consistent with the known cardiotoxicity of PAHs to fish embryos (Incardona et al. 2004; 2009; 2016). For example, in larvae exposed to 25% or more stormwater runoff, the mean atrial area was increased and the shape of the ventricle was altered. The cardiac morphology exhibited in larvae exposed to stormwater runoff was very similar to the cardiac injury phenotype observed in herring embryos exposed to oil (unpublished data, John Incardona). This type of cardiac injury has been linked to reduced cardiorespiratory fitness suggesting that stormwater runoff exposure could result in delayed adverse outcomes for exposed herring (Incardona et al. 2015).



Representative images of larval herring bodies (A) and hearts (B, left lateral view) from control and 50% stormwater runoff exposure treatments. (A = atrium, V = ventricle)

A comparison of the relative abundance of polycyclic aromatic hydrocarbon (PAH) chemicals in creosote-treated wood pilings (CTWP), low-density polyethylene passive samplers, and herring embryos exposed to CTWPs

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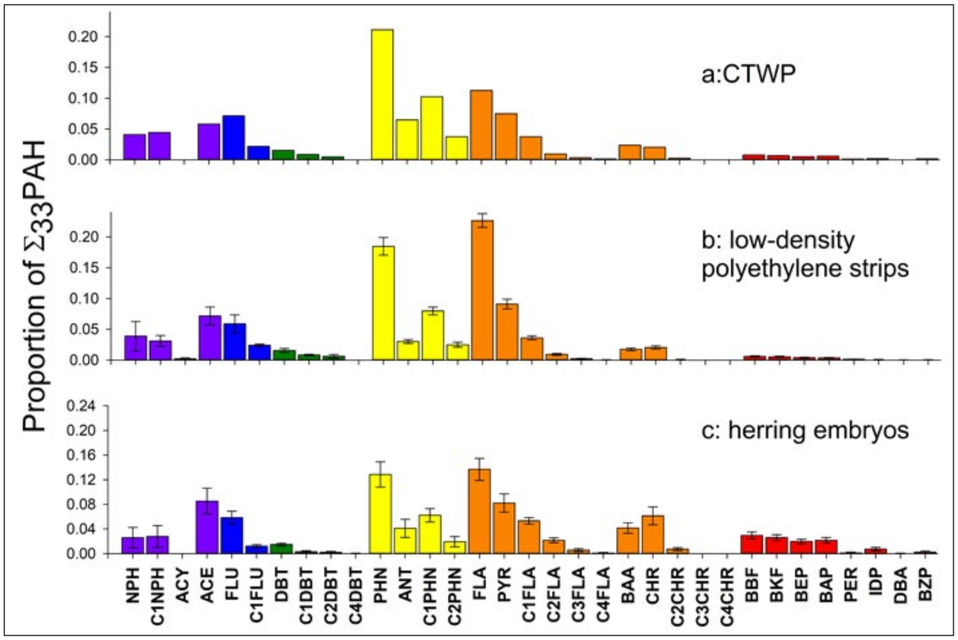
https://wdfw.wa.gov/conservation/research/projects/marine_toxics/

- **Herring embryos exposed to creosote-treated wood pilings (CTWP) accumulated polycyclic aromatic hydrocarbons in a pattern similar to the CTWP source.**
- **Passive samplers (simple low-density polyethylene strips) have utility as a proxy for embryos in field settings.**

Fish embryos spawned in Puget Sound nearshore marine habitats face a risk of exposure to a wide variety of toxic chemical pollutants during their incubation. Of particular concern are polycyclic aromatic hydrocarbons (PAHs), chemicals originating from oil spills, combusted fossil fuels, and creosote-treated wood pilings (CTWPs). Removal of CTWPs and prohibiting their use in marine waters are two recovery practices aimed at reducing PAHs and other creosote-related chemicals in marine waters. We used manually spawned and field-deployed Pacific herring embryos (*Clupea pallasii*) as a sensitive indicator of PAH exposure from CTWPs, to test the efficacy of a CTWP removal project in Quilcene Bay, Washington. An incomplete CTWP removal process resulted in unintended exposure of herring embryos to CTWP chemicals, resulting in an unanticipated opportunity to describe uptake of CTWP chemicals in developing embryonic fish in a field setting.

To better understand the link between this putative PAH source and embryos, we measured PAHs in wood fragments from the CTWPs, and in passive sampling devices (simple low-density polyethylene strips) which were deployed with the caged herring embryos (incubated for 10 days of a 12-day incubation period). The proportional concentration of each PAH chemical (33 parent and alkylated homolog PAH compounds) are reported here in these three matrices: (a) CTWPs, (b) passive samplers, and (c) herring embryos (Figure). Overall, the PAH pattern in these matrices were similar, albeit with a few notable differences. The total mass of PAHs in all matrices was dominated by 3-ring (yellow-colored bars) and 4-ring (orange bars) PAH compounds. Phenanthrene (PHN) and fluoranthene (FLA) were the most abundant PAHs, individually accounting for 13 to 23% of total PAHs, and their alkylated homologs were always less abundant than parent PAHs. The sulfur-containing heterocyclic PAH dibenzothiophene (DBT), which is often reported in creosote, and two of its alkylated homologs (C1DBT and C2DBT; green bars) were measured in all matrices at low levels. Low-molecular-weight two- and three-ring PAHs including naphthalenes (NPH), acenaphthene (ACE; violet bars) and fluorenes (blue bars) were detected in all matrices. Embryos exhibited a slightly heavier PAH signal than the CTWP and passive samplers, with greater proportions of four- to six-ring compounds (orange and red bars) such as benzo(*a*)anthracene (BAA), chrysene (CHR), benzo(*b*)- and benzo(*k*)fluoranthene (BBF and BKF), and benzo(*e*)- and benzo(*a*)pyrene (BEP and BAP). These results suggest that although herring embryos exposed to CTWPs accumulated PAHs in a pattern roughly equivalent to the creosote source, the greater abundance of four- to six-ring compounds in embryos indicate possible differential uptake or metabolism of PAHs in embryos. The strong congruence of PAH patterns in the passive sampling devices with CTWP wood, and their overall similarity with the embryo PAH pattern, suggests these devices have value as a proxy for embryos in studies evaluating the dissolution of PAHs from CTWP wood, and the threat of PAHs to living embryos in field settings.



The proportional concentration of each of the 33 parent and alkylated homolog PAH compounds in the three matrices: (a) creosote-treated wood pilings (CTWPs), (b) low-density polyethylene strips (passive samplers), and (c) herring embryos.

Polychlorinated biphenyls (PCBs) in the Pacific sand lance, Puget Sound, Washington

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https://puget.usgs.gov/

- **Pacific sand lance demonstrate maternal transfer of PCBs to their eggs.**
- **Larger fish, both males and females, had higher PCB concentrations compared to smaller fish, and the trend was consistent at both study sites.**

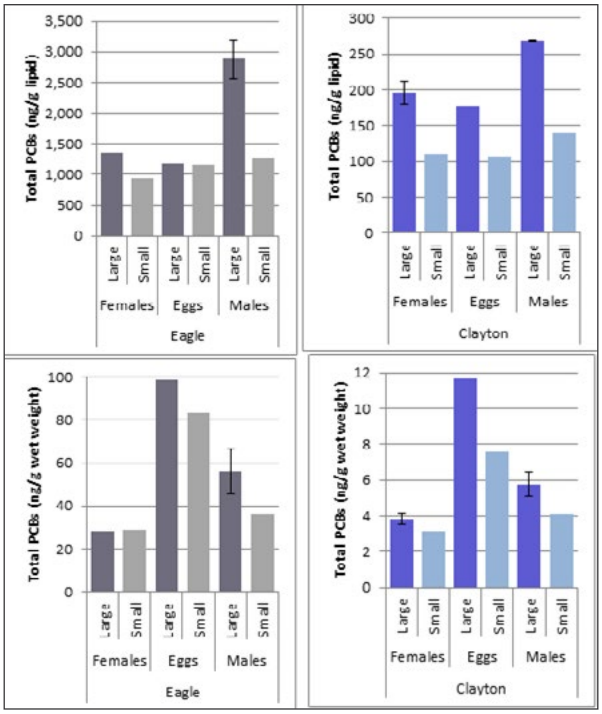
Forage fish are small, abundant, schooling planktivores that form a critical link in marine food webs by transferring energy from plankton up to birds, fishes, and marine mammals. Forage fishes in Puget Sound include the iconic Pacific herring as well as lesser known species such as surf smelt and the Pacific sand lance. There are significant knowledge gaps regarding the basic life history and population status of Pacific sand lance and no information regarding potential stressors such as contaminants.

As part of the USGS Coastal Habitats in Puget Sound program, juvenile and adult sand lance collected in 2014 in North Sound (Clayton Beach near Bellingham, Washington) and a historically-contaminated urban area (Eagle Harbor) were analyzed for more than 200 urban contaminants including polychlorinated biphenyls (PCBs). This effort represents the first data on toxic contamination in sand lance in Puget Sound. PCB concentrations (sum of 209 congeners) in sand lance tissue from Eagle Harbor were about ten times higher than in comparably-sized fish from Clayton Beach. Juvenile sand lance (recently transformed from the larval stage) had PCB concentrations similar to or higher than adult fish at both sites suggesting the potential for maternal transfer of PCBs to eggs.

To investigate this potential route of exposure, we collected sexually mature male and female sand lance in two size classes (~100 mm and >130 mm fork length) from Eagle Harbor and Clayton Beach in 2016. The males and females in the small size class were estimated to be first year spawners, and fish in the larger size class were estimated to be 2nd or 3rd year spawners. PCB concentrations were determined for composites of whole body fish tissue from egg-bearing females, from the eggs removed from collected females, and from whole body fish tissue from males. Similar to the 2014 survey, PCB concentrations in fish tissue from Eagle Harbor (mean 1100 ng/g lipid) were about 10 times higher than in tissue from Clayton Beach (mean 175 ng/g lipid). There was evidence of bioaccumulation with a clear size effect for both males and females at both sites, with the larger fish having higher PCB concentrations (Figure). We concluded that sand lance demonstrate maternal transfer of PCBs to their eggs based on three findings (Figure):

- All egg samples (both sites and both size classes of females) contained PCBs
- PCB concentrations in females and their eggs were similar
    - Lipid content was 6.5 - 8.5% in eggs, 2 - 3% in females and males
- PCB concentrations in males were higher than comparably-sized females and eggs
    - This trend was strongest in larger size class which were assumed to be 2nd or 3rd year spawners

Adult Pacific sand lance in a range of sizes. Photo: T. Liedtke



Total PCBs (ng/g lipid top panels, ng/g wet weight bottom panels) measured in composites of whole body fish tissue or eggs removed from collected females from Eagle Harbor or Clayton Beach. Large females had a mean size of 139 mm at Eagle Harbor and 140 mm at Clayton Beach. Large males had a mean size of 133 mm at both sites. Small females and males had a mean size of 100 mm at Eagle Harbor and 97 mm at Clayton Beach. Note the y-axis scale differences between Eagle and Clayton graphs.

Contaminants of emerging concern in Puget Sound waters and fish and potential adverse effects

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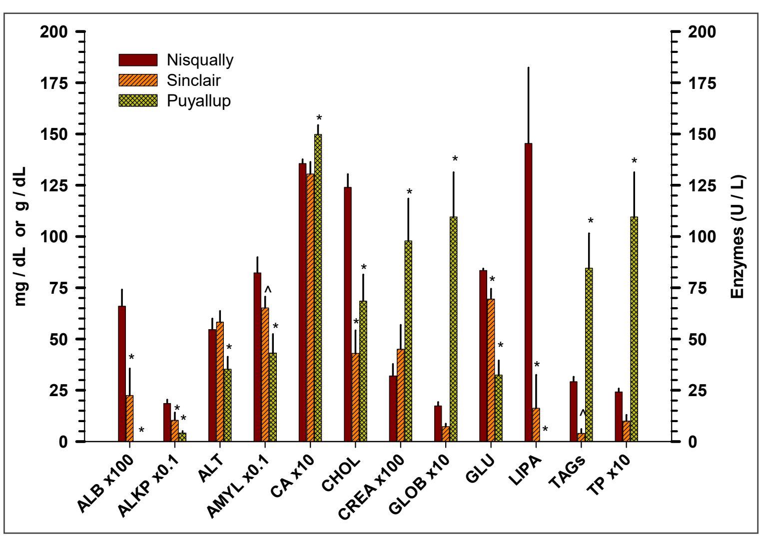
http://deohs.washington.edu/faculty/gallagher_evan

- **High levels of CECs found in effluent, estuarine water, and juvenile Chinook and staghorn sculpin at two WWTP-impacted estuaries in Puget Sound.**
- **Fish exposed to CECs in local Puget Sound estuaries exhibited altered physiology that may indicate adverse effects and an increased probability of mortality.**

Our recent work assessed the occurrence and concentrations of a broad range of contaminants of emerging concern (CECs) found in local estuaries within Puget Sound. In addition to effluent from wastewater treatment plants (WWTP), we sampled estuary water and whole-body juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and Pacific staghorn sculpin (*Leptocottus armatus*) in estuaries receiving effluent. We analyzed these matrices for 150 compounds, which included pharmaceuticals, personal care products (PPCPs), and several industrial compounds. Collectively, we detected 81 analytes in effluent, 25 analytes in estuary water, and 42 analytes in fish tissue (Meador et al., 2016). A number of compounds, including sertraline, triclosan, estrone, fluoxetine, metformin, and nonylphenol were detected in water and tissue at concentrations that may cause adverse effects in fish. Although concentrations of most detected analytes were present at relatively low concentrations, our analysis revealed that overall CEC inputs to each estuary amount to several kilograms of these compounds per day. Additional analysis of these data included an evaluation of predicted concentrations of pharmaceuticals in fish blood to human therapeutic values for assessment of potential adverse effects. After applying safety and uncertainty factors to the data, our results show that predicted fish plasma concentrations for a variety of PPCPs occurred in the range expected to produce adverse effects in fish (Meador et al., 2017). In juvenile Chinook from the field, several blood chemistry parameters, such as lipids, glucose, and a few enzymes, in addition to other indicators of health, were measured as potential metabolic disruption, which was observed in fish from the WWTP-impacted estuaries. These blood chemistry values were relatively consistent among fish collected from the two effluent-impacted sites and substantially different compared to reference site fish. We consider these parameters as important early indicators of metabolic stress, even though organismal characteristics (lipid content and condition factor) were not different among sites indicating an early response (Meador et al., 2018). We also observed mitochondrial dysfunction in these fish, which is adverse for actively growing fish (Yeh et al., 2017). We further explored fish physiology with metabolomics to provide a more complete characterization of metabolic impairment. Metabolomics is the evaluation of small endogenous molecules and products of metabolism such as amino acids, fatty acids, nucleotides, and other important compounds in physiological pathways. A high percentage of these important endogenous compounds were significantly different between fish from the reference estuary compared to fish from the two WWTP-impacted sites, which exhibited similar responses for a number of compounds. These metabolomic data allowed us to explore altered or impaired metabolic pathways, which may help identify the most important CECs responsible for the observed responses and possibly mechanisms. While many of the PPCPs result in therapeutic effects for people, these same effects such as lowering lipids and glucose or altering behavior are considered adverse for fish and likely result in population-level effects (Meador, 2014).



What's for lunch? Photo: JP Meador and Neal Herbert (NPS)

Left: Blood chemistry parameters for juvenile Chinook salmon from two WWTP-impacted sites (Puyallup River estuary and Sinclair Inlet) compared to a reference site (Nisqually River estuary). Albumin (ALB), alkaline phosphatase (ALKP), alanine transaminase (ALT), calcium (CA), cholesterol (CHOL), creatinine (CREA), total globulins (GLOB), glucose (GLU), inorganic phosphate (PHOS), lipase (LIPA), total proteins (TP), and triacylglycerols (TAGs).

SSRIs in WWTP effluents and their disposition and effects in salmonids and marine flatfish

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1. NOAA NWFSC; 2. UW; 3. WDFW TBiOS

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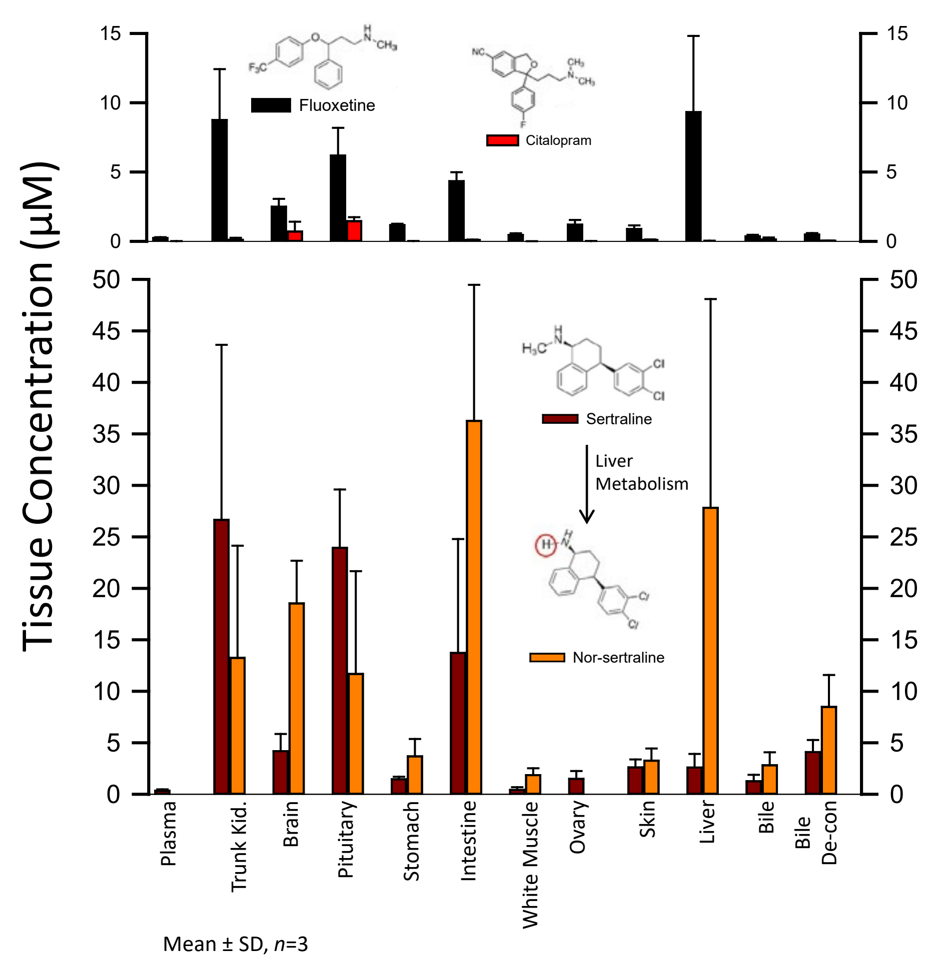
- **Sertraline (Zoloft) is potentially the most harmful SSRI-type pharmaceutical to aquatic wildlife.**
- **Sertraline is extensively metabolized in fishes to nor-sertraline. Monitoring programs should include nor-sertraline.**

In the Puget Sound region, more than 90% of municipal wastewater treatment plant (WWTP) effluents are directly released into the marine environment. We surveyed eight WWTP effluents for six different selective serotonin reuptake inhibitors (SSRIs) and found total levels varied between 77 and 1,673 ng/L. The most abundant SSRIs (>90% of ∑SSRI) detected were citalopram >>> fluoxetine > sertraline. Other SSRIs monitored were paroxetine, venlafaxine, maprotiline, norfluoxetine, desmethylsertraline and were either not detected or a small fraction of the total SSRI content (norfluoxetine). We subsequently performed a series of in vivo and in vitro exposures to assess the uptake, metabolism and effects of these SSRIs both as a mixture (at ratios observed in WWTP effluents) and as individual chemicals in salmonids and English sole. Static water exposures to an SSRI mixture in rainbow trout revealed sertraline was the most rapidly absorbed SSRI with an uptake clearance of approximately 35 ml/hr/g, nearly 10x more rapid than fluoxetine. Citalopram was the least absorbed SSRI. Subsequent continuous exposures of trout and English sole to a similar SSRI mixture indicated the kidney>> liver > brain were the tissues that accumulated the highest concentrations of SSRIs (Figure 1). Substantial formation of the sertraline metabolite norsertraline was observed in both trout and English sole. Concentrations of norsertraline were similar to, or higher than sertraline in some tissues such as the liver and brain. High levels of sertraline and norsertraline were found in bile. Subsequent tests using enzymatic deconjugation of bile samples indicated that only 25% of total sertraline and norsertraline is in free (un-conjugated) form. In vitro metabolism studies using hepatocytes or liver homogenates confirmed sertraline is the most rapidly metabolized SSRI. Additional in vitro effects studies using primary pituitary cells and isolated ovarian follicles, found the most sensitive effect of SSRI exposure was antagonism of the estrogen induced expression of the beta subunit for luteinizing hormone, indicating that SSRI exposure might affect the reproductive cycle. Overall, these results suggest sertraline is the SSRI most likely to bioaccumulate and become biotransformed by fishes, resulting in tissue levels near the threshold for biological effects. Supported by EPA-STAR grant R835167, WA Dept. of Ecology G1400206.



Tissue concentrations of various SSRI-type pharmaceuticals in adult feamle rainbow trout. The trout were exposed for 72 hrs in a static water exposure system that contained a mixture of fluoxetine, sertraline and citalopram at an initial concentration of 20 µM / SSRI. Sertraline was the most rapidly absorbed SSRI and extensively converted to its de-methylated product nor-sertraline, as indicated on the graph.

Uptake and trophic changes in PBDEs in the benthic marine food chain in SW British Columbia, Canada

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http://ssamex.org/

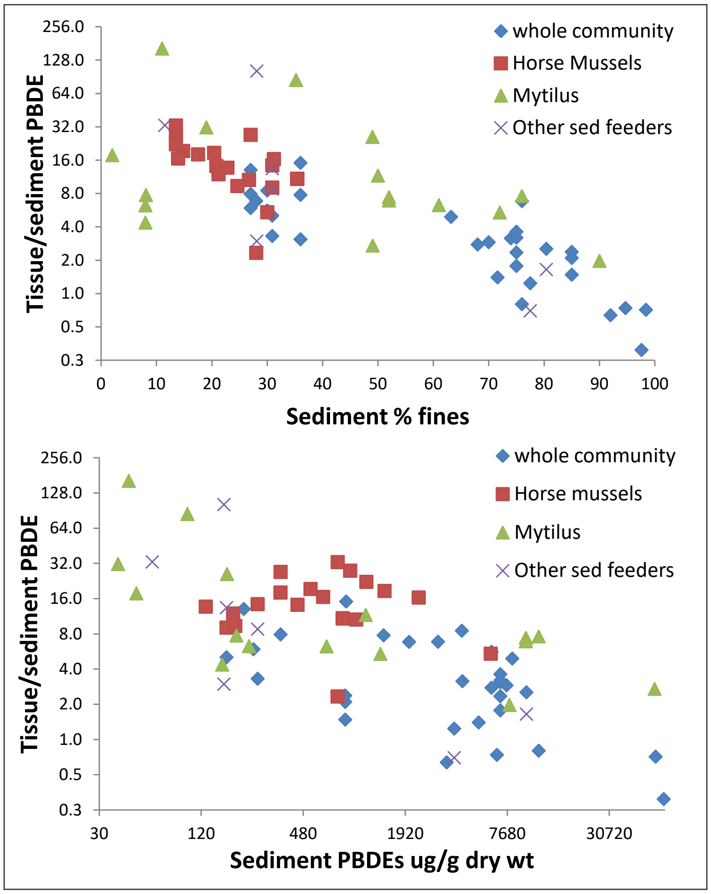
- **Tissue PBDE variance (r^2=0.70) was best explained by sediment AVS, PBDEs, organic lability and input, with elevated levels near wastewater outfalls.**
- **Lipid-normalized PBDEs do not accumulate much at higher trophic levels, whereas dry-weight PBDEs and lipid content do.**

We examined sediment physical and geochemical effects on uptake of PBDEs into marine sediment feeders, and transfer to higher trophic fauna. This work follows from Burd et al. (2014). Results are described in Burd et al. (2019), as follows. Correlations showed that sediment PBDEs increased with %TOC, OC flux and %fines. A multiple regression showed that mixed benthos tissue PBDE variance (r^2=0.70) was best explained by sediment AVS, PBDEs, organic lability and input, with elevated tissue PBDE values near wastewater outfalls. The ratio of dry weight tissue/sediment PBDEs for mixed infaunal benthos declined with increasing sediment PBDEs, resulting in lower tissue values than sediment values (=tissue dilution or ratio <1) at >10,000pg/g in harbours (Fig. 1). Ratios also decreased with increasing %fines, resulting in regional differences. These patterns imply over-saturation of tissues from habitat sources or that high fines and sediment concentrations make PBDEs less bio-available.

Dry weight PBDE concentrations increased >100x between background deposit feeders and predators (polychaetes, crabs, bottom fish, seal), but lipid weight increased only <1.3x, suggesting remarkably high uptake in low-lipid sediment feeders, and that PBDEs don't accumulate at higher trophic levels, but lipid content does. Filter-feeders had lower lipid-weight PBDEs than deposit feeders resulting in lipid weight increases of ~5-6 times, highlighting the importance of food resources in higher trophic fauna for bio-accumulation.

The dominant nona- and deca-BDEs in sediments decline considerably in importance with initial consumption by deposit and filter feeders, with a concurrent increase in the tetra-hexa congeners in tissues. These changes are attributed mainly to debromination of the larger molecules in the guts of sediment consumers, and secondarily to their metabolism in hepatic tissues and/or selective excretion.

The invertebrate sediment feeders near municipal wastewater outfalls and in background locations tended to have the same general proportions of congeners in their tissues but these were considerably different from congener proportions in the matched sediment samples. However, the harbour sediment feeders had higher proportions of deca-BDE than all other samples, and an overall similar proportional congener composition to their matched sediment samples. Uptake of PBDEs may be much more rapid at high sediment PBDE concentrations, but the resulting decline in tissue/sediment ratio observed suggests the PBDEs in highly contaminated sediments mostly pass un-modifed through the guts. Deca-BDE persists patchily throughout the marine food chain, reflecting variable dependence on sediment versus pelagic food resources, along with long-term storage in certain tissues. In the higher trophic level (and longer life-span) fauna, debromination of penta and hexa-BDEs to tetra-BDEs continues over time, but obviously more slowly than the initial debromination of the deca- and nona-BDEs. Ultimately, the tetra-BDEs appear to be a metabolic "dead-end" in the breakdown process, showing by far the greatest accumulation throughout the food chain.



Tissue accumulation (Tissue/sediment) of dry weight PBDEs for various benthic particle feeders (mixed fauna or "whole" community) relative to A) sediment PBDE, and B) sediment % fines.

Toxicity of pharmaceutical drugs to embryonic zebrafish

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- **Toxicity assays of pharmaceuticals on developing zebrafish embryos show that gemfibrozil may alter fish growth, development, and lipid metabolism.**
- **Toxicity observed in laboratory experiments supports continued research into impacts of pharmaceuticals on fish health in natural environments.**

Contaminants of emerging concern (CECs) are ubiquitous aquatic contaminants that include pharmaceutical drugs and personal care products (PPCPs). Pharmaceutical compounds have been detected at elevated concentrations in fresh and marine waters of the Puget Sound region, finding their way into waterways primarily through sewage discharges containing un-metabolized and improperly disposed of drugs. As these medications are specifically designed to influence biological activity at low doses, there is increasing concern that pharmaceutical-derived aquatic contaminants could be environmental stressors to non-target organisms. However, the aquatic toxicity of these contaminants, especially in complex mixtures, has not been thoroughly characterized. In order to better understand PPCP toxicity, zebrafish embryos (<48 hpf, hours post fertilization) were exposed to two cardiac-specific medications, triamterene (a diuretic used to control hypertension) and gemfibrozil (a fibrate used to regulate cholesterol), as both single-chemicals and binary mixtures. Embryos (n=15) were exposed until 72 hpf in triplicate glass petri dishes to concentrations ranging from 0.01 μg/l to 10 mg/l of triamterene and 0.001 to 10 mg/l of gemfibrozil. Exposure solutions were renewed daily, and water and vehicle (ethanol) controls were exposed concurrently. Endpoints including embryo length, eye area, yolk sac area, and various cardiac abnormalities (e.g., edema, altered heartbeat, and blood regurgitation) were measured in digital photos and video of individual embryos (n=5) under magnification using *ImageJ* software.

Morphometric analysis revealed that gemfibrozil elicited dose-dependent decreases in eye area and embryo length, as well as dose-dependent increases in yolk sac area and cardiac abnormalities (see Figure). Triamterene did not induce significant dose-dependent morphological trends. Results from mixture trials were compared to toxicity predicted by a response-addition model. Additive toxic effects were observed in all endpoints, with potential synergism evident in yolk sac size at higher exposure concentrations (Photo). Notably, larger yolk sacs measured in the higher

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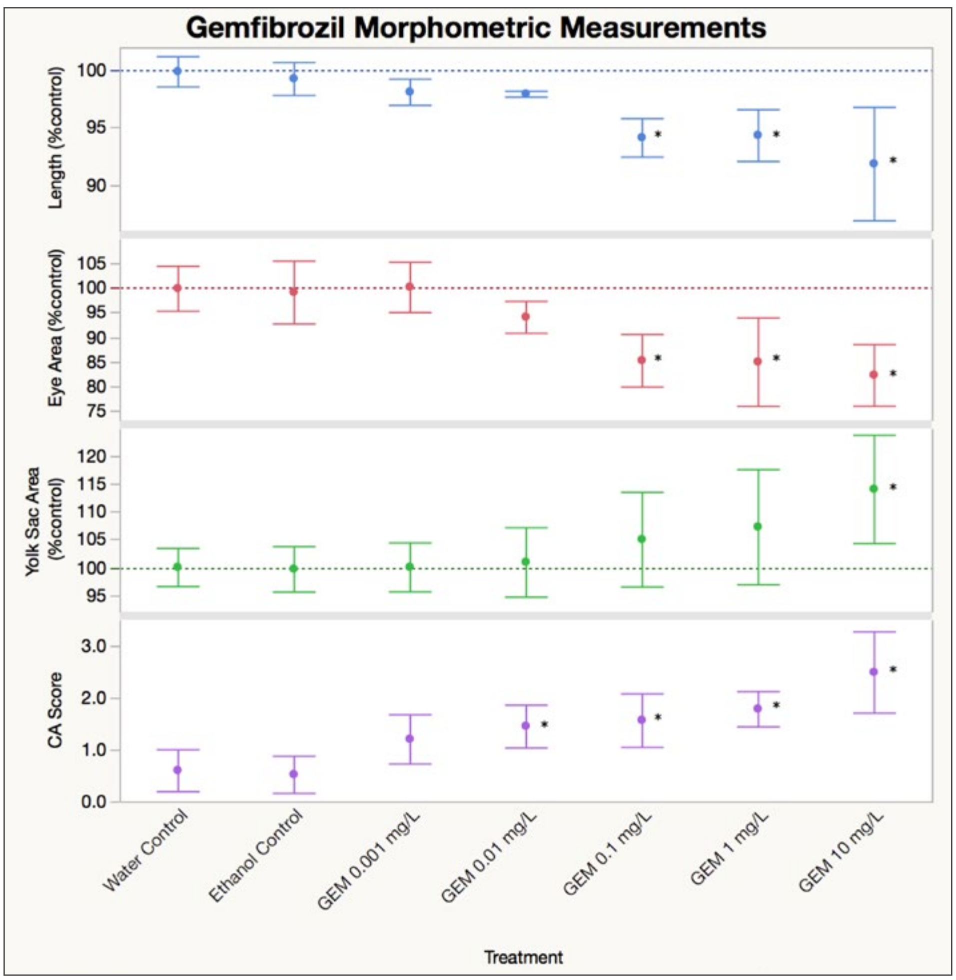
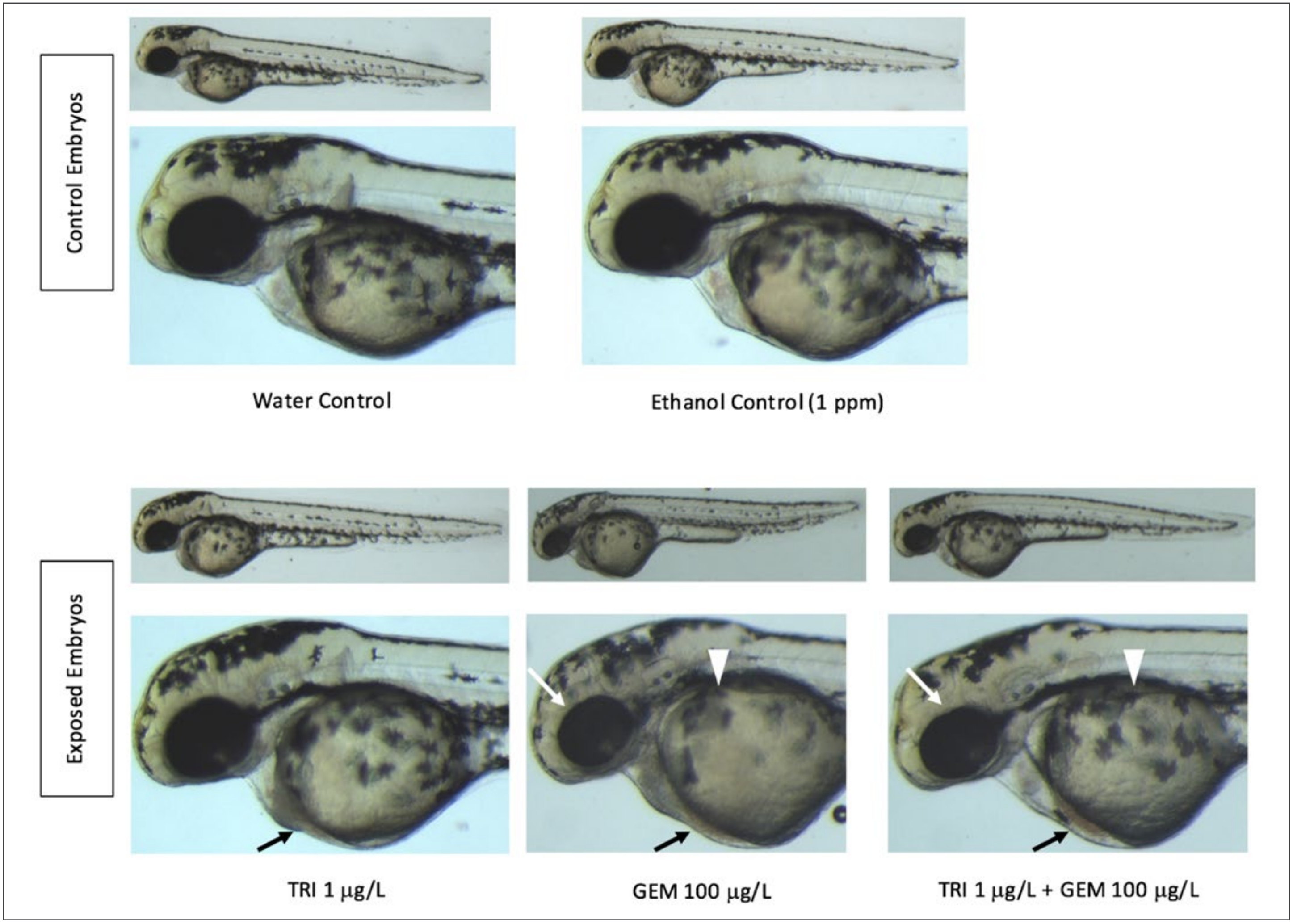


Dose-dependent toxicity of gemfibrozil to zebrafish embryos is evidenced by reductions in embryo length and eye area as well as increases in yolk sac size and occurrence of cardiac abnormalities (CA score). Circles show means of 4-12 embryos each, bars are standard error, and asterisks denote statistically significant differences from water controls as determined by one-way ANOVAs with Tukey-Kramer post hoc test.

[CONTINUED]

gemfibrozil exposures implied the drug is altering the embryo's ability to metabolize lipids. Because of the potential adverse metabolic consequences of altered lipid metabolism in developing fish embryos, thin layer chromatography coupled with flame ionization was used to quantify lipid levels in exposed embryos. Results showed elevated lipid levels in gemfibrozil-exposed embryos, suggesting the drug disrupts lipid metabolism. This metabolic pathway may be altered by the presence of other drugs, since the mixture of triamterene and gemfibrozil together did not alter lipid levels compared to control fish.

These trends indicate that PPCPs may be important environmental stressors to fish early life stages, especially drugs that affect lipid metabolism and subsequent growth and development. Expanding this research to Puget Sound fish is an important next step to understanding the potential adverse effects of pharmaceutical drugs, especially as complex mixtures, on the health, development, and ecology of fish and their aquatic habitats. This research highlights the need to regulate the disposal of pharmaceuticals, and adds to the growing body of research into the environmental consequences of pharmaceuticals.



Photomicrographs of control zebrafish embryos, as well as embryos exposed to 1 µg/l triamterene, 100 µg/l gemfibrozil, and a mixture of the two drugs at those same concentrations, show evidence of toxicity. Black arrows indicate pericardial blood pooling, white arrows indicate small eye phenotype (microphthalmia), and white triangles indicate enlarged yolk sac. Photo: Ronit Jain

Assessing 21st-century contaminants of concern using integrative passive sampling devices to obtain more meaningful and cost-effective data on impacts from stormwater runoff

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- **Passive sampling devices provide supplemental data to reduce costly traditional monitoring and can allow continuous surveillance of receiving waters and conveyance systems.**
- **Surveillance monitoring with passive samplers should prove very useful for fingerprinting likely sources of contamination in stormwater runoff in the areas monitored.**

In many cases stormwater compliance monitoring is labor intensive, expensive, and largely unsuccessful in providing the data needed to support stormwater management goals. In addition, data from manual grab sampling and automated composite sampling are rarely collected in a manner that provides the information required to identify sources of contamination, evaluate the effectiveness of Best Management Practices, or inform effective decision making.

Furthermore, monitoring is often driven by the need to meet low concentration benchmarks for metals and other constituents that do not take into account loading into the receiving waters, resulting in arbitrary monitoring requirements (monthly or seasonally) that are not tied to the driving forces within the watershed such as hydrology (flow regime), weather (storm events and antecedent dry periods), and upland land use and cover (Rosen and Johnston 2015, US Navy 2016).

To help address these issues, passive sampling devices including Polar Organic Chemical Integrative Samplers (POCIS) were used to sample for a wide range of household chemicals (caffeine, diethyltoluamide (DEET), cotinine, and bisphenol a), personal care fragrances (galaxolide, musk ketone, and tonalide), pharmaceuticals (triclosan, ibuprofen, acetaminophen, carbamazepine, and metformin), and endocrine disrupting compounds (estrone, octinoxate, and tris-(2-chloroethyl) phosphate (TCEP)) in stormwater runoff. The POCIS samples weakly hydrophobic (log K_{ow} ≤4) organic chemicals that bind to a polymeric (hydrophilic-lipophilic-balanced (HLB)) sorbent sandwiched between polyethersulfone (PES) membranes (Alverez 2010).

Figure 1. Location of Sinclair and Dyes Inlets within the Puget Sound and Salish Sea (insert) and passive sampler deployment locations in Sinclair Inlet and reference locations on the Kitsap Peninsula and Bainbridge Island, WA (red triangles).

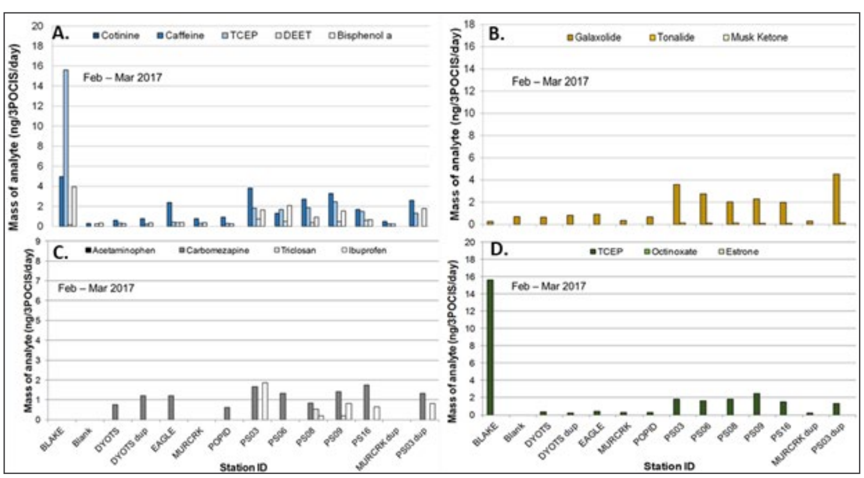

Figure 2. Mass accumulation on POCIS (ng of chemical extracted from 3 POCIS per day of deployment) following sampling from sites in Sinclair Inlet and nearby reference sites during Feb. - Mar. 2017 for household chemicals (A), fragrances (B), pharmaceuticals (C), and endocrine disrupting compounds (D).

In the Puget Sound, a network of monitoring stations was established in Sinclair and Dyes Inlets to assess runoff from industrial areas of Naval Base Kitsap (NBK) as well as commercial, residential, and rural runoff regimes within the watershed (Figure 1). Passive samplers were deployed in marine waters on floating docks and submerged in a freshwater stream and lake for varying deployment periods of 14 to 60 days during wet and dry weather conditions. The passive samplers were co-located with ambient monitoring stations (Johnston et al. 2018) to provide a framework for comparison with traditional sampling.

The POCIS results showed that a broad spectrum of organic compounds could be reliably detected from the surveillance monitoring (Figure 2). Passive sampling devices provide supplemental data to reduce costly traditional monitoring and can allow continuous surveillance of receiving waters and conveyance systems. Surveillance monitoring with passive samplers should prove very useful for finger printing likely sources of contamination in stormwater runoff in the areas monitored.

DEPARTMENT OF ECOLOGY State of Washington

Using biofilms to assess sources of toxics in rivers and streams

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- **Biofilms passively and actively accumulate toxics (e.g., PCBs and metals) in rivers and streams.**
- **Validation studies show that biofilms are an effective tool in the assessment for sources and bioaccumulation of toxics.**

Biofilms are a collection of algae, microbial biomass, and organic detritus, which contribute to the base of the food web in rivers and streams (photo). In contaminated waterbodies biofilms can take up and bind contaminants from the water (Hill and Napolitano, 1997; Nimick et al., 2011). In a number of studies over the last few years the Washington State Department of Ecology (Ecology) has been using the contaminant concentrations in biofilms to assess spatial distribution of metals and organic contaminants in rivers and streams (Marshall et al., 2014; Hobbs and Friese, 2016; Hobbs, 2018). We have also been measuring the bioconcentration of toxics from water to assess accumulation in higher trophic levels.

In order to verify the utility of biofilms as passive samplers of contaminants in the water column, we have carried out a number of validation exercises to compare chemical concentrations among different media (Hobbs and Friese, 2016; Hobbs, 2018). For organic contaminants (e.g. polychlorinated biphenyls, PCBs), water column concentrations were measured using manufactured passive samplers (semi-permeable membrane devices, SPMDs) during various flow regimes. Our results show a strong, statistically significant relationship (r^2 = 0.77; p <0.001) between dissolved PCB concentrations in the water column and the concentrations bound in and on biofilms. Furthermore, the composition of the PCBs is very similar between the water and biofilms, implying that there is very little alteration of the chemical composition during bioconcentration (Figure). Calculated bioconcentration factors from water to biofilms range from approximately 800 to 1600, where the variability is likely attributable to the composition of the total PCBs and rates of uptake for individual congeners. The validation of chemical concentrations between SPMDs and biofilms has also proven robust for polybrominated diphenyl ethers (PBDEs) and dichlorodiphenyltrichloroethane (DDT) and metabolites.

Biofilm accumulation on a river cobble. Diatoms tend to dominate the algal communities of biofilms, which give it the brown color. Photo: William Hobbs

The uptake of dissolved metals by biofilms and periphytic algae has generally received more study than organic chemicals. Dissolved metals in water are actively taken up by periphyton and bind to the organic matrix of the biofilm (Cadmus et al., 2018). Metals are also bound to the organic components of stream sediments. Investigations by Ecology in a former mining area have shown that metal concentrations in periphyton are proportional to concentrations in the water. Furthermore, when compared to stream sediment, the tissue matrix of the biofilms more closely reflects the spatial variability in metals inputs to the stream. Lastly, community composition of the periphyton is strongly correlated (r^2 = 0.97; p <0.001) to the burden of metals in the tissues (Figure), implying a possible toxicological impact to the organism.

Overall, the use of biofilms in source identification studies for toxics has proven to be highly effective under a number of hydrologic conditions and for various toxic contaminants.

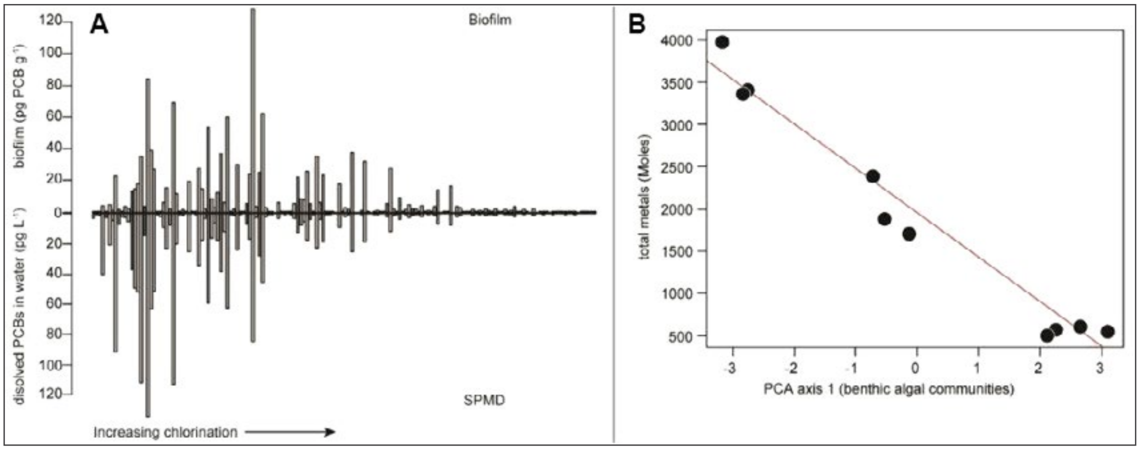

Figure: (A) PCB congener results for biofilm (top) and water (bottom) samples from the same site; congeners increase in chlorination from left to right. (B) Regression of the total metal burden measured in the biofilm tissues against the PCA axis 1 scores of periphyton communities.

Are otters toxic? A trial in using enzyme-linked immunosorbent assays (ELISAs) to measure contaminants in captive sea otter diet and feces

SEATTLE AQUARIUM

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1. Seattle Aquarium

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- **The Seattle Aquarium ran trials to measure PBDEs, PCBs, glyphosate and pyrethroids in sea otter scat and seafood diet items, using ELISA kits.**
- **It was determined that ELISA kits could be used as an initial monitoring and screening tool, but values of concern should be further tested using gas chromatography and mass spectrometry methods.**

In 2016, the Seattle Aquarium began a trial in using enzyme-linked immunosorbent assays (ELISAs) to measure PBDEs in wild and captive Northern river otter scat (see 2016 toxics synthesis report). In 2017, the project was expanded to measure three additional compounds in captive sea otter fecal samples, as well as diet items fed to the marine mammals at the Aquarium. Sea otters are apex predators with small home ranges that live in the coastal nearshore environment. These mustelids have average daily food requirements of 25% of their body mass per day (Riedman & Estes, 1990). Because these animals feed on a large quantity of benthic invertebrates, they are thought to have the capacity to quickly biomagnify contaminants from food sources. Diets of exhibit animals at the Aquarium consist of sustainably harvested restaurant quality butter clam, surf clam, mussels, pollock, capelin, herring, and shrimp from local and international vendors. These items are of interest because they are also found in local Salish Sea waters. Contaminant ELISA kits included polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs), glyphosate and pyrethroids. These contaminants consist of a flame retardant, industrial chemical, an herbicide and insecticide, respectively.

Initial results indicate that the four compounds were low for all sample types (Figures 1 and 2). All levels were below adverse effect thresholds to fish and below daily oral exposure limits to humans. The Puget Sound Partnership lists adverse effect thresholds for fish as 2,400,000 ppb for PCBs and 1,400,000 ppb for PBDEs. For human ingestion, the FDA set human daily limits of PCBs to 2,000 ppb from fish and shellfish, and 3,000 ppb in eggs. The EPA lists human daily limits of glyphosate at 2,000,000 ppb, and pyrethroids at 5,000,000 ppb. All samples fell below these threshold levels, indicating that the diet items are also safe for human consumption.

Samples from the 2016 study were subsequently tested with a gas chromatograph and mass spectrometer at the Northwest Fisheries Science Center. Differences in values resulted in further ELISA method changes and revisions. The Seattle Aquarium is working with the Woodland Park Zoo, Northwest Fisheries Science Center and Vancouver Aquarium to validate the ELISA method of toxics monitoring. Earlier in 2018, a river otter from the 2016 trial died of old age and natural causes, and matched samples of typical food items, blood, muscle, liver, fat, skin and fecal were collected. Research staff will run these when funding allows, to correlate values between diet items and feces in comparison to other sample types (e.g. fat and liver tissue). Our objective is to continue to optimize methods so it can be determined if these kits may be used as a viable option in contaminant testing.

Once validated, these kits could be used as a quick and cost effective monitoring tool to analyze marine mammal prey items within the Salish Sea and outer Washington coast. Values of concern (e.g. high) could then be run using gas chromatography and mass spectrometry for confirmation and to inform management.

Ultimately, the Seattle Aquarium will use this data for animal care, but also to inform the public about toxic contaminants found in fish and invertebrates common within sea otter diets and the potential hazards to wild sea otters and other nearshore marine life.

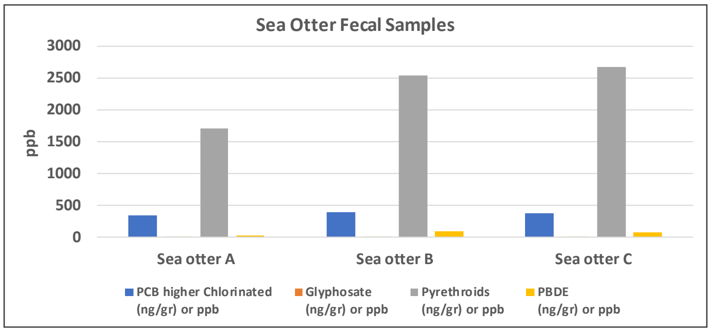

Figure 1. Contaminants measured in opportunistically collected sea otter fecal samples at the Seattle Aquarium. Pyrethroid values were highest (up to 2665 ppb) while glyphosate values were lowest (less than 10 ppb).

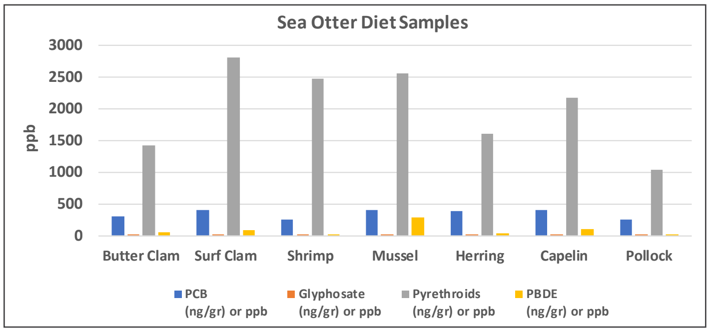

Figure 2. Contaminants measured in sea otter diet samples (sustainably caught restaurant quality items from local and international vendors). Pyrethroids were highest in surf clams (2,815 ppb), followed by PCBs in capelin (408 ppb), PBDEs in mussels (288 ppb) and glyphosate in mussels (12 ppb).

Biogeochemical cycling of polybrominated diphenyl ethers in the Strait of Georgia - preliminary results

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1. UBC

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In recent decades, polybrominated diphenyl ethers (PBDEs) have been increasingly used as flame retardants in many consumer products. Their release in the environment is an increasing concern due to their wide dispersal, persistence, toxicity, and tendency to bioaccumulate up the trophic chain. Despite this concern, however, detailed quantitative understanding of their biogeochemical cycling in the environment is still incomplete, particularly in the marine environment.

This study was designed to quantify the sources, sinks, and biogeochemical cycling of PBDEs in the coastal waters off British Columbia. Seawater samples were collected from different depths and filtered to quantify dissolved PBDEs (>100 L per sample), and particulate PBDEs (>500 L) were collected using large volume pumps (Fig. 1). Samples were analyzed at SGS AXYS (Sidney, BC). The ^{234}Th/^{238}U disequilibrium in the water column and ^{234}Th activity in filtered particles were also measured to quantify the sinking flux of particulate PBDEs (Cai et al., 2006). Finally, a box model (Wang, 2015) was used to calculate a preliminary mass balance of dissolved PBDE in the Strait of Georgia (SoG).

Dissolved concentration profiles measured in May 2017 were similar for all PBDE congeners (Fig. 2). Lowest concentrations occurred at 25 m, possibly due to removal by phytoplankton. Concentrations increased towards the surface, suggesting significant input from the Fraser River or the atmosphere. Highest concentrations were found at intermediate depths, reflecting a subsurface (75-150 m) discharge of effluent from the Iona wastewater treatment plant. Depth of maximum PBDE concentration varied with the level of bromination of the congeners, suggesting PBDEs are released to

- **We discovered a systematic variation in the depth of maximum concentration with the level of bromination of different PBDE congeners.**

seawater by desorption from sewage particles as the effluent plume rises to its level of neutral buoyancy. As the more brominated congeners desorb at a slower rate, they are released at shallower depths. Particulate PBDE concentrations were much lower than dissolved concentrations, and highly variable in time and space. Particulate concentrations were below detection limits during a phytoplankton bloom, likely due to a dilution effect of high biomass and slow kinetics of adsorption from seawater. PBDE sinking flux calculated from the ^{234}Th/^{238}U disequilibrium increased from 25 to 150 m, because flux at 25 m reflects input from the Iona effluent plume. The flux measured at 150 m in 2017 was significantly higher than the accumulation rate in sediments measured in 2003-2005 (Grant et al., 2011), pointing to an increase in PBDE input to the SoG in recent years.

Finally, when we added known input from 2005 effluent and the Fraser River to the box model, assuming no addition from Pacific Ocean water or removal to sediment, the predicted concentration was much lower than measured. There are three possible explanations for this discrepancy: (1) input from wastewater treatment plants has increased since 2005, (2) there are additional sources, yet to be identified, and (3) the measured concentrations do not represent the average concentration for the entire SoG. These hypotheses will be tested by (1) measuring PBDE concentrations in current effluents, (2) assessing PBDE input through the atmosphere and urban run-off, and (3) conducting a synoptic survey of PBDE concentration in the SoG.

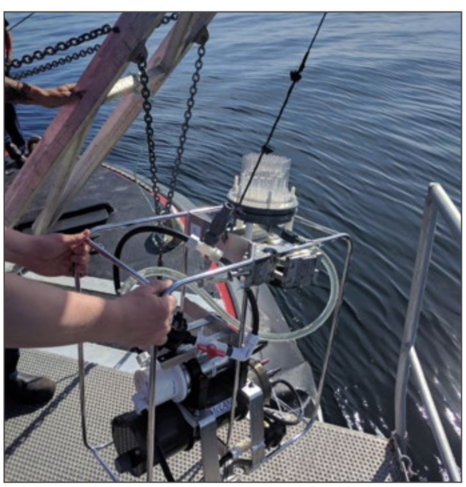

Figure 1. In-situ large volume pump used to collect particulate PBDE and ^{234}Th samples. Photo: Y. Sun

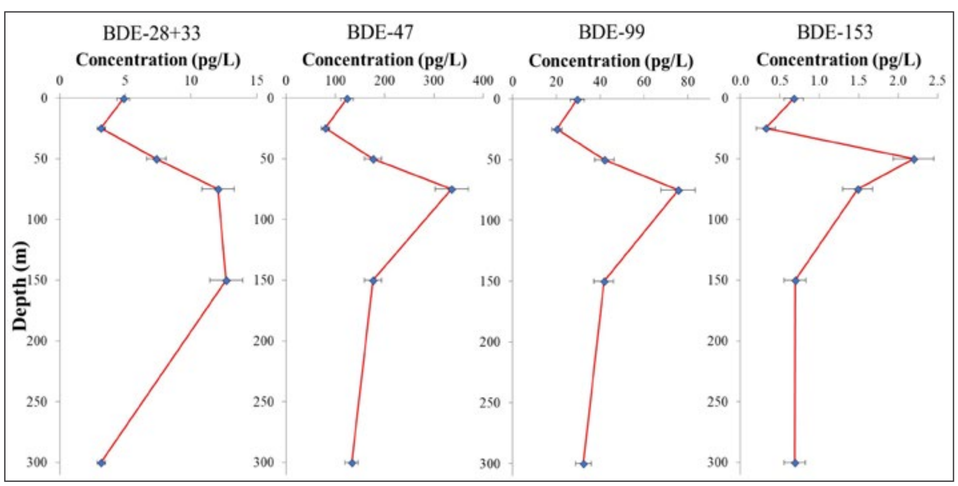

Figure 2. Depth profiles of dissolved PBDEs in the Strait of Georgia (49°15.00'N, 123°40.00'W) from May 2017. These select congeners have different levels of bromination.

Dispersion and removal of two toxic trace metals (Ag & Cd) in the Strait of Georgia

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1. UBC

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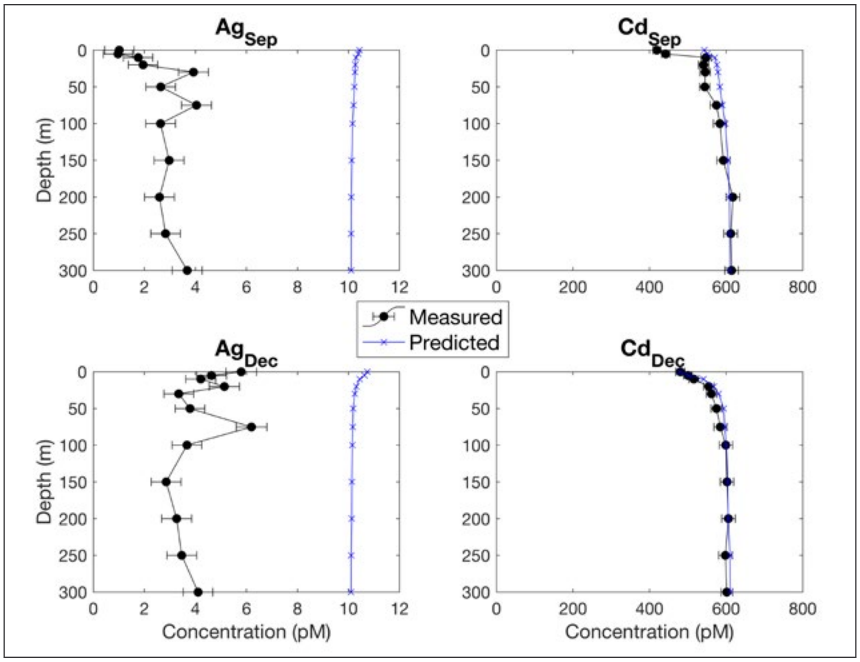
- **The Iona Island wastewater treatment plant is not a significant point source of Ag or Cd to the Strait of Georgia.**
- **Dissolved Ag concentrations in the Strait of Georgia are much lower than expected. Its seasonal variability will be determined through ongoing measurements.**

Silver (Ag) is classified as an environmental hazard because it is a toxic and persistent pollutant with a strong tendency to bioaccumulate in aquatic organisms (Luoma, 2008). With the advent of nanotechnology, nanoscale particles (1-100 nm) comprised of Ag are widely used in medical applications and consumer products. As such, it is necessary to monitor concentrations of Ag in the receiving waters of Strait of Georgia (SoG) due to the potential of increasing discharge. Cadmium (Cd) levels in coastal waters of British Columbia also require attention because farmed oysters have been found to accumulate Cd to levels that exceed export limits, restricting access to lucrative international markets (Kruzynski, 2004). The problem arises in part from the naturally high Cd concentration in the Pacific Ocean. Therefore, Ag and Cd are two critical trace metals that need to be monitored in the SoG.

To assess the impact of wastewater discharge, weekly effluent samples from Metro Vancouver's Iona Island wastewater treatment plant (WWTP) were analyzed for dissolved and total Ag and Cd in 2015. Our results show that the average dissolved Ag measured in effluent was about 80 times higher than in the incoming water from the Pacific Ocean; dissolved Cd concentrations were in the same order of magnitude as water from the Pacific Ocean. A steady-state Salish Sea box model originally developed by Wang (2015) was used to assess the relative contribution of the main sources of Ag and Cd into the SoG. Preliminary analysis suggested that metal fluxes from the Iona outfall were insignificant compared with inputs from the Fraser River and the Pacific Ocean.

Seawater samples were collected in the SoG (49°15.00' N, 123°40.00' W) using trace metal clean Go-FLO bottles deployed on Kevlar line and triggered with Teflon messengers from September 2017 onwards. Samples for dissolved trace metals were filtered through a 0.2 µm AcroPak™ capsule. Nutrient samples were also taken from the same GO-FLO bottles to measure nitrate, phosphate, and silicate. Our September results show that dissolved Ag and Cd in the near surface layer were significantly lower than their concentrations at deeper depths. This surface depletion in metals coincides with a drawdown in macronutrients. In-situ measurements of fluorescence indicated that there was a small phytoplankton bloom at the time of sampling, which explains uptake of macronutrients and trace metals in the surface water. In December, surface depletion of metals was less noticeable, likely due to low phytoplankton biomass. If we assume that conservative mixing between the Fraser River and the Pacific Ocean is the only control of trace metals in the SoG, we can calculate the expected concentrations of dissolved Ag and Cd for each sample based on its salinity. Comparisons between the predicted and our measured concentrations are shown in Figure 1. For Cd, the measured concentrations in December agree very well with the predictions. In September, Cd concentrations in the surface layer were lower than predicted, which indicates uptake by phytoplankton. Surprisingly, all measured Ag concentrations were significantly lower than the predicted values. This deficit in Ag throughout the water column cannot be explained solely by biological uptake , especially in deep waters where phytoplankton growth is negligible due to low light conditions. Our results seem to suggest that Ag is removed from the water column through a process that is currently unknown. Ongoing measurements will provide further information on the temporal variability, sinking fluxes, and possible removal mechanisms of Ag and Cd.



Dissolved Ag and Cd measured in September and December 2017 at 49°15.00' N, 123°40.00' W in the Strait of Georgia; error bars represent 95% confidence intervals. Predicted concentrations assume conservative mixing between the Fraser River and upwelled Pacific water.

Sources, timing, and fate of sediment and contaminants in the nearshore: insights from geochemistry

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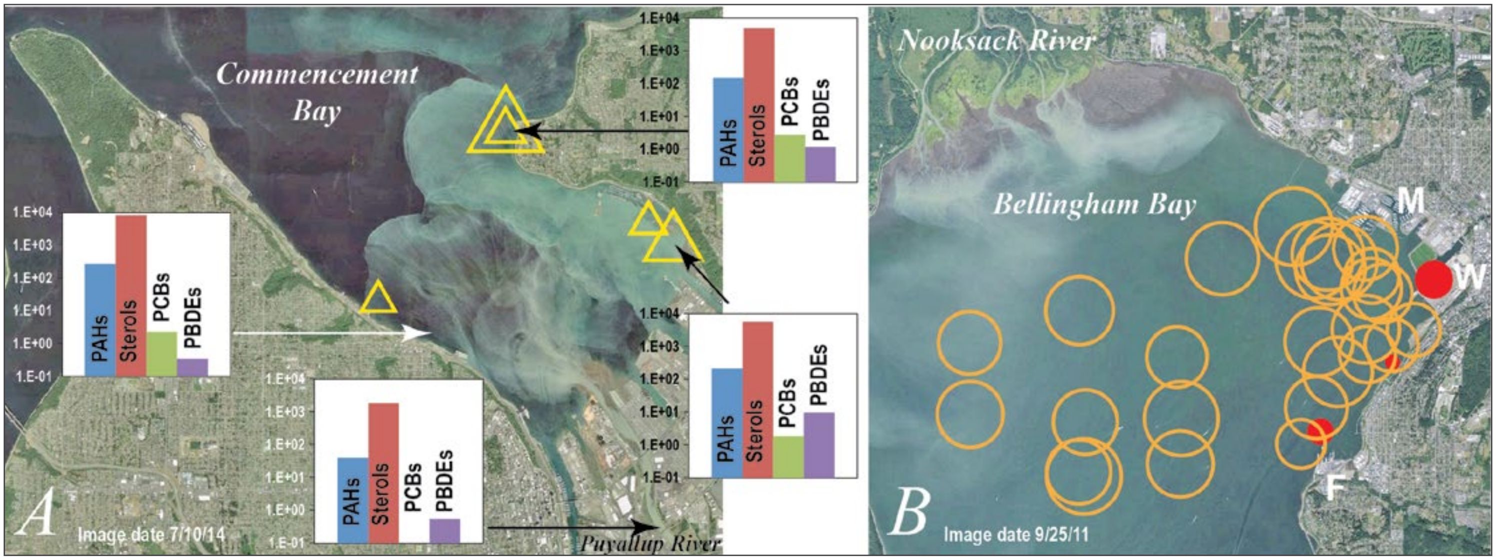
- **Geochemical sourcing shows riverborne sediment and contaminant transport and deposition in the nearshore.**
- **Geochemical aging distinguishes recent versus pre-existing sediment and contaminant deposition in the nearshore.**

Rivers in Cascade watersheds carry sediment with a volcanic composition that is distinct from the plutonic composition of the Puget lowlands. Compositional properties (signatures) allow discrimination of river-sourced Cascade from lowland sediment, and inferences about transport pathways. Surface sediment on land contains atmospheric radionuclides whose known decay rates define monthly (^{7}Be) and decadal (^{210}Pb) timescales of sediment inputs from land to nearshore regions. We used geochemical signatures to source river-borne sediment in two urban embayments in Cascade watersheds: Commencement Bay (CB) and Bellingham Bay (BB). We concurrently determined sediment contaminant levels on single samples and, in CB, used geochemical aging to distinguish contaminants in recent winter outflow from those that were pre-existing. Methods are described in Takesue et al. (2017). Geochemical signatures showed that Puyallup River (PU)-sourced fine sediment (<63 µm) accumulated more along the northeast (NE) shore of CB than the southwest: median 91% and 69%, respectively. River-sourced sediment from recent winter storms, containing higher ^{7}Be activities (open triangles, Fig. 1A), also accumulated on the NE shore and had lower contents of PAHs, fecal sterols, and potentially toxic metals (TM, not shown) compared to the south shore; only PBDEs were higher overall (column graphs, Fig. 1A). Lower ^{7}Be and ^{210}Pb activities in south shore sediment indicated that contaminants there were associated with older sediment. Existing sediment in CB contained higher levels of urban contaminants than new PU material. No PAH, PCB, or TM levels in CB exceeded Washington State marine sediment quality standards (WAMSQS). Geochemical signatures were not distinct in the Nooksack River watershed and lowlands, precluding sediment sourcing in BB. PAH ratios in BB sediments were ubiquitous (open circles, Fig. 1B), suggesting atmospheric rather than riverine transport, except for three or four sites along the urban waterfront that were indicative of local combustion sources (closed circles, Fig. 1B). Elevated TM occurred offshore of Fairhaven (cadmium; copper, Cu; lead, Pb; zinc, Zn), Whatcom Creek Waterway (Pb, Zn), and the marina (Cu, Zn). No PAH or TM concentrations in BB exceeded WAMSQS. Insights gained from sediment geochemistry about the sources, timing, transport, and fate of riverborne fine sediment and contaminants in nearshore regions are valuable components of monitoring programs that can help guide habitat restoration and resource management decisions toward effective and sustainable outcomes.



Google earth maps showing sediment and contaminant distributions in A) Commencement Bay and B) Bellingham Bay. Open triangles in (A) show organic-carbon normalized ^{7}Be activities summed over 0-8 cm. Column charts in (A) show concentrations of: polycyclic aromatic hydrocarbons (PAHs), sterols, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) summed over 0-2 cm; arrows show sample locations. Circles in (B) show PAH ratios [fluoranthene / (fluoranthene + pyrene)] indicative of biomass/coal combustion (open circles) and vehicle emissions (closed circles). Fairhaven (F), Whatcom waterway (W), marina (M)

Effects of a neonicotinoid mixture on an aquatic invertebrate community

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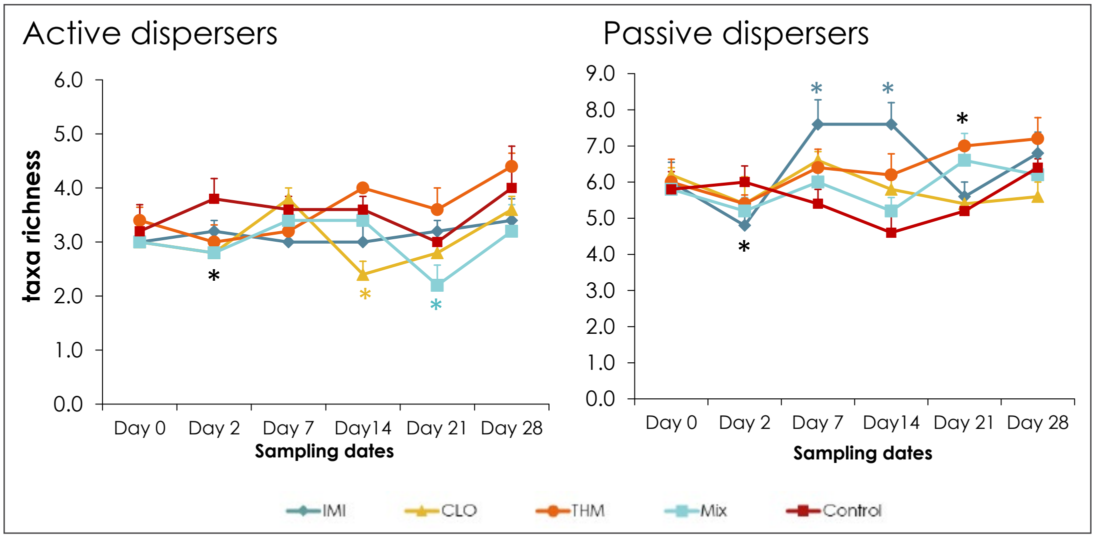
- **Neonicotinoid insecticides are detected in surface water in the Puget Sound area.**
- **Results indicate that a neonicotinoid mixture alters the aquatic invertebrate community at low concentrations.**

Neonicotinoid insecticides represent about a quarter of the global market and their use is increasing globally. Among them, clothianidin, imidacloprid and thiamethoxam are widely used as systemic insecticides on corn and soybeans, but they are also used for lawn and garden care and as topical flea medicines. Neonicotinoids are highly soluble in water and persistent in soil, and even though they are not intended for use in water bodies, they may enter in the aquatic compartment via spray drift, runoff or leaching, and contribute to downstream aquatic toxicity. In Washington State, imidacloprid is almost always detected in surface water in the Puget Sound area (WSDA, 2018), at concentrations usually lower than 0.1 µg/L but exceeding 1 µg/L in some sampling sites; it was detected at 1.74 µg/L in the Big Ditch slough, a creek providing habitat for salmons in the Skagit wildlife area.

Monitoring data for neonicotinoids in the environment are limited, with most studies focusing on single-insecticide exposure (mainly imidacloprid). Very little is known concerning the impact of neonicotinoid mixtures on the environment and their combined toxicity on invertebrate communities. Since neonicotinoid contamination is likely to induce a top-down trophic cascade in a community dominated by invertebrate predators, we ran an outdoor mesocosm experiment to test the effects of a neonicotinoid mixture made up of clothianidin, imidacloprid and thiamethoxam on an aquatic invertebrate community.

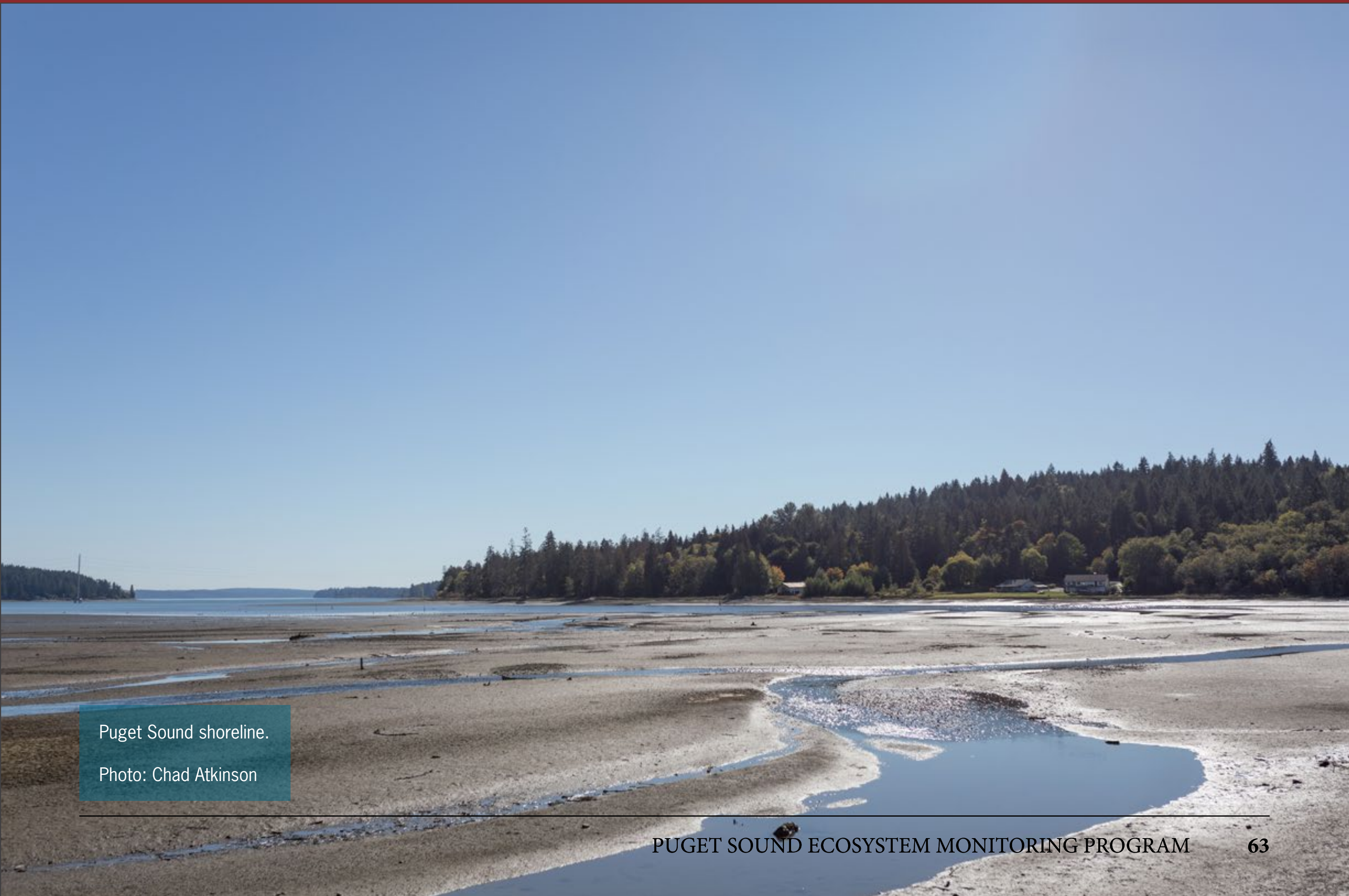
Outdoor microcosms (76L plastic tubs) were set up on the campus of the Puyallup Research and Extension Center (47°11'18.2"N, 122°19'43.9"W) in August 2017. The pools were filled with well water, enriched with rabbit food, dry leaf litter (*Quercus* sp.) and 250 mL of pond water from nearby ponds to provide nutrients, phytoplankton and zooplankton. Common invertebrate predators, such as water boatmen (Corixidae), collected from nearby ponds, were added into each pool prior insecticide application. Treatments consisted of pesticides being applied individually, in addition to a mixture of all three. Clothianidin was applied at 3.11 µg/L, imidacloprid at 0.256 µg/L, thiamethoxam at 1.49 µg/L (5 replicates for each treatment). Five pools remained untreated as control. The community was sampled one day before treatment, then two days after exposure, seven days, and weekly until the end of the experiment (28 days after treatment). Three weeks after exposure, the diversity of the active dispersers (mainly insects) decreased significantly in the mixture-treated pools in comparison to the control, while the passive disperser diversity (mainly zooplankton) increased. Among the insects, the nematocera group (dipterans) were negatively affected by the treatments three weeks and four weeks after exposure (Kruskal-Wallis test, $p = 0.0484$ and $p = 0.0074$, respectively), chironomids being the most impacted taxa. *Scapholeberis* sp., the most abundant zooplanktonic taxa at the beginning of the experiment, was less abundant in the mixture-treated pools than in control after the exposure through the end of the experiment, although not significantly.



Effect of neonicotinoids on the taxa richness. Active dispersers: insects. Passive dispersers: zooplankton (copepods, ostracods and cladocerans). *: Significant differences between the treatment and control (Fisher's LSD test following RM ANOVA, p < 0.05).

Biological monitoring of stormwater and stormwater treatment (2018).

Photo: Chad Atkinson, UW Tacoma



Puget Sound shoreline.

Photo: Chad Atkinson

A community bioretention system treating stormwater runoff from several houses in Mill Creek, WA. The incorporation of these systems provides treatment to improve water quality, promotes infiltration to replenish local groundwater, and results in runoff patterns that are more similar to those from natural systems.

Photo: Matt Vasa (2018)

SECTION 3:
What is being done about it?
MANAGEMENT

Toxics in Fish Implementation Strategy

Department of Commerce

PUGET SOUND INSTITUTE

Linda Bentley[1], C. Andrew James[2]

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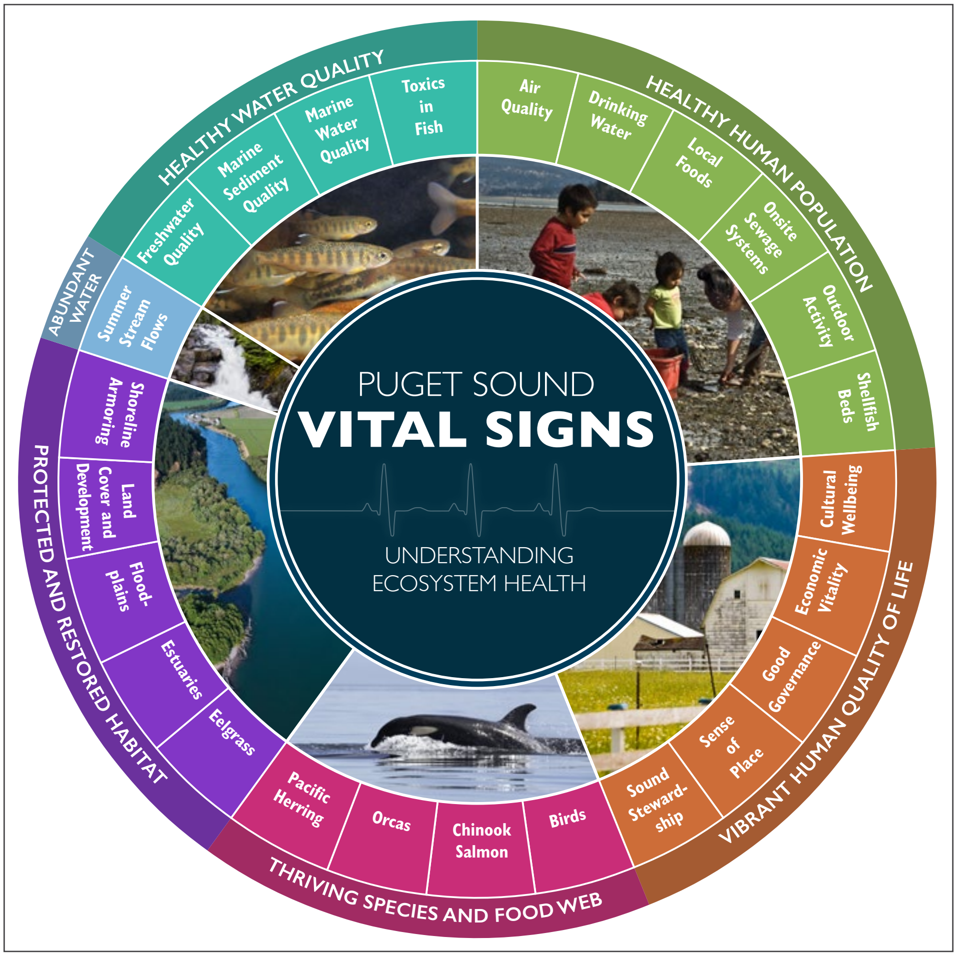
- **The Toxics in Fish Implementation Strategy is a recovery plan that will be used to guide funding and activities to reduce the impacts of toxics contaminants on marine fish and the humans that consume them., to be completed in 2019, will be used as a funding guidance.**

The Toxics in Fish Vital Sign establishes a broad recovery goal regarding toxic contaminants in Puget Sound stating that, fish populations will not be harmed by toxics contaminants and that they will be safe for consumption by predators and humans. The Vital Sign includes specific recovery targets covering a suite of chemical classes (PCBs, PAHs, PBDEs, and EDCs) and fish species (salmonids, English Sole, and Pacific herring). The targets were established based on fish-health or consumption threshold values allowing the comparison of measured contaminating concentrations in fish with the threshold levels to determine whether the fish (or the predators that consume them) would potentially be harmed by the contaminants, and if they are safe to eat.

Implementation Strategies are recovery plans aimed at meeting specific Vital Sign targets. They provide a roadmap for achieving the Vital Sign targets and serve as a fundamental part of the adaptive management framework for the Puget Sound. Each Implementation Strategy provides a situation analysis, focusing mainly on the causes and contributing factors to a particular problem and identifies broad strategies and specific actions which are thought to most likely lead to ecosystem recovery. The strategy and actions can serve as funding guidelines to federal, state, and local agencies for project and program implementation.

A Toxics in Fish Implementation Strategy is currently being developed under a project funded by the EPA National Estuary Program. Experts from a broad range of groups (university research, environmental monitoring, regulatory, regulated, and NGO) have been called together to help identify priority causes and solutions to Toxics in Fish. They have used a wide array of toxics monitoring provided by the WDFW TBiOS program, Ecology's sediment monitoring program, and other regional monitoring combined with relevant scientific literature to focus on causes and solutions. Although still under development, the broad recommendations include identifying and accelerating the clean-up of contaminated sites, removing the sources of contaminants, prioritizing contaminants of emerging concern based on risk to species, and regulatory reform. The Toxics in Fish Implementation Strategy will be completed in 2019 and subsequently be used as a funding guide thereafter.



The Toxics in Fish Vital Sign represents an important segment of the goals and targets for Puget Sound recovery, as shown on the Puget Sound Vital Signs wheel. Source: Puget Sound Partnership

Washington Department of FISH and WILDLIFE

DEPARTMENT OF ECOLOGY State of Washington

Copper concentrations in five Puget Sound marinas

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- **Copper from antifouling paint is taken up and bound to suspended matter and algae and then deposited on the bottom sediments in marinas.**
- **Dissolved Cu concentrations in water were above current state water quality criteria for acute exposure in one semi-enclosed marina for isolated samples.**

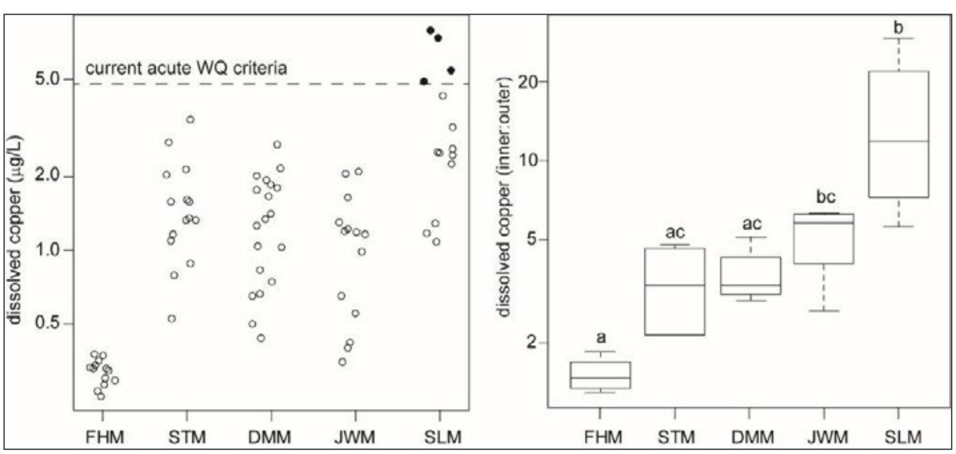
Marinas have been shown to contribute elevated levels of metals to marine waters, copper (Cu) in particular (Schiff et al., 2004). The Cu comes primarily from antifouling paints which are designed to discourage biofouling (barnacles, mussels, and other organisms) of boat hulls. In 2011 the Washington State Legislature passed the Recreational Water Vessels – Antifouling Paints Law (RCW Chapter 70.300) to phase out Cu in marine antifouling paints. However, following a review of recent data and possible substitutions, Ecology made the recommendation that the phase out of Cu be delayed until 2021 to complete further study (Penttila, 2017), which led to passage of House Bill 2634.

In 2016 and 2017, the Washington State Department of Ecology (Ecology) completed a baseline study of copper in five Puget Sound marinas of different configuration and size and assessed potential impacts to marine biota (Hobbs et al., 2018). Four sampling events were conducted between September 2016 and June 2017. Sample media included: water (dissolved and total fractions of metals), sediments (suspended and bottom), and biota (transplanted mussels and biofilms). All marinas were assessed within the breakwaters among the moorage slips and at local reference locations outside the marina. Water sampling occurred at times when upland stormwater discharges were not an issue.

Concentrations of dissolved Cu were occasionally high enough inside one marina to be above the state water quality criterion for acute impacts to aquatic life (Figure). Suspended sediments that were settling to the bottom of the marinas were collected over three to five month periods during the study. Suspended sediments and bottom sediments reliably showed higher Cu concentrations inside the marinas compared to outside the marinas. In addition, marinas with higher Cu concentrations in water also had higher concentrations in the suspended sediments.

None of the measured Cu concentrations in bottom sediments collected in this study suggested a possible impact to benthic (sediment-dwelling) invertebrates. Biofilms (algae) grown on artificial substrates inside the marinas had higher Cu concentrations in the marinas with higher dissolved Cu concentrations in the water; similar to suspended particulate matter. Lastly, transplanted mussels deployed inside and outside the marinas had good survival and increased growth characteristics following the deployment period. However, mussel tissue concentrations of Cu did not conclusively show differences between inside and outside locations, nor were the concentrations different from clean reference samples.

Overall, Ecology found strong evidence that Cu accumulates inside the study marinas to higher levels than outside marinas, regardless of marina configuration. Marinas that are more enclosed, where water is slower to flush in and out, accumulated higher levels of Cu than more open marinas (Figure). This study provides an adequate baseline dataset to measure progress as a result of recent legislation, towards the reduction of Cu to Puget Sound from marinas.



(Left) Dissolved copper in marina waters, where black dots are above the current state water quality criterion. (Right) The relative (inside:outside) dissolved copper concentrations in marinas over the year; letters above the box that differ are significantly different. (x-axis) Marinas are more enclosed (slower flushing) from left (open) to right (enclosed). FHM=Friday Harbor Marina; STM=Swantown Marina; DMM=Des Moines Marina; JWM=John Wayne Marina; SLM=Skyline Marina.

John Wayne Marina in Sequim Bay.
Photo: Melissa McCall

Mitigation of stormwater pollutants by porous asphalt

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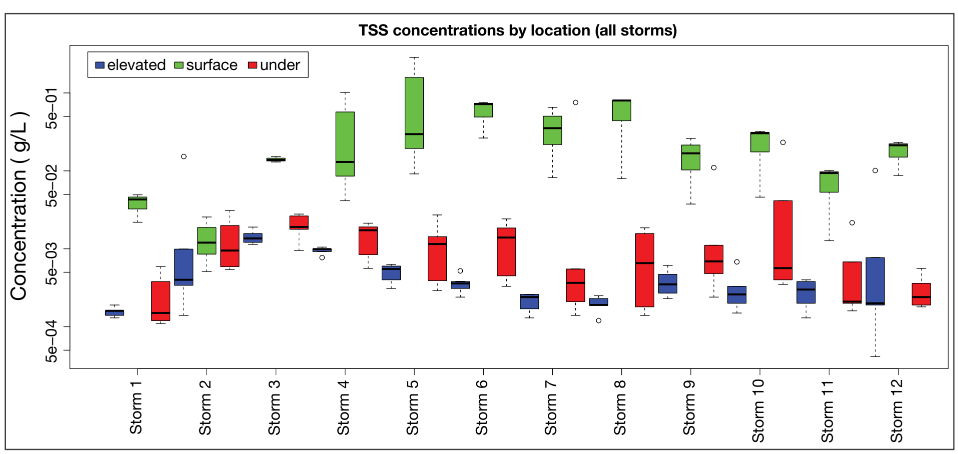
http://www.wastormwatercenter.org/

- **Porous asphalt systems have the potential to mitigate the impacts of stormwater in terms of quantity, suspended sediment, and phosphorous.**

Recent advances in green stormwater infrastructure (GSI) technology show that these systems can to some extent restore the natural pathways that stormwater takes from landscape to stream. Porous asphalt pavements are one of several GSI techniques that are increasingly used across the country to mitigate the effects of stormwater on downstream receiving waters. In the State of Washington, the use of GSI is mandated for new or retrofitted construction projects that meet certain criteria. This work is a performance study of a 9-cell replicated asphalt pavement test facility that was installed at the Washington State University's Puyallup Research and Extension Center Campus, Puyallup, WA. The asphalt test facility comprised 9 lined cells - 3 cells were constructed with conventional impervious asphalt and 6 with porous asphalt. Runoff from the impervious cells served as a control and were compared to runoff that had infiltrated the porous asphalt surface and had been collected through a series of subsurface drains. Essentially all the stormwater that had infiltrated through the sub-base aggregate was monitored and collected as outflow. Artificial and natural storm events were used to test both hydrologic and biogeochemical properties of the two systems. Pollutants that were evaluated included suspended sediments, metals, nutrients, and hydrocarbons. Previous published results from this work showed that porous asphalt pavements were able to infiltrate as much as 99.5% of incident rainfall. In terms of water quality, preliminary results from this work suggest that porous asphalt pavement systems are also capable of considerable treatment of several key stormwater pollutants. In terms of primary treatment, preliminary findings suggest that over 95% of Total Suspended Sediments (TSS) were removed when stormwater from a standard pervious asphalt pavement was compared to stormwater emanating from the subsurface drain of a porous asphalt system. Similarly, over 80% of total phosphorous and orthophosphate was removed from stormwater effluent through a porous asphalt system. These results while preliminary suggest that porous asphalt systems are a useful tool in the GSI toolbox.

Infrastructure and instrumentation used to capture stormwater infiltration into 9 test pavement cells at WSU's Research and Extension Center in Puyallup, WA. Photo: Aaron Copado



The distribution of measured Total Suspended Sediments (TSS) concentrations across 12 storms over 5 years. Surface samples from THREE standard impervious asphalt cells (green) were compared against effluent samples from elevated (blue) and subsurface (red) drains that collected effluent from SIX porous asphalt cells. Note: Y-axis is plotted on log-scale.

Highway runoff treatment performance evaluation of compost amended biofiltration swales

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https://www.youtube.com/watch?v=99FykSG-ZzQ https://www.tacoma.uw.edu/cuw

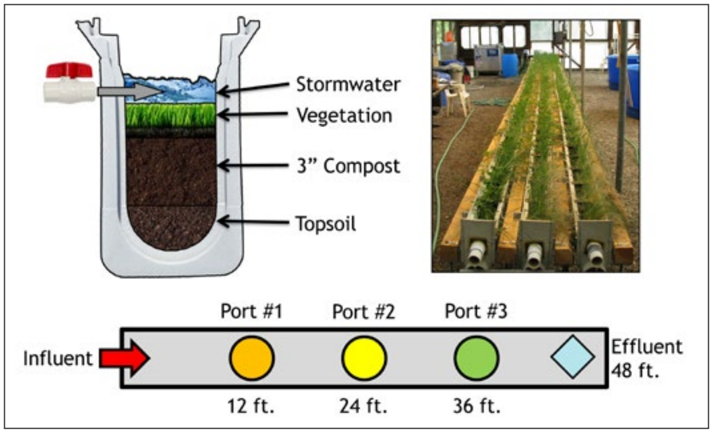
Urban road runoff, which contains a complex mixture of chemical pollutants and is a pervasive threat to aquatic animals, contributes to poor surface water quality in urbanized areas. Engineered treatment systems installed along roadways are intended to decrease the pollutant load entering urban waterways. However, few treatment technologies have been evaluated for their ability to protect aquatic organisms, and significant knowledge gaps exist about toxicant characteristics in road runoff. In this ongoing study, we are evaluating the chemical and biological performance of compost-amended biofiltration swales (CABS) for treatment of highway runoff. CABS are designed according to Washington State Department of Transportation (WSDOT) guidelines (WSDOT, 2014), and are vegetation-lined channels with a 3-inch blanket of compost. A 100 ft-long field-scale CABS was installed on WA State Route (SR) 518 in 2009, and the technology was approved by the WA Dept. Ecology as a best management practice for treatment of total suspended solids (TSS), copper (Cu), and zinc (Zn) (Ecology, 2011).

In the current study, we are collecting influent and effluent samples from the WSDOT field CABS and assessing performance with a variety of methods, including traditional targeted analyses (i.e., dissolved metals (Cu, Zn), polycyclic aromatic hydrocarbons (PAHs), and TSS), analyses of non-targeted analytes via high resolution mass spectrometry (HRMS), and toxicity testing via zebrafish (*Danio rerio*) embryo sub-lethal assays (McIntyre et al., 2014). Additionally, we built a laboratory-scale CABS at the Washington State University Puyallup Research & Extension Center. The laboratory-scale CABS consists of triplicate, 4-inch wide, 48-ft long channels that essentially represent a "slice down the middle" of the field-scale CABS. Flow rate and slope of the system are adjustable, and both surface water and infiltrate sampling ports are located every 12 feet along the length of the system. Performance assessments include chemical analyses and toxicity assays. Results from the laboratory-scale CABS will inform our understanding of removal mechanisms, and the effect of hydraulic retention time (HRT) on treatment efficacy. Further, we are characterizing both SR-518 and SR-520 runoff to identify previously unrecognized toxicants and indicator compounds in non-targeted data that scale with water quality improvements and may be used to assess treatment performance more broadly.

- **The efficacy of stormwater treatment technologies can be evaluated holistically via paired water chemistry analyses and toxicity assays.**
- **The effectiveness of compost amended bioswales (CABS) for contaminant removal and toxicity reduction increases with hydraulic retention time.**

Results from the first year of this study indicate removal of both metals and organic pollutants in the field- and laboratory-scale CABS. More infiltration capacity (i.e., a dry system) and longer HRT improved overall removal of chemical contaminants. Further, we observed that sorption is a key removal mechanism, as evidenced by more effective removal of relatively non-polar contaminants. For toxicity assays, the most apparent sub-lethal impact on zebrafish embryos was pericardial edema (fluid accumulation around the heart), which is indicative of PAH exposure. Notably, fish embryos exposed to effluent from the laboratory CABS showed less edema, indicating a reduction in toxicity during treatment.

Washington State Department of Transportation field-scale CABS, located on west-bound SR-518, near SeaTac Airport. Photo: Katherine T. Peter



Road runoff collected from the westbound onramp to SR-520 in Seattle, WA is pumped into the laboratory CABS system, and surface flow is sampled every 12 feet along the three replicate channels. Vegetation includes a mixture of clover and fescue as prescribed in the WSDOT Highway Runoff Manual.

Roads to ruin: the threats of urbanization to conservation of Coho Salmon, a sentinel species

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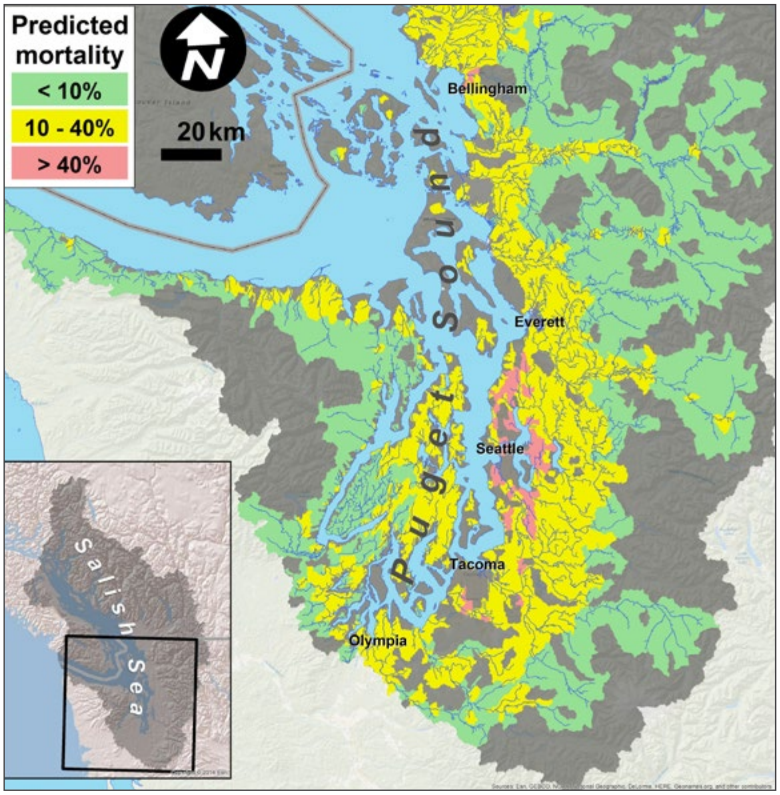
- **Puget Sound Coho Salmon returning to natal urban streams experience high pre-spawn mortality rates, likely owing to toxic urban stormwater runoff.**
- **Roads and cars are associated with Coho mortality, and predictive maps identify hotspots of mortality syndrome for all of Puget Sound.**

Urbanization poses a global threat to virtually all ecosystems, which is a challenge to species conservation. Our understanding of the impacts of anthropogenic ecosystem engineering is typically focused on physical habitat loss, as agricultural and forested lands are replaced with urban infrastructure. However, aquatic habitats are also chemically degraded by urban development, often in the form of toxic stormwater runoff, and this impact is poorly understood. Since the late 1990s, Coho Salmon adults returning to their natal urban streams in the Puget Sound Basin experience high rates of spawner mortality syndrome, which occurs when otherwise healthy adults die before they have spawned. Forensic evidence to date suggests that toxic urban stormwater runoff is the likely causative agent (Scholz et al., 2011) and that this high mortality is a threat to wild Coho population viability (Spromberg & Scholz, 2011). The ability to identify stream basins currently at risk for this syndrome is critical to conservation efforts of Coho Salmon, which are a species of concern under the Endangered Species Act.



Predicted mean Coho Salmon spawner mortality throughout the Puget Sound Basin using outputs from statistical modeling.

This research project, which was a joint effort between the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS), characterized the landscape ecology of spawner mortality syndrome across an urban gradient in the Puget Lowlands. Analyses were based on identifying relationships between in situ Coho spawner mortality time series data, and climate and landscape scale characteristics of the associated built environment. We found that this gradient was largely defined by road density and traffic intensity, and positively related to Coho mortality. This finding was consistent with other studies (Spromberg et al., 2016; McIntyre et al., 2018) that suggest motor vehicles are the likely source of chemical mixtures that wash off urban landscapes into Coho spawning streams. In addition, we used the output from our statistical models to generate a predictive mortality risk map for the entire Puget Sound Basin (Figure). The map identified likely hotspots for Coho spawner die-offs in unmonitored basins across Puget Sound.

Our analyses improve our understanding of the interplay between urbanization and climatic drivers of the mortality syndrome. Further, they are easily transferable to other regions, and can be used for siting green stormwater infrastructure in the current built environment and in future development scenarios. Indeed, NGOs, and various state, county and municipal entities have already begun using our methods and predictive maps for green stormwater infrastructure planning. The official release of our most recent scientific paper (Feist et al., 2017) received broad attention from media outlets, which brought the spawner syndrome into clear focus for many Puget Sound citizens, who had been observing the phenomenon for years but had not realized the connection between stormwater and motor vehicles. Subsequently, NMFS and the USFWS have developed a citizen science web portal (https://arcg.is/0SivbL) for people to upload their observations of the spawner mortality syndrome, which will improve the accuracy and quality of future predictive models. The portal also serves to better educate the public about the significance of stormwater runoff to the health of Puget Sound, which has strong policy implications for future stormwater mitigation plans.

DEPARTMENT OF ECOLOGY State of Washington

How effective creosote-treated piling removal can help save a cornerstone species

Celina Abercrombie[1], Russ McMillan[1]

1. Ecology

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https://ecology.wa.gov/Spills-Cleanup/

Pacific herring (*Clupea pallasii*) are a cornerstone species of the Northwest food web. Herring spawn on seagrass, macroalgae, rocks, and a variety of structures, including creosote-treated pilings. Treated pilings leach polycyclic aromatic hydrocarbons (PAHs) into the environment and contribute to contaminant loading in sediment, water, and biota (Department of Natural Resources, 2013).

In 2015-2017, the Toxics Cleanup Program (TCP) worked with Pope Resources to complete the largest creosote-treated piling removal project in Puget Sound – the Port Gamble Bay Cleanup – as part of a larger baywide cleanup and restoration effort. Over 8,500 pilings were removed from the bay, the majority of which were located at a former mill site in intertidal and shallow subtidal habitats, and on or adjacent to documented herring spawning areas.

The extensive number of pilings at the Port Gamble sawmill contributed to elevated concentrations of PAHs in sediments throughout the bay (Department of Ecology, 2012). Intertidal sediment samples at the former mill site had a mean PAH concentration of 653 ug/kg or 74.8 toxic equivalency quotient (TEQ; Department of Ecology, 2012). The cleanup level at this site was 16 ug/kg TEQ for carcinogenic PAHs (Department of Ecology, 2012).

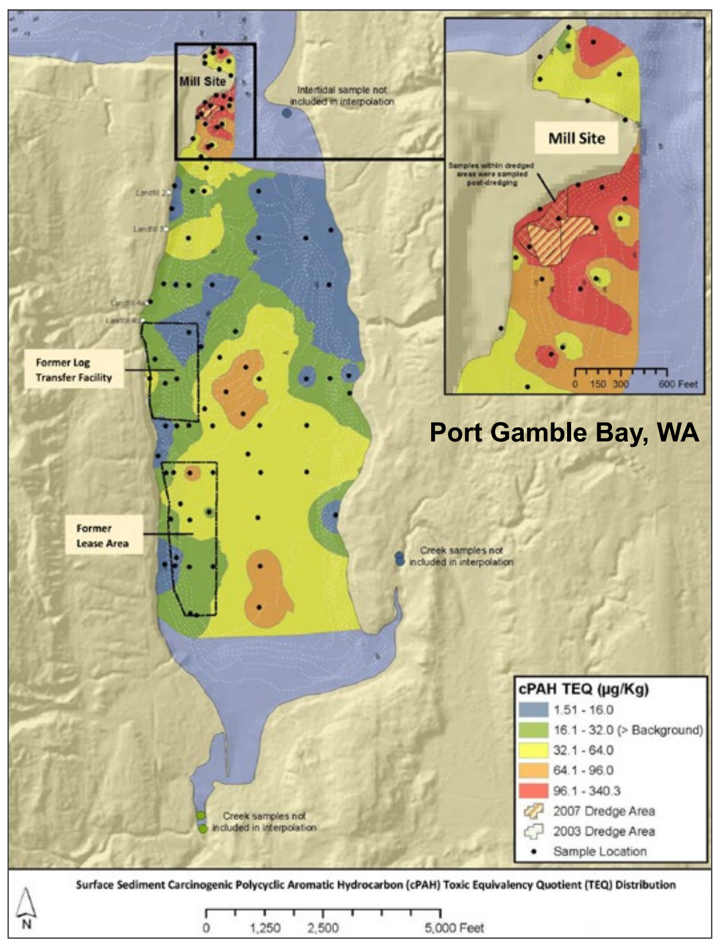
Prior to cleanup, TCP worked with the Washington Department of Fish and Wildlife to conduct a herring embryo mortality study to examine the effects of PAHs and other contaminant exposure during this sensitive life stage. Relatively high concentrations of PAHs associated with treated pilings were measured in both eggs and sediment around the former mill site. Egg concentrations ranged from 2.8 ng/g to 110 ng/g (West et al., 2015), and sediment concentrations ranged from 15.6 ppm to 92.9 ppm (Port Gamble S'Klallam Tribe, 2015).

The density and numbers of creosote-treated pilings located around the former mill site coupled with the higher concentrations of PAHs measured in egg and sediment samples illustrate the potentially detrimental conditions developing herring embryos encounter. Similar studies, such as the Quilcene Bay piling removal project, showed that failure to properly remove creosote-treated pilings from the marine environment can result in increased PAH exposure to embryos (West et al., 2016).

The results of these recent studies, in conjunction with the larger body of literature, is being used by the TCP to target removal of creosote-treated pilings as a source control measure at our cleanup sites. TCP is focusing on complete and effective removal of treated pilings and preparing guidance as part of our Sediment Cleanup Users Manual II that captures the need for full removal, best management practices, and examples of where this work has been successful.

- **Proper removal of creosote-treated pilings reduces PAH releases to the environment and exposure to aquatic organisms.**

Sites like Port Gamble illustrate the importance of creosote-treated piling removal in and around known herring spawning areas. Proper removal is critical to reducing PAH releases and exposure that contribute to reductions in productivity and health of important ecological resources in the Salish Sea.



Map of surface sediment carcinogenic aromatic hydrocarbon (cPAH) toxic equivalency quotient (TEQ) distribution in Port Gamble Bay, WA.

Environmental monitoring and lessons learned at the Commencement Bay dredged material disposal site

John Nakayama[1], William Hafner[1], Celia Barton[2], David Fox[3], Lauran Warner[3]

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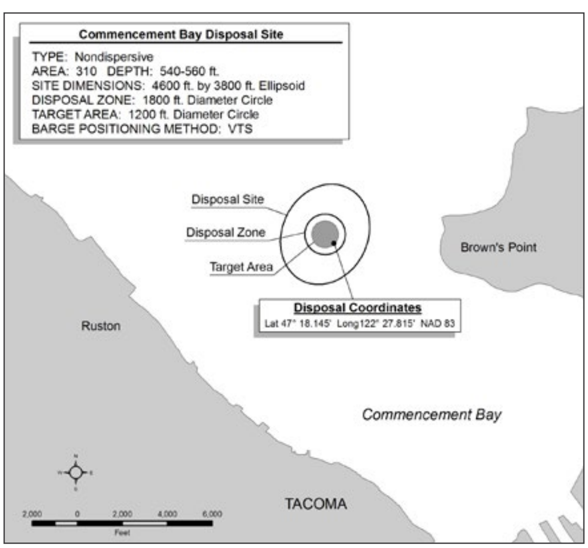
https://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/

- **Ten environmental monitoring events at the Commencement Bay non-dispersive aquatic dredged material disposal site have confirmed the site is performing as designed.**

Sediment grab sampling in Commencement Bay. Photo: John Nakayama



Commencement Bay non-dispersive aquatic dredged material disposal site.

Dredged material disposal in Puget Sound is managed by the Dredged Material Management Program (DMMP), an interagency partnership consisting of state and federal regulatory agencies in Washington State. The Commencement Bay non-dispersive aquatic dredged material disposal site in Tacoma, WA, was established in June 1988 by the Puget Sound Dredged Disposal Analysis (PSDDA) program (predecessor of the DMMP), under the dredged material management plan for central Puget Sound sites (PSDDA 1988). The DMMP developed a monitoring framework around three questions to assess the physical, chemical, and biological effects of dredged material disposal at Puget Sound non-dispersive aquatic disposal sites and their surrounding environments: 1) Does the dredged material stay on site?, 2) Has dredged material disposal caused the biological effects conditions for site management to be exceeded at the site?, and 3) Are unacceptable adverse effects due to dredged material disposal occurring to biological resources off site?

In the 29 years since the Commencement Bay disposal site was established, over 8.6 million cubic yards of dredged material has been taken to the site, and the DMMP has conducted 10 environmental monitoring studies to ensure compliance with the Clean Water Act and to verify that the disposal site was performing as designed. During five of the monitoring events, sediment profile imaging (SPI) showed offsite migration of dredged material that exceeded the 3 cm monitoring threshold. The material seen offsite was due to lateral movement of sediment after disposal, due to dynamic collapse and currents, and confirmed by Short-Term FATE (STFATE) modeling conducted by the U.S. Army Corps of Engineers, Seattle District. Offsite migration of dredged material has not been observed since the drop zone target was shifted in 2007 to increase dredged material capacity and reduce the rate of growth of the mound height. Only one occurrence was reported where perimeter sediment chemistry exceeded the Washington State Sediment Quality Standards (SQS) for three chemicals of concern. In 2003, the SQS was exceeded for phenol (2 stations), and butylbenzylphthalate and bis(2-ethylhexyl)phthalate (1 station). A DMMP study of phenol conducted in 2005 suggested that the phenol may have come from natural sources (e.g. pine needles) and generally does not persist in the environment. All of the other monitoring events showed perimeter sediment chemistry concentrations well below SQS criteria.

Overall, the ten monitoring events showed that the Commencement Bay site was working as designed, provided robust and important information for site management, and allowed for adaptive management to address issues as they occurred. Some limitations identified included: 1) understanding the impact of area-wide temporal changes to sediment chemistry relative to monitoring results, 2) understanding the potential for onsite bioaccumulation of chemicals related to dredged material, and 3) interpreting benthic infauna community data due to area-wide temporal changes occurring in Puget Sound. As the Commencement Bay site moves into its 30th year of operation, the DMMP is evaluating the lessons learned at the site to inform potential refinements to the overall monitoring framework.

Copper and zinc in urban runoff: potential pollutant sources and release rates

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https://fortress.wa.gov/ecy/publications/SummaryPages/1703018.html

- **Releases of copper and zinc in the built environment were estimated for a western Washington urban sub-basin with various land uses using literature values and GIS analysis.**
- **An estimated 360 kg of copper and 2,700 kg of zinc are released each year from the 18.6 km^2 study area. The primary sources of copper and zinc are identified, and a field study is being conducted to ground-truth release estimates.**

Copper and zinc in stormwater runoff can be harmful to a variety of aquatic organisms. Roof runoff, which contains both copper and zinc, has been shown to be toxic to rainbow trout, fathead minnows, and aquatic invertebrates (Bailey et al., 1999; Tobiason & Logan, 2000). Pre-spawn mortality of salmon on the west coast has been linked to urban runoff (Spromberg et al., 2016).

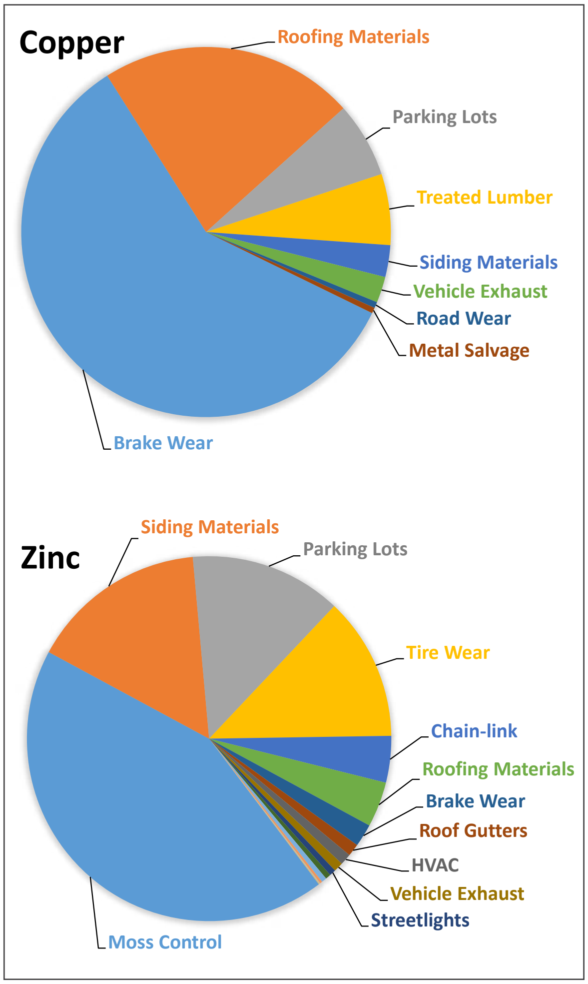
A number of studies have looked at potential sources of copper and zinc in urban environments and concluded that concentrations of copper and zinc are highest in commercial and industrial areas, with stormwater concentrations often exceeding water quality criteria for the protection of aquatic life (Norton et al., 2011; Hobbs et al., 2015). However, few comprehensive surveys have been performed on individual sources of copper and zinc.

In order to address this lack of information, releases of copper and zinc in the built environment were estimated for portions of a western Washington urban sub-basin containing a mix of residential, commercial, industrial, and undeveloped land uses (Bookter, 2017a). Objectives of the project were to determine sources, estimate potential releases, rank sources by potential contribution, qualify uncertainty, and identify data gaps.

Literature-derived release rates, exposed surface area of construction materials, annual vehicle miles traveled, and annual precipitation values were used to calculate total releases on an annualized basis. Surface areas of construction materials were determined using local county assessor data and GIS-digitized building footprints. Vehicle kilometers travelled were tabulated from current traffic count data and also estimated by the number of households present on minor roadways where traffic data are not collected.

On average, an estimated 360 kg (800 pounds) of copper and 2,700 kg (5,900 pounds) of zinc are released each year from the 18.6 km2 (7.2 square-mile) study area. The primary sources of copper are vehicle brake wear, roofing materials, parking lots, treated lumber, building siding, and vehicle exhaust. The main sources of zinc are moss control products, building siding, parking lots, vehicle tire wear, chain-link fence, roofing materials, and vehicle brake wear. The sources with the most uncertain and variable release values are roofing materials, parking lots, and metal salvage operations.

In order to ground-truth these release estimates, a sampling study was initiated in the study area during early-2018 (Bookter, 2018b). The sources selected for this on-going field evaluation are those with the greatest potential to contribute copper and zinc to the environment, and the greatest uncertainty and variability around the initial release estimates. Sampling includes rainwater washoff from four types of roofing materials, three types of siding materials, roof gutters, light standards, and chain-link fences. The overall study (literature-based estimates and sampling component) focuses on copper and zinc releases that may be useful for future source control efforts but does not address fate and transport of these chemicals following their release.



Copper and zinc releases in an 18.6 km2 urban watershed by source type. Total annual releases are estimated to be 360 kg of copper and 2,700 kg of zinc.

Assessing the impacts of toxic mixtures over a broad geographic scale: challenges and first steps

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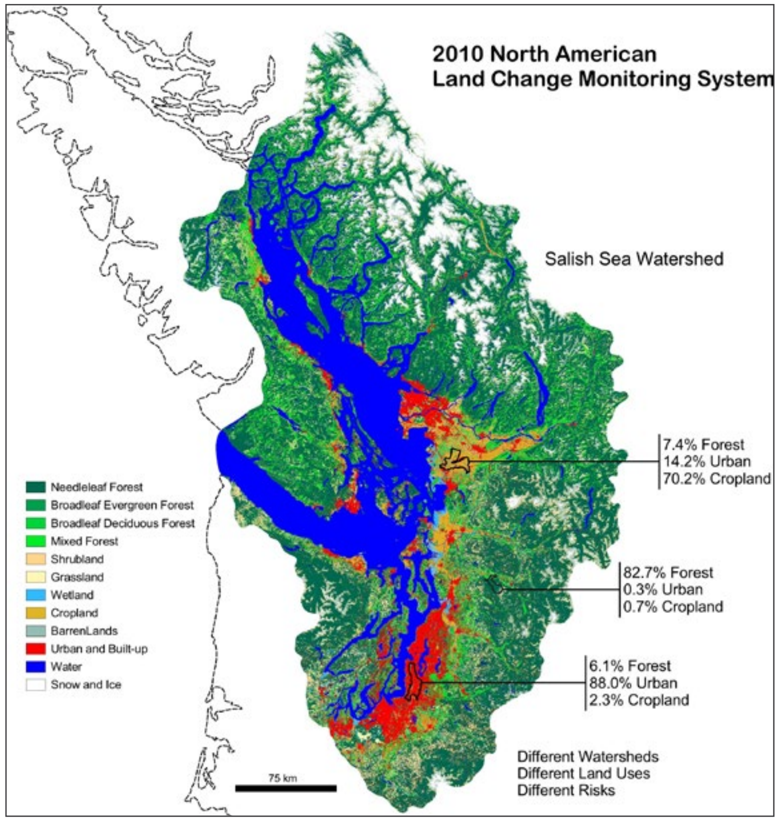
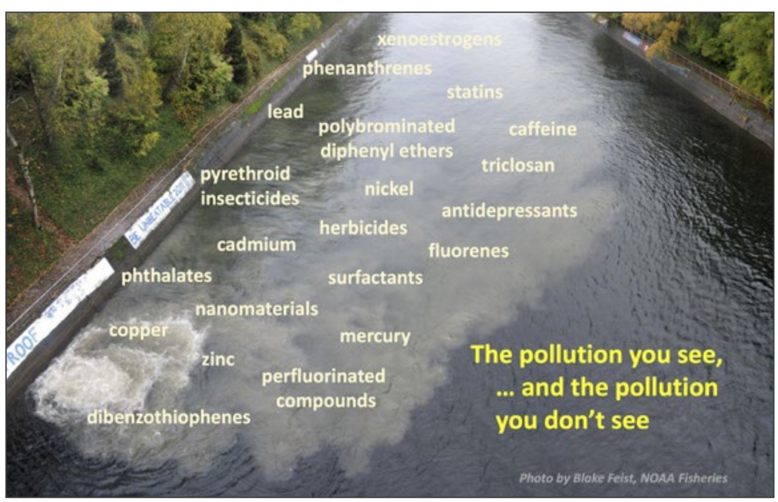
- **Aquatic species in the Salish Sea are at risk of exposures to complex mixtures of toxic chemicals.**
- **Land use analyses can be used as a surrogate to identify priority watersheds where contaminant exposures are more likely to pose a risk.**

Assessing the risks posed by chemical mixtures on aquatic species is a complex process. Ideally, comprehensive data are available on mixture exposure (e.g. chemicals present and their concentrations) and effects (e.g. mechanisms of action and toxicity data). However, this data can be challenging to obtain, even for a single location and time, such as a laboratory study or field site. Risk assessments often need to cover much larger scales that encompass entire watersheds populated by wide-ranging species. This increase in scale substantially increases the risk assessment complexity. The thousands of chemicals currently in use lead to potential environmental mixture exposures, including pesticide runoff and municipal wastewater discharges. At the landscape scale the nature of chemical mixtures will vary across space and time. For example, across even a single crop dozens of different pesticides may be used at different times of the year. At this increased complexity, currently available monitoring data are inadequate for describing realistic exposure scenarios and effects on aquatic species. Therefore, creative solutions are required to utilize sources of data that can identify where and when risk may be the greatest. Sources of data are available to develop a less-detailed, but still useful, landscape-scale risk assessment for mixtures. These include data on sites of potential use (e.g. crop locations and pesticide labels) or release (e.g. mapping of discharge permits). For example, the use of crop designations to represent where pesticide use is allowed can be a surrogate of actual use to establish where the greatest potential for exposure occurs. Similarly, aquatic species exposure to complex mixtures discharged in wastewater can be related to urban land uses and permit distributions. Relating contaminants associated with land use to the land uses within watersheds can be used to aggregate the risks posed by chemical mixtures to watersheds (i.e. create a "risk" index). Importantly, this landscape scale risk assessment for mixtures can establish priority watersheds for monitoring and further study. The next steps are to develop a process to prioritize the relative risks and identify important data needs necessary for more detailed mixture analyses in the context of a landscape-scale risk assessment.



Map of land types within the Salish Sea based on the 2010 North American Land Change Monitoring System (https://landcover.usgs.gov/nalcms.php). Land use within three of the watersheds highlights how different combinations of land use can produce risk.



Discharge into the Montlake Cut in Seattle, Washington following a rain event. Photo: Blake Feist

Performance of bioretention in managing stormwater pollutants

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- **Bioretention is the most common onsite stormwater management practices due to their hydrologic and water quality treatment benefits.**
- **Bioretention using current default soil media (60 sand: 40 compost) in Western Washington export nutrients and some dissolved metals with low concentrations.**

Bioretention is an engineered structure to manage stormwater from surrounding hard-surfaces by mimicking natural processes of soils and plants. The bioretention soil media (BSM), the filtration mechanism of bioretention, captures particles and pollutants in stormwater. Plants placed around the sides of bioretention facilities take up pollutants and stormwater, and support microorganisms and soil structure.

Many studies including on-site monitoring and modeling confirmed reduced stormwater surface-flow and pollutant removal (e.g. total suspended solid, dissolved metals and fecal coliform) using bioretention. Washington Department of Ecology rated bioretention as 'enhanced' pollutant treatment system per the 2012 Stormwater Management Manual for Western Washington (SWMMWW). Enhanced treatment for bioretention means the facility provides the following removal rates when common stormwater concentrations are evaluated (influent levels are greater than 100mg/L TSS, 0.005 – 0.02mg/L dissolved copper, and 0.02-0.3 mg/L dissolved zinc).

- TSS removal at a rate greater than 80%
- Dissolved copper removal higher than 30%
- Dissolved zinc removal higher than 60%

Several recent studies found significant removal of organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) and phthalates. Additionally, Ecology's default BSM (60% sand and 40% compost) prevented biological toxicity for Coho salmon.

However, several local studies found bioretention soil mixes (60:40 included) releases nitrate, phosphorus, and dissolved metals (arsenic and nickel) at least temporarily. Other factors also impact the bioretention performance and cause additional problems, such as improper design and lack of routine maintenance, soil erosion, inlet blockage or clogging, and high plant die-off. These issues concerned many stormwater managers in the region. Stormwater managers and regulators need to better understand the performance of bioretention, critical design criteria, maintenance requirements and limitations, so that they can confidently manage their installation in new and redevelopment projects across the jurisdictions.

Stormwater Action Monitroing (SAM), a coordinated stormwater monitoring program created by municipal stormwater permit stakeholders in Western Washington, aims to get new scientific information to improve stormwater management practices and support updates in policies, guidance and regulation. Several on-going and new studies, funded by SAM, are focused on bioretention sizing, soil mix composition, toxicity removal, and specific pollutant removals (See table).

Examples of current stormwater management and bioretention guidelines and manuals are:

- Stormwater management manual for Western Washington: Washington State Department of Ecology
- Low impact Development-Technical Guidance Manual for Puget Sound: Washington State University Extension & Puget Sound Partnership
- Rain Garden Handbook for Western Washington-A guide for Design, Installation, and Maintenance: Washington State University Extension
- Status update on Bioretention Soil Media: Washington State Department of Ecology

Bioretention in MillCreek, WA. Photo: Matt Vasa

Table. On-going and new bioretention studies funded by Stormwater Action Monitoring (SAM)

Primary focus	SAM study
Flow	• Raingarden and Bioretention assessment protocol
Pollutants	• Bioretention amendment with fungi • Bioretention reduction of PCBs • Bioretention alternative soil blends for a low phosphorus release • Longevity of toxicity protection by bioretention
Receiving water impacts	• Regional stormwater facility in Federal Way
Maintenance	• Mulch choices for bioretention maintenance

Developing high-performance bioretention filter media to protect water quality and aquatic organisms

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- **New high-performance media significantly improves water quality treatment for bioretention systems.**

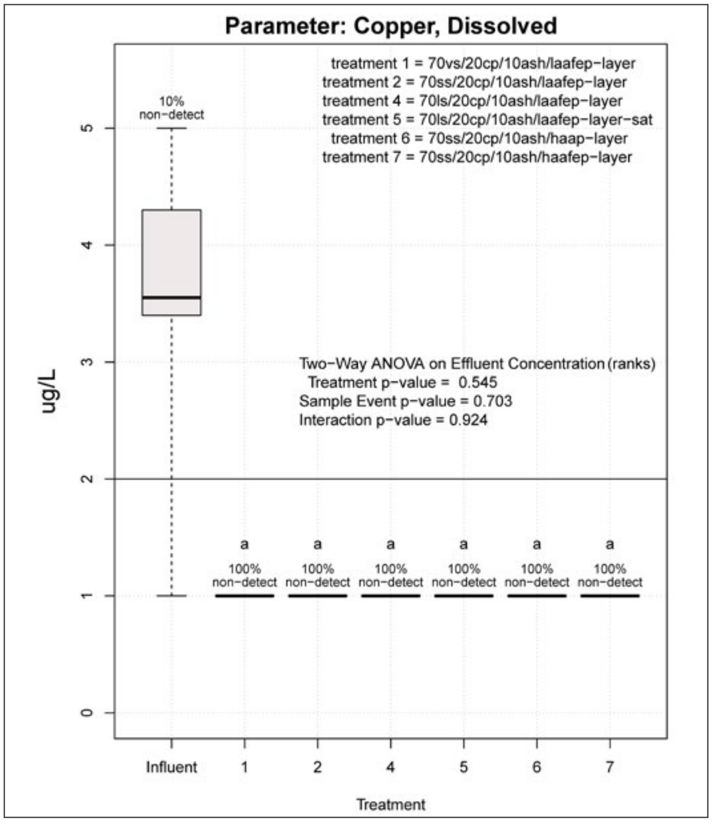
To protect marine and fresh receiving waters, the current Washington State, Phase I and Phase 2 municipal National Pollutant Discharge Elimination System (NPDES) stormwater permits require the use of low impact development (LID) practices where feasible as the first option for managing stormwater.

Bioretention is the most widely applicable and flexible BMP in the suite of LID practices. Bioretention systems may include under-drains, especially in areas with soils that are less suitable for infiltration. In these cases, a portion of the treated runoff is discharged back into the stormwater conveyance system and into local receiving water bodies. The current Washington State Department of Ecology (Ecology) specification for bioretention soil media (BSM) in western Washington (Ecology 2012) is a mixture of 60 percent sand and 40 percent compost (60/40). While the 60/40 BSM can provide reliable water quality treatment for some contaminants (e.g. solids removal, zinc, hydrocarbons, and possibly bacteria), regional and national research indicate that nitrogen, phosphorus, and copper are often exported from BSM containing compost (Herrera, 2015a; Herrera, 2015b; Herrera, 2016; Mullane et al. 2015; Hunt et al. 2006).

In response to these findings, The Bioretention Work Group (BWG) consisting of local jurisdictions (Kitsap, King and Thurston Counties, Cities of Seattle, Redmond and Tacoma), Department of Ecology, and Herrera Environmental Consultants have been working to develop high-performance bioretention media that reduces or eliminates contaminant export, improves contaminant capture and protects aquatic organisms.

Over the past five years many new media components and blends have been evaluated through rigorous testing procedures to determine if the materials are clean (do not export contaminants) and how well they capture pollutants. Recent findings suggest these new media blends show promise to significantly improve bioretention performance. Particularly promising is using a primary media placed above a secondary polishing layer. The primary media provides an initial physical and chemical filter and a substrate for plant growth while the polishing layer is designed as a final filter relying on chemical processes (e.g. adsorption and complexation. Initial research with this approach indicate that many stormwater contaminants can be reduced to near or below detection limits for typical residential and commercial stormwater influent concentrations. Figure 1 shows results for dissolved copper from recent lab experiments using large (20 centimeter) columns that were dosed five times with stormwater over a period of one month. Other contaminants, including zinc, nitrate-nitrite, fecal coliform, and total and ortho phosphorus showed similar results. Boxplots represent median, 25th and 75th percentiles and lowest and highest value using Two-way ANOVA on ranks. Letters represent significant difference among treatments using Tukey's HSD.

Research on these high-performance media will continue or approximately two more years. The final phase of research will include testing how well these new media protect aquatic organisms. The findings from this and previous research will be submitted to Ecology with recommendations for an additional Washington State bioretention media specification. These new media will provide an additional tool for applications protecting sensitive receiving waters and the aquatic organisms from toxic stormwater.



Reduction of dissolved copper in stormwater by various high-performance bioretention media. Detection Limit equals 2 μg/L. One-half detection limit used for non-detects and statistical analysis.

Notes: Treatment descriptions are as follows: vs, ss and ls = various sands; cp = coir; ash = biochar; aa = activated alumina; fe = iron; l = low content; h = high content; p-layer = polishing layer

Cleanup status of the Hylebos Waterway, Commencement Bay Superfund site

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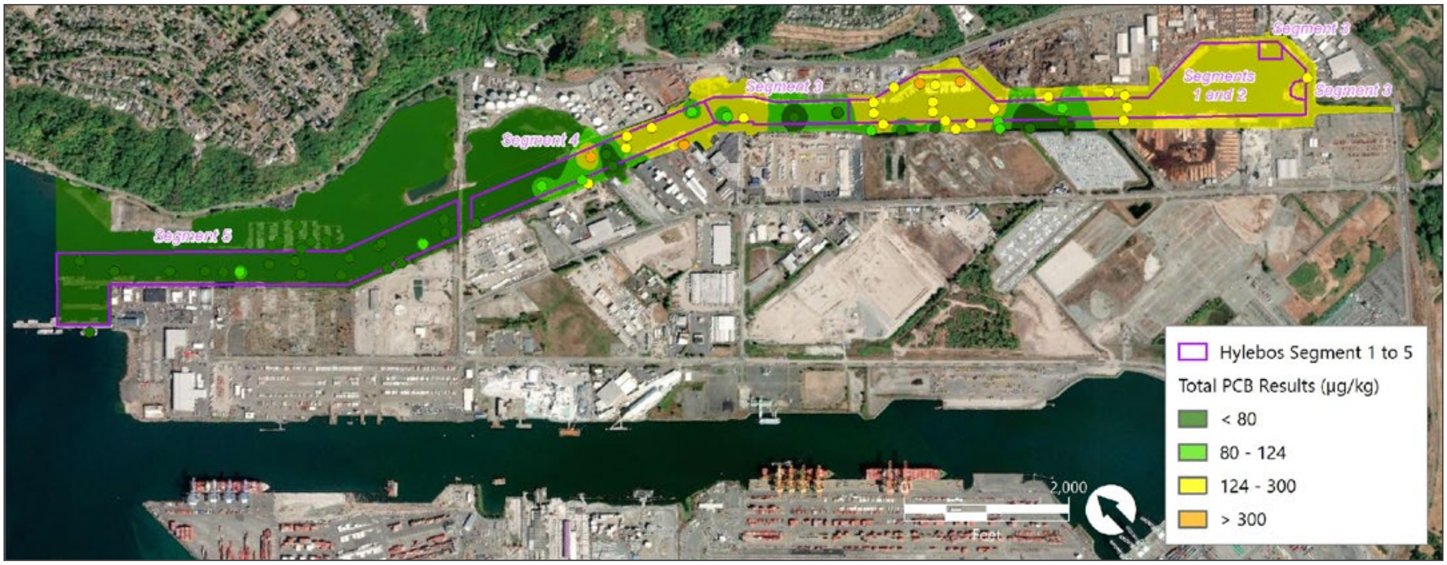
- **Hylebos Waterway cleanup actions, completed from 2002 to 2008, in total consisted of dredging 1.2M cubic yards of sediment, capping of 5 acres and natural recovery of 10 acres.**
- **Long-term monitoring performed from 2016 to 2017 shows that more than 99% of the waterway has now met cleanup levels and site-wide recovery is anticipated by roughly 2025.**

The Commencement Bay Nearshore-Tideflats Site ("Site") in Tacoma, WA is one of the first Superfund sediment megasites (cleanup costs exceeding $50 million) where construction has been completed. The Site encompasses an active industrial/commercial seaport that abuts approximately 11 square miles of estuarine habitat. The Hylebos Waterway is one of nine cleanup units in Commencement Bay, which was further segmented by EPA to facilitate cleanup implementation. EPA's sediment cleanup remedy included a combination of source controls, dredging, capping, and natural recovery to achieve Site-wide cleanup levels.

Segment 1 – 2 cleanup actions were completed from 2002 to 2006 and included environmental dredging and disposal of 580,000 cubic yards (cy) of contaminated sediment and wood debris, along with 2 acres of engineered capping. Segment 3 – 5 cleanup actions were concurrently completed from 2002 to 2008 and included environmental dredging and disposal of approximately 620,000 cy of contaminated sediment, 3 acres of engineered capping, and 10 acres of natural recovery.

As part of long-term monitoring to verify the effectiveness of sediment cleanup, surface sediment sampling throughout the Hylebos Waterway was performed from 2016 to 2017. While highly localized areas in Segment 2 – 4 marginally exceeded cleanup levels during this most recent post-construction monitoring event, more than 99% of the Hylebos Waterway has now met cleanup levels. For example, while surface sediment polychlorinated biphenyl (PCB) concentrations in individual samples ranged up to approximately 10% above the 300 microgram per kilogram (µg/kg) cleanup level, the current surface-weighted average PCB concentration throughout the Hylebos Waterway is approximately 103 µg/kg, below EPA's projected post-construction goal of 124 µg/kg (Figure).

In addition to PCBs, localized nearshore sediment areas in Segment 3 – 5 currently also marginally exceed cleanup levels for polycyclic aromatic hydrocarbons (PAHs) and hexachlorobutadiene (HCBD). However, since completion of construction, the extent of Hylebos Waterway sediments exceeding PCB, PAH, and HCBD cleanup levels has declined substantially (up to approximately 90%) due to ongoing natural recovery processes. Site-wide PCB, PAH, and HCBD recovery is anticipated to continue to reduce surface sediment concentrations over time, such that cleanup levels throughout the Hylebos Waterway will likely be met by roughly 2025, particularly if additional focused nearshore source control actions are completed by property owners. The next post-construction monitoring event is targeted for 2020.



Results of 2016-2017 surface sediment sampling in Hylebos Waterway following cleanup activities.

Changes to long-term status-and-trends sediment monitoring to assess nutrient enrichment and climate change pressures in Puget Sound

DEPARTMENT OF ECOLOGY State of Washington

Margaret Dutch[1], Sandra Weakland[1], Valerie Partridge[1], Dany Burgess[1], Angela Eagleston[1]

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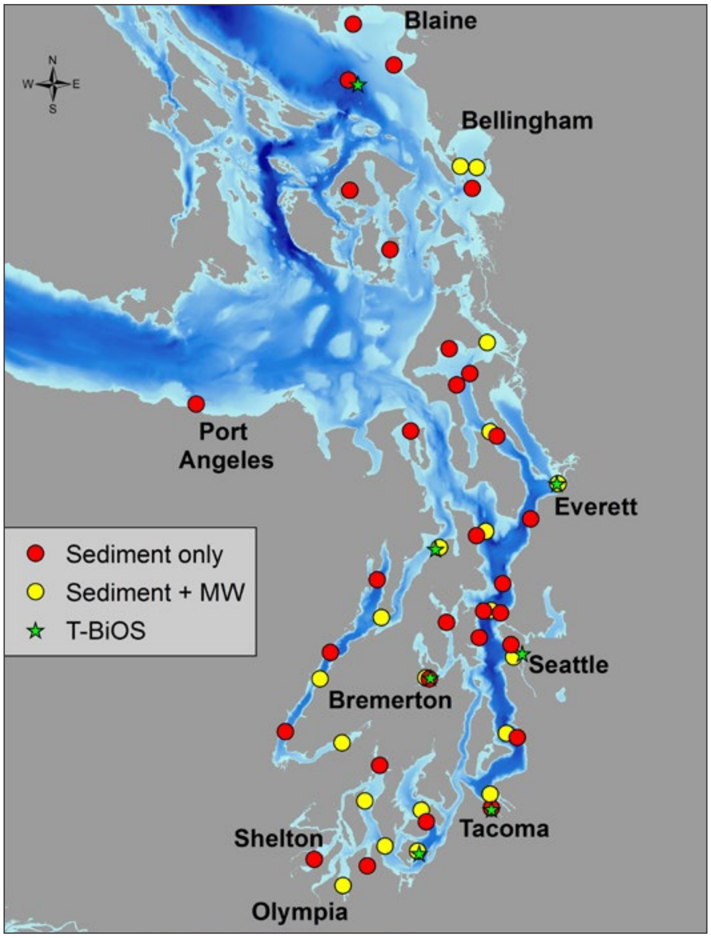
- **The Puget Sound Sediment Monitoring Program has been redesigned based on analyses of data from 28 years of sediment and benthos sampling.**
- **Revisions include expanded annual sampling and new suites of benthos and biogeochemistry parameters to assess climate change and nutrient loading.**

The condition of Puget Sound sediments and sediment-dwelling invertebrates (benthos) has been monitored by the Washington State Department of Ecology (Ecology) since 1989 as part of the Puget Sound Ecosystem Monitoring Program. Ecology's Marine Sediment Monitoring Program, originally developed to characterize the impact of toxic contaminants from point-source discharges on the benthos, has recently been redesigned to assess a wider suite of environmental parameters that may reflect nutrient enrichment and climate change pressures.



After 28 years, monitoring of Puget Sound sediments has indicated that toxic contaminants are generally detected in concentrations below regulatory thresholds in most locations. In urban bays, trends in toxic chemical concentrations above regulatory thresholds have been mixed, likely due to changes in point-source and stormwater discharges. Overall, benthos abundance and diversity declined in numerous locations, with little correspondence found among chemistry, toxicity, and benthos measures (Weakland et al., 2017, 2018; Partridge et al., 2018). Benthic organisms may be responding to pressures related to nutrient loading and climate change, rather than chemical contamination. Based on these findings, the program has been redesigned to assess a wider suite of environmental parameters Puget Sound-wide (Dutch, 2018).

As part of the redesign, 50 stations will be sampled annually as part of the long-term sediment assessment (Figure 1). Spatial patterns and aerial estimates (km^2), as well as change over time, will be determined for measured variables. To compare sediment and benthos condition to other Puget Sound monitoring programs, 20 of these stations are aligned with those of Ecology's Marine Waters Monitoring Program, while seven are aligned with the Washington Department of Fish and Wildlife's Toxics-focused Biological Observing System (TBiOS) monitoring locations.

New biotic and biogeochemical parameters have been added to the existing suite of biotic, physical, chemistry, and toxicity parameters. One-time annual measurements include:

- **Benthos:** Enumeration, lowest taxonomic level identification, size class, biomass estimates, ecological function.
- **Physical:** Temperature, salinity, station depth, sediment grain size.
- **Biogeochemistry:** Total carbon, total organic carbon, total inorganic carbon, total nitrogen, C:N ratio, total sulfides, biogenic silica, δ13C and δ15N stable isotopes.
- **Chemistry:** Metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, polybrominated diphenyl ethers, phthalates.
- **Toxicity:** Exploring new assays and funding sources for annual or 5th year testing.

[CONTINUED NEXT PAGE]

Sampling stations for the revised long-term element of Ecology's Puget Sound Sediment Monitoring Program, including 20 stations co-located with Ecology's Marine Waters (MW) Monitoring Program (yellow dots) and 7 stations co-located with WDFW's TBiOS monitoring program (green stars).

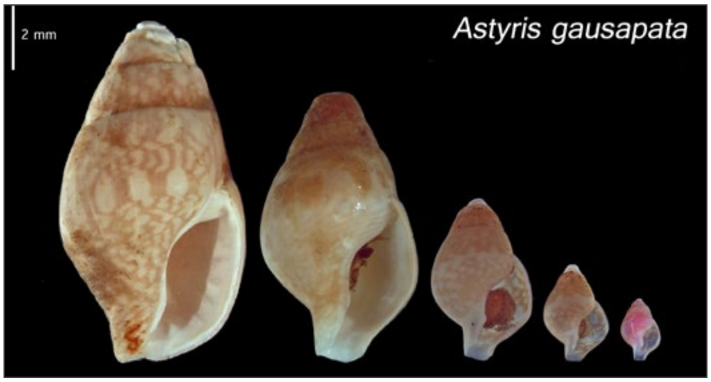
[CONTINUED]

Other parameters being considered in pilot studies include:

- **Nutrient and dissolved oxygen flux rates** as measures of sediment diagenesis.

Annual assessment of six urban bays in rotation, begun in 2007, will continue. In addition, sediments are provided to regional scientists assessing microplastics, foraminifera, harmful algal blooms, and environmental DNA (eDNA).

Annual monitoring data will be analyzed to determine patterns and relationships between parameters, as well as changes over time. While continuing to monitor toxics-related pressures, findings will be examined to address new hypotheses and questions, and to develop new environmental indicators relating to the effects of nutrient and climate change pressures on Puget Sound's sediments and benthos.



Top L: Echinoderm *Brisaster latifrons*. Top R: *Metacarcinus gracilis*, the "graceful rock crab". Bottom L: Size series of *Astyris gausapata*, a marine gastropod collected from Puget Sound. Bottom R: Size series of *Scalibregma californicum*, a marine polychaete collected from Puget Sound. Photos: Dany Burgess and Angela Eagleston, Ecology

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