2016 SALISH SEA TOXICS MONITORING REVIEW

A Selection of Research

A Product of the 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
N. Gulf Islands
Basin Boundary
Vancouver Island
Strait of Georgia
Fraser River
S. Gulf Islands
Mt. Baker
Skagit River
San Juan Islands
Cape Flattery
Strait of Juan de Fuca
Pacific Ocean
Olympic Peninsula
Puget Sound
Hood Canal
Glacier Peak
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

ACKNOWLEDGEMENTS

This document was put together by a collaborative effort of investigators from over twenty agencies in the greater Salish Sea watershed. We appreciate the time and effort that was provided. The journey to preserving the Salish Sea as a home to all species relies on the continued collaboration and dialogue of all.

EDITORIAL TEAM

C. Andrew James, University of Washington Tacoma
Jennifer Lanksbury, Washington Dept. of Fish and Wildlife
Deb Lester, King County, Dept. of Natl Resources & Parks
Sandie O'Neill, Washington Dept. of Fish and Wildlife
Tanya Roberts, Washington Dept. of Ecology
Connie Sullivan, Puget Soundkeeper Alliance
Jim West, Washington Dept. of Fish and Wildlife

Disclaimer

The data and accompanying 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, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

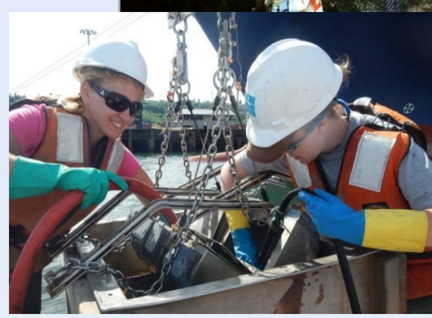
In addition, we would like to point out that this document is not a comprehensive synthesis of the entirety of the contaminant-related monitoring or research in the Salish Sea. The PSEMP toxics workgroup continues to strive to cast an ever-widening net to bring together as much of the region's toxics work as possible.

Puget Sound Ecosystem Monitoring Program

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 knowledge and understanding. The group meets bi-monthly.

More information can be found at https://sites.google.com/a/psemp.org/psemp/toxics-workgroup.

Corresponding Editor: jamesca@uw.edu



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Section 1 Cover Page: Chasina Bottom Trawl, by Connie Sullivan.
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Design, formatting, and layout assistance was provided by Kevin Brown (US EPA). The effort is much appreciated.

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2016 SALISH SEA TOXICS MONITORING REVIEW
A SELECTION OF RESEARCH

Introduction

This document represents an overview of selected recent monitoring and research activities focused on toxic contaminants in the Salish Sea. Over the past 150 years of industrialization, human activities have introduced a variety of chemicals into the Salish Sea, at levels that can be harmful to people and aquatic biota. A number of these chemicals are toxic and have the potential to harm or threaten the Salish Sea ecosystem, including industrial chemicals (e.g., polychlorinated biphenyls [PCBs]), flame retardants (e.g., polybrominated diphenyl ethers [PBDEs]), plasticizers, and dioxins. Additional chemicals that may pose a threat to the Salish Sea ecosystem include pharmaceutical and personal care products (PPCPs; e.g., medications, household chemicals, beauty products, etc.) and chemicals used in agriculture, landscaping and yard care (e.g., current use and legacy pesticides, livestock pharmaceuticals, etc.). Some PPCPs and other organic chemicals are considered endocrine disrupting compounds (EDCs). Exposure to very low concentrations of EDCs can alter the endocrine system of aquatic biota. Polycyclic aromatic hydrocarbons (PAHs), released during the combustion of fossil fuels and wood are commonly detected throughout the region. Elevated concentrations of toxic metals are also a significant concern; even naturally occurring metals can become concentrated to toxic levels in the environment because of human activity. Collectively, these toxic chemicals reach the Salish Sea through a variety of pathways, including stormwater runoff, atmospheric deposition, industrial and municipal discharges, and agricultural runoff.

Regionally, significant effort has gone into understanding the level of risk posed by the presence of toxic contaminants in the environment, and how best to address unacceptable risk. The purpose of this document is to provide a snapshot of regional efforts through a series of one-page program contributions. These contributions provide an overview of the status and trends for some toxics, and highlight current efforts to identify and mitigate sources, clean up contaminated systems, and restore ecosystem function.

This review presents a compilation of information provided by scientists and managers implementing toxics-related monitoring, research and remediation programs in and around the Salish Sea. Over 40 research programs contributed information to this document. Each contributor was challenged to distill complex information into a short synopsis to provide key highlights of their work. Our goal was to provide an overview of recent work to assess toxic contaminants that could be used by legislators, program managers, policymakers, students, and scientists to better understand the extent of regional efforts, provide an overview of the organizations conducting this work, and identify important and outstanding questions.

The inspiration for this effort rose from the 2016 Salish Sea Ecosystem Conference. We recognized and appreciated the value of the broad network of scientists from Washington and British Columbia (BC) afforded by the conference. A key goal of our effort was to document the toxics focused work presented there, and also to expand the coverage to include as much additional related information as possible. However, it is important to note that this effort is not intended to be an exhaustive review of regional efforts to address toxic contaminants

in the Salish Sea. We extend our thanks to the contributors and applaud their dedication to understanding toxic contaminant stressors in the Salish Sea ecosystem, in addition to working towards solutions to address these stressors.

This review is organized into three broad categories: What is happening? (Status and Trends), Why is it happening? (Processes Affecting Status and Trends) and What can be done? (Management). Section 1 describes the current status and trends of some contaminants and generally includes monitoring efforts that examine their presence, distribution, magnitude of concentration, and change through time in the Salish Sea ecosystem. Section 2 includes investigations that assess why change may be occurring. Section 3 includes studies that describe some of the efforts underway to improve our ability to address and remediate toxic contaminants in the environment.

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

Section 1: What is Happening? (Status and Trends)

Status

Efforts are currently underway to protect, preserve, and recover the Salish Sea ecosystem, including reduction of contaminant inputs into streams, rivers and marine habitats (e.g., Puget Sound Partnership watershed and salmon recovery plans; Salmon Salish Sea Marine Survival Project, and the Canadian Federal Contaminated Sites Action Plans at Rock Bay and Esquimault Harbour). However, regional population growth is likely to bring continued landscape alterations and increased contaminant inputs through point (e.g., oil and chemical spills, industrial and municipal wastewater discharges, etc.) and non-point source discharges (stormwater runoff, agriculture, atmospheric deposition, etc.). The majority of studies summarized in this section highlight the current status of contaminants in Salish Sea ecosystems. The investigations cover a wide variety of contaminants including trace metals, PAHs, persistent organic pollutants (POPs) such as PCBs, PBDEs, and DDTs (dichlorodiphenyltrichloroethane), and contaminants of emerging concern (CECs; e.g., PPCPs, and microplastics).

Numerous toxic contaminants are detected at elevated concentrations in water, sediment, and biota within developed regions of the Salish Sea watershed, often at levels of concern for the health of aquatic biota and people. Trace metals such as copper, zinc, lead, and cadmium have accumulated to levels of toxicological concern in urban sediments (Kazmiruk et al.) and were present in eelgrass (e.g., copper; Gaeckle), mussels (e.g., zinc, lead and copper; Lanksbury et al.), and oysters (Bendell et al.) at sites adjacent to developed areas. Marine plant and invertebrate species in nearshore environments adjacent to developed landscapes have also accumulated hydrocarbons (PAHs). Willie et al. found that elevated PAH concentrations in nearshore blue mussels in southern BC were associated with elevated PAH exposure-related enzyme activity in Barrow's goldeneyes (a sea duck) wintering and feeding on these mussels. This finding suggests that these birds were exposed to higher PAHs levels than those overwintering in more pristine sites in northern BC.

Due to their limited ability to be metabolized, POP concentrations increase over time and bioaccumulate in the tissues of biota and people. As a result, concentrations of many of these contaminants are significantly greater, and are biomagnified, in higher trophic level organisms. Benthic marine species like eelgrass (Gaeckle), mussels (Lanksbury et al.), spot prawns, and crabs (Hardy et al.) collected from urbanized landscapes had elevated POP concentrations.

Additional studies document that POPs are present throughout the food web, often at levels known to cause adverse effects. Approximately one-third of the juvenile Chinook salmon sampled from Puget Sound rivers and nearshore marine habitats contained POP concentrations high enough to affect their health, and potentially their early marine survival in the Salish Sea. Toxic contaminants may be contributing to their decline and limiting their recovery (Carey et al.). To better understand the influence of toxic contaminants on salmon populations, Lundin et al. are developing a model to evaluate the sub-lethal population level impacts of contaminants on Chinook salmon in Puget Sound's Lower Duwamish Waterway.

POPs were also detected in Puget Sound sand lance (Conn et al.; Good et al.) and other forage fish. Good et al. found that PCBs and PBDEs levels in forage fish consumed by seabirds (i.e., rhinoceros auklets) were greater in inland waters compared to fish from outer coast locations. As such, POP body burdens for pre-fledging rhinoceros auklet chicks in Puget Sound colonies were higher than those in outer coast colonies. POP concentrations in Puget Sound herring and Chinook salmon were also more elevated than those in other West Coast populations (O'Neill et al.). Killer whales feeding in the Salish Sea also accumulate higher POP concentrations, though Lundin et al. demonstrate that contaminant concentrations in whales can be, among other things, related to age, birth order, prey abundance, and reproductive status (for females). These studies demonstrate that POPs enter the Salish Sea primarily through urbanized bays, but are also pervasive through the pelagic food web.

A number of CECs, including those that are also EDCs, may pose some risk (e.g., effect to growth, development, and reproduction) to organisms in the Salish Sea. Da Silva et al. measured several EDCs in Puget Sound English sole and found elevated levels of Bisphenol A and tert-octylphenol in fish from urbanized sites. Indicators of estrogenic exposure were highest in fish from Elliott Bay. Microplastics have also recently emerged as a concern in marine ecosystems because of their ubiquity, in addition to the fact that they are consumed by plankton and shellfish. Dudas et al. found microplastics in both wild and cultured clams consumed by people in BC, while Bertram et al. found microplastics in the gut of 85% of the Pacific sand lance they sampled in BC. Microplastics were also found in the guts of juvenile Chinook salmon sampled from the east coast of Vancouver Island, BC (Collicutt et al.). Results from these studies indicate a significant potential for transfer of microplastics to upper trophic levels of the food web, as well as to people that consume these organisms.

Toxic contaminants in the Salish Sea also pose a risk to the health of people. Schultz et al. demonstrated that people exposed to household and workplace dust containing PBDEs had elevated blood levels of this flame-retardant. Additionally, Schultz et al. and Cade et al. reported higher blood PBDE levels in seafood consumers than in non-seafood consumers because marine fish and shellfish have relatively high levels of PBDEs, including the hydroxylated- and methoxylated (MeO)- forms. Furthermore, Schultz et al. suggested that some marine origin MeO-PBDEs may be useful markers of PBDE exposure from seafood.

Wastewater and stormwater runoff have been identified as important pathways for contaminants to enter the Salish Sea. Landry et al. described two ambient monitoring programs related to stormwater tracking in the Fraser River and Burrard Inlet, BC. The monitoring results inform a water quality index, which includes water, sediment, and fish metrics. Waters in the Fraser River and Burrard Inlet are ranked as good and fair, respectively. Yazdanpanah et al. described an additional ambient monitoring program in Boundary Bay, BC, and ranked their current ambient conditions as marginal.

Trends

A number of monitoring programs collect long-term contaminant data to track change over time and several of these are highlighted here. West et al. (a), Johnson et al., and Jack et al. provide data for PCBs and other POPs in Puget Sound fish. Two additional contributions present over 20 years of sediment data. Weakland et al. discuss ambient sediment results collected under the Puget Sound Ecosystem Monitoring Program (PSEMP) since 1989, and Fourie et al. showcase a breadth of data collected as far back as 1988 from the eight Puget Sound dredge disposal sites managed under the interagency Dredge Maintenance Monitoring Program (DMMP).

All programs indicate that urban bays are the most degraded; however, in general, concentrations of monitored contaminants have largely declined over the last decades as a result of cleanup and source control actions. PSEMP ambient sediment monitoring showed decreasing contaminant concentrations at its most contaminated urban stations. The DMMP has noted that cleaner sediments disposed at more urban sites may result in localized reductions in contaminant levels.

A review of PCB and PBDE concentrations in Pacific herring and English sole between 1994 and 2015 indicated that PBDE levels decreased or remained stable, with the exception of one location where levels increased (West et al. (a)). However, West et al. (a) reported that PCB levels in these fish increased slightly in several areas. Johnson et al. showed a general decline of PCBs, PAHs and DDTs in juvenile Chinook since NOAA began monitoring this species in the 1980s. In addition, laboratory analytical changes over time can complicate trend analysis. Method changes have improved precision, but make comparison of data collected over time challenging, as Jack et al. demonstrated in their evaluation of Lake Washington fish tissue PCB results.

Despite a general decline in some contaminant concentrations, concern remains. PCB and PAH concentrations in tissue still frequently exceed toxicity thresholds for juvenile Chinook. Results from Ecology's ambient sediment program indicate that, while contaminant levels tend to be decreasing, benthic community health is declining Sound-wide (Weakland et al.). Additionally, trends on many chemicals are lacking.

Section 2: Why is it Happening? (Processes Affecting Status and Trends)

While much work has been done to address chemical pollution in the Salish Sea, there is much we do not know; systematic and analytical challenges remain. West et al. (b) discussed findings that challenge previous thinking about PCB dispersal, proposing that rather than settling to sediments as previously expected, PCBs and other POPs bound to organic matter may remain suspended, and continually re-enter the food web through lower trophic levels. POPs in the lower trophic level organisms are passed up the food web to higher trophic levels. O'Neill et al. documented that herring and salmon feeding in Puget Sound have a unique contaminant fingerprint compared to other West Coast populations. Moreover, differences in contaminant fingerprints in southern resident killer whales and Chinook salmon (major prey for whales) can be used to show spatial segregation of whale pod foraging habitats (O'Neill et al.). Food web modelling by Pelletier et al., using the Puget Sound Regional Toxics Model, indicates that, apart from areas with the most highly contaminated sediments, water concentrations will continue to drive PCB levels in organisms. However, the model also indicated that without significant contaminant reductions in urban bays, PCB tissue levels in resident Chinook will continue to occur at levels of concern. PBDEs also remain an issue and Johannessen reported that wastewater is a major source in the Strait of Georgia. Although PBDEs have been phased out of production, there is a significant

inventory of existing products containing PBDEs. As a result, release of PBDEs and substitute chemical flame retardants into the environment will continue.

To date, our approach to address toxic contaminants has generally focused on a few classes of compounds, leaving thousands of potentially harmful contaminants largely unexplored. Though limited data are available for contaminants such as pharmaceuticals and personal care products, results suggest there may be a cause for concern. While the suite of analyzed toxic contaminants can be increased as budget allows, a chemical-by-chemical approach does not allow us to assess the full universe of contaminants, nor to understand the full impact these chemicals have on ecosystem health. It is becoming apparent that new analytical methods and investigation techniques are needed. Fortunately, researchers have a broad array of tools at their disposal. The recent introduction of non-target chemical analysis allows a departure from the previous compound-specific approach, as James et al. present in their discussion of quadrupole time-of-flight mass spectrometry (QTOF-MS/MS) in the management section below. New paradigms to both manage toxics in commerce and to monitor them in the environment are needed. To truly understand the health of the Salish Sea Ecosystem it may be necessary to rethink our approach. Alava et al., for example, proposed utilizing data in new ways, creating a framework of indicators that would provide tools for assessing contamination in key species.

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

The contributions included in this report describe monitoring and research efforts that will improve our understanding of contaminant occurrence and impact throughout the ecosystem. These efforts are a key component necessary to manage toxic anthropogenic compounds in the Salish Sea. This understanding is critical to develop programs that will prevent or reduce harm to the species that are important to fisheries and other economies, to people who consume these resources, and to the species that make up a healthy ecosystem. Work is also underway that will improve monitoring techniques to enhance our ability to better understand the impacts of emerging contaminants, improve our understanding of fate and transport of contaminants in the Salish Sea ecosystem, and test and evaluate new methods for remediation and recovery.

Several contributions included here address improvements or modifications to monitoring techniques. Conn et al., for example, described an effort to better understand the transport of contaminants associated with sediments and other suspended particles in rivers and streams. Green et al. evaluated whether measurement of toxic contaminants in otter feces is a suitable approach to estimate contaminant exposure through their diets. James et al. described a new analytical approach utilizing QTOF-MS/MS with the capability of revealing the presence of thousands of compounds in a single sample; important to fully evaluate contaminant behavior and exposures.

Understanding how contaminants move through the ecosystem helps prioritize and focus the most important areas and pathways for prevention, cleanup, and restoration. West et al. (b) described several characteristics of the Salish Sea that may exacerbate uptake of POPs directly from water, rather than via sediments. These contaminants continue to accumulate at higher trophic levels, as evidenced by the unique contaminant patterns measured in Chinook salmon populations and killer whale pods that reside and feed in the Salish Sea. Similarly, Pelletier et al. described an updated modelling effort used to estimate source-loading and predict cleanup thresholds for selected contaminants. Lundin et al. detailed a study aimed at quantifying population-level

impacts of toxic chemicals on Chinook salmon in the Duwamish/Green River, such as mortality, sub-lethal growth and reproduction effects, and effects of prey abundance.

A crucial aspect of environmental investigations is to identify, evaluate, and pinpoint specific contaminant sources to direct the actions necessary to reduce or eliminate impacts. Johannessen described a multi-year study to evaluate the controversial discharges of poorly treated wastewater from Vancouver and Victoria. Results of this study indicate that these wastewater discharges may be important PBDE sources to the Salish Sea, though the contribution of other contaminants is unclear. Stormwater has previously been identified as an important pathway for many toxic contaminants. Two contributions from the Puget Sound Stormwater Science Team by Davis et al. and McIntyre et al. focused on investigation of the causes and possible treatment of pre-spawn mortality of Coho salmon in Puget Sound streams. In addition, Stormwater Action Monitoring (SAM, formerly the Regional Stormwater Monitoring Program) is undertaking several investigations to improve our collective understanding of stormwater impacts, as Lubliner described in two contributions. Phase I data collected under SAM allowed characterization of regional urban stormwater, as described in Hobbs et al.

Two of the many focused cleanups in the region are summarized here. Duncanson et al. reported on the cleanup of an industrial waterfront utilizing traditional approaches, while Kirtay et al. discussed a potentially novel approach of immobilizing contaminants in nearshore sediments through the addition of activated carbon. Both projects focus on reducing environmental exposures of harmful contaminants.

Summary

While the contributions in this document are not intended to be comprehensive, nor inclusive of all of the work going on in the Salish Sea, they have allowed us to identify a few key points:

- Aquatic biota are exposed to contaminants at levels that can adversely affect their health and the health of people that consume them.
- The levels of some contaminants have declined in sediments and aquatic biota as a result of successful management actions.
- Contaminants of emerging concern such as estrogenic chemicals and microplastics are widespread and frequently detected.
- Better analytical and measurement methods, improved models, and ongoing monitoring continue to improve the ways we characterize fate, transport, and biological impacts of toxic contaminants.
- Contaminant source control and cleanup have been an effective approach to reduce sediment contaminant loads in many areas.
- Stormwater impacts and responses are being addressed through coordinated regional efforts.
- On-the-ground remediation of contaminated sites is ongoing throughout the region.

SECTION 1: WHAT IS HAPPENING?

(STATUS AND TRENDS)

Trace metals in urban estuaries; implications for remediation

Tamara N. Kazmiruk[1], Vasily D. Kazmiruk[1], Ken I. Ashley[2], Leah I. Bendell[1]

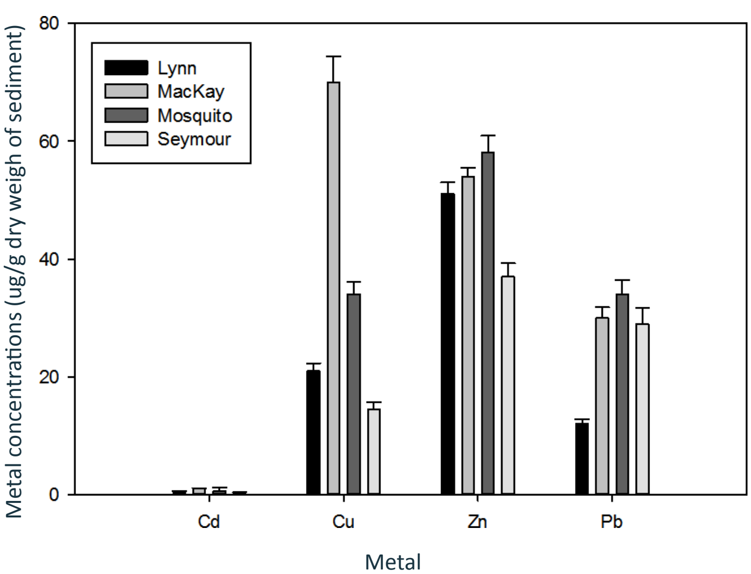
1. Ecotoxicology Research Group, Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada; 2. Rivers Institute, British Columbia Institute of Technology, Burnaby, BC, Canada

- Urban estuarine sediments accumulated trace metals such as copper, zinc, lead, and cadmium to levels of toxicological concern.
- Metals tended to accumulate in depositional zones on finest particles with greatest surface area and organic matter.

Estuaries, as semi-enclosed bodies of water, are associated with input, transport, and accumulation or export of materials. The ability of estuarine sediments to integrate long-term information and the marked tendency for trace metals towards solid phase partitioning makes sediments attractive for assessing the impact of industry and urban development on the fluvial ecosystem over time (Birch, et al., 2001).

This study first determined concentrations of copper (Cu), zinc (Zn), lead (Pb), and cadmium (Cd) within the estuarine sediments of Mackay Creek, Mosquito Creek, Lynn Creek, and the Seymour River (near Vancouver, British Columbia, Canada). Estuaries were sampled for sediments during periods of low tide (May - November, 2014) and sediment metal concentrations were measured using a Flame Atomic Absorption Spectrophotometer (FAAS, Perkin Elmer). One-way ANOVA with Holm-Sidak post hoc multiple comparison tests applied to determine where differences occurred indicated significant differences ($p<0.001$ for all) among the four estuaries (as shown below) as:

Comparison of overall sediment metal concentrations in four urban aquatic ecosystems. Values are means with S.E.



Cd; MacKay>Lynn=Mosquito>Seymour, F=39,
Cu; MacKay>Mosquito>Lynn=Seymour, F=91,
Zn; Lynn=MacKay=Mosquito>Seymour, F=16.2,
Pb; MacKay=Mosquito=Seymour>Lynn, F=22.4

The range of trace metal concentrations in sediments of the four estuaries indicated that Cu occurred at concentrations nine-fold, Zn two-fold and Cd eight-fold above the value of Canadian Interim Sediment Quality Guidelines (ISQG) in sediments from Mackay Creek and Mosquito Creek, and Pb three-fold above the value of ISQG in sediments from Mackay Creek and Seymour Creek (CCME, 1995). Metal concentrations in all estuaries were greatest in regions of accretion as indicated by accumulations of organic matter and percent silt suggesting these two factors have some influence on metal accumulation patterns within these urban estuaries.

In a recent review on the sediment-contaminant dynamics in environmental systems conditioned by human activities, Taylor and Owens (2009) recognized the need for better sampling and monitoring of sediment and sediment-associated contaminant behaviour within urban rivers and basins. This need stemmed from the recognition that more than 50% of the global population resides in urban environments, and with the abundance of contamination sources, impacts on both human and ecosystem health could be significant. Further, as urban systems comprise anthropogenically altered landscapes (e.g., impervious land surfaces, highly modified stream channels), the fate of contaminants within these systems will be highly altered as compared to more natural ecosystems. Understanding how contaminants behave within urban systems, as presented in our study, therefore becomes a critical need to first allow an assessment of risks posed by contaminants and second to provide information allowing for the restoration of these systems to a less contaminated state.

For more information: Tamara N. Kazmiruk, tkazmiru@sfu.ca

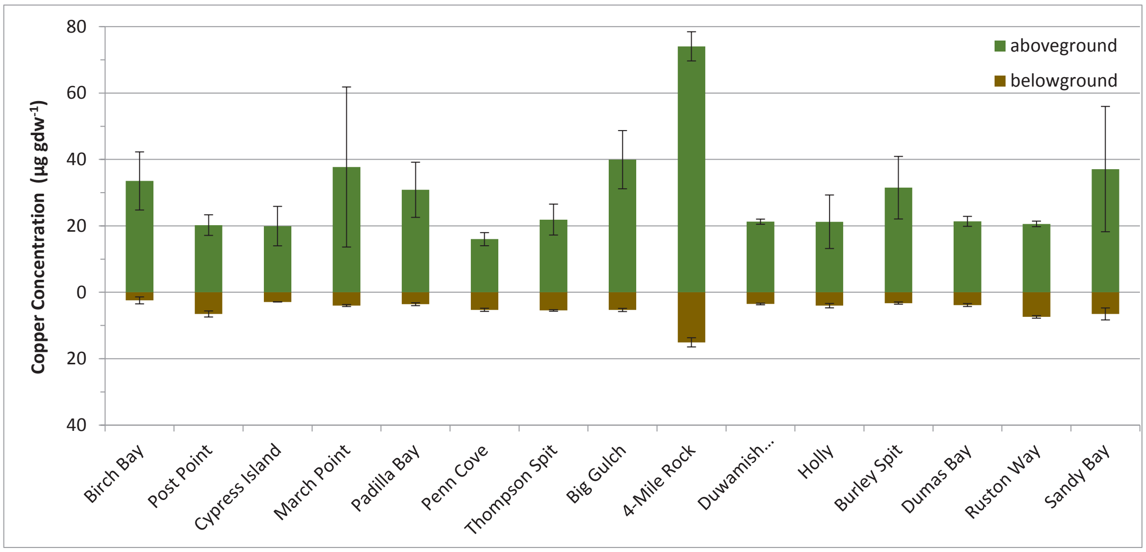
Assessment of nutrient, metal, and organic contaminant concentrations in eelgrass (*Zostera marina* L.) in Puget Sound, WA

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES

Jeffrey L. Gaeckle

Nearshore Habitat Program, Washington State Department of Natural Resources

- Conducted a baseline assessment of nutrients, metals, and organic contaminants in eelgrass (*Zostera marina* L.) throughout Puget Sound, WA.
- Observed significantly higher concentrations of copper and PAHs in eelgrass biomass at a sites near developed areas.



Average concentration (µg gdw^{-1}, ± SE) of copper (Cu) in the above- and belowground compartments of eelgrass (*Zostera marina* L.) measured at 15 sites throughout Puget Sound.

This study assessed the concentrations of nitrogen, carbon, metals (e.g., As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V, and Zn), and organic contaminants (e.g., polycyclic aromatic hydrocarbons - PAHs, polychlorinated biphenyls - PCBs, and polybrominated diphenyl ethers - PBDEs) in above- and belowground eelgrass (*Zostera marina* L.) biomass at 15 sites throughout Puget Sound, WA.

The concentrations of carbon, nitrogen, and metals in eelgrass were within the range observed in other seagrass, and eelgrass specific, studies worldwide (Duarte 1990, Hemminga and Mateo 1996, Lewis and Devereux 2009). Overall the concentrations of organic contaminants were low, likely due to limited uptake and accumulation potential by seagrass because of the small percentage of lipids in seagrass biomass. Isotope concentrations of carbon (C) and nitrogen (N) showed no clear pattern. With the exception of one site (Sandy Bay), the C:N ratio was consistently below 10 in aboveground eelgrass biomass and below 15 in belowground biomass, indicating eelgrass in Puget Sound is exposed to relatively high concentrations of nitrogen.

The concentrations of some metals (e.g., As, Cd, Cr, and Cu) were highest near developed areas, but the patterns were not consistent across all analyzed metals. Concentrations of copper in the above- and belowground biomass were highest at Four-Mile Rock, a site down current from a developed and industrialized waterfront (Figure). Although levels of arsenic measured in eelgrass biomass were orders of magnitude less than an earlier study (USFWS 1994), the aboveground eelgrass biomass at Padilla Bay had the highest concentrations of arsenic, in contrast to low levels measured at March Point.

The concentration of PAHs in above- and belowground compartments of eelgrass were significantly higher at Four-Mile Rock and Big Gulch, areas of relatively high development, compared to the other Puget Sound sites. The PAH concentrations in eelgrass at Fidalgo and Padilla Bays were relatively low compared to results from the earlier USFWS study.

In general, the concentrations of persistent organic pollutants (POPs) were low or undetectable, particularly in contrast to organisms with higher lipid content than eelgrass (e.g., mussels; Lanksbury et al. 2014). Low concentrations of PCBs, PBDEs, dichlorodiphenyltrichloroethanes (DDTs), chlordanes, and hexachlorocyclohexanes were found in eelgrass but there was no clear pattern relative to potential contamination sources. In some cases, eelgrass collected in close proximity to industrialized areas had higher levels of contamination than other sites, however this pattern was not consistent as some less developed and more pristine sites also had relatively high levels of persistent organic pollutants.

This study provides the first Puget Sound-wide assessment of carbon, nitrogen, metal, and organic contaminant concentrations in above- and belowground eelgrass biomass. Many factors affect the concentrations of these substances in seagrass, including their availability in the system, the physical and chemical properties of the environment, and plant health. Although this study was conducted at one point in time and at a limited number of sites, the results provide insight on the role of eelgrass in the cycling of these compounds throughout greater Puget Sound.

Using transplanted mussels to assess contaminants in Puget Sound's nearshore habitats

Jennifer Lanksbury[1], Laurie A. Niewolny[1], Andrea J. Carey[1], Sandra M. O'Neill[1], James E. West[1], Gina Ylitalo[2]

1. Washington Department of Fish and Wildlife; 2. NOAA, Northwest Fisheries Science Center

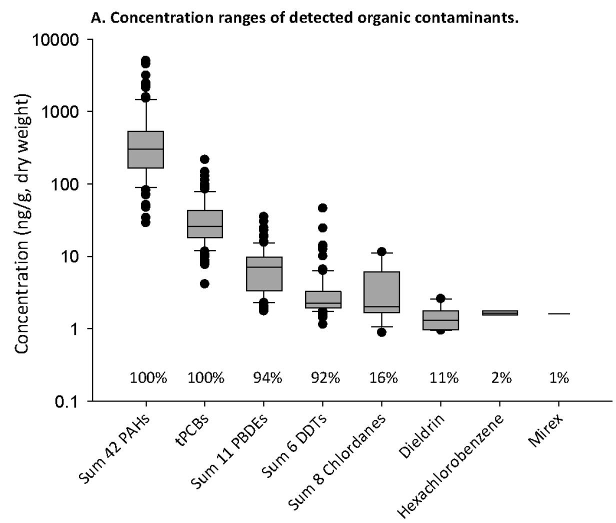
- Our findings suggest toxic contaminants are entering the nearshore food web of the Puget Sound, especially along shorelines adjacent to highly urbanized areas; polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and dichlorodiphenyltrichloroethanes (DDTs) were the most abundant organic contaminants measured in mussels.
- There were significant positive correlations between upland watershed land development and nearshore levels of PAHs, PCBs, PBDEs, DDTs, lead, copper, and zinc.

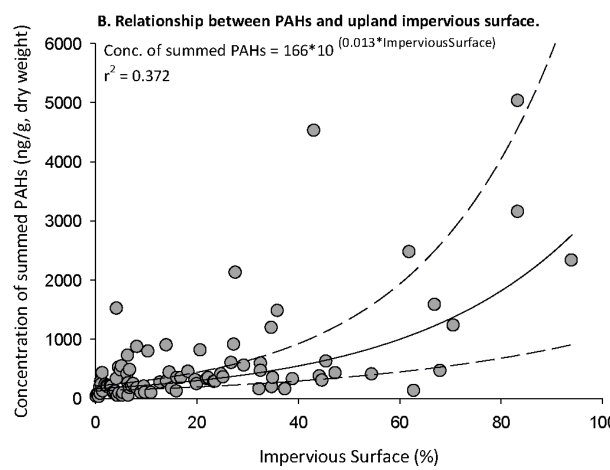
Understanding the sources, fate, and transport of contaminants in the Puget Sound nearshore marine food web improves our ability to mitigate the harm pollution causes to the biota residing in our nearshore environments. In the winter of 2012/13 the Washington Department of Fish and Wildlife (WDFW), with the help of other state, county and city agencies, tribes, non-governmental organizations (NGOs), and citizen science volunteers, conducted the first synoptic, Puget Sound-wide assessment of toxic contaminants in nearshore biota, using bay mussels *(Mytilus trossulus)* as the indicator species. Since wild mussels were not available in all areas, transplanted mussels taken from a relatively uncontaminated aquaculture source in Penn Cove, Whidbey Island, were used for this pilot study.

Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and dichlorodiphenyltrichloroethanes (DDTs) were the most abundant organic contaminants measured (Figure A). PAHs and PCBs were detected in mussels from every site and the highest concentrations were observed in four of the Puget Sound's most urbanized embayments: Elliott Bay, Salmon Bay, Commencement Bay, and Sinclair Inlet. PBDEs and DDTs followed a similar pattern, though lower in overall concentration. Lead, copper, zinc, cadmium, mercury, and arsenic were also detected in low levels at all of the study sites. There were significant positive correlations between upland watershed land development (impervious surface) and nearshore levels of PAHs (Figure B), PCBs, PBDEs, DDTs, lead, copper, and zinc. PAH analyte pattern analysis in mussels (not shown for brevity) suggested the majority of nearshore sites were dominated by pyrogenic sources; however, atypical patterns at a few locations suggested petroleum sources may have contributed a larger proportion in those areas. In addition, PCB congener-ratio analysis suggested urban embayments in the central Puget Sound are sources of PCBs for non-urban areas.

These findings suggest toxic contaminants are entering the nearshore food web of the Puget Sound, especially along shorelines adjacent to highly urbanized areas. The nearshore contaminant patterns observed in this study support patterns observed in previous mussel monitoring studies in the Puget Sound, where higher concentrations ("hotspots") were found in areas of high urbanization (Kimbrough et al., 2008; Mearns 2001; Puget Sound Action Team, 2007). This pattern is also seen in studies of benthic and pelagic fish and shellfish in the Puget Sound (Carey et al., 2014; West et al., 2001) confirming the role of urbanization as a major source of pollution to our marine waters.

As a result of the success of this pilot study, a new, collaborative mussel monitoring program has emerged in Puget Sound. This new program is principally funded through Stormwater Action Monitoring, but includes a number of other sponsoring entities including many who participated in the pilot study. In addition, hundreds of WDFW and NGO citizen science volunteers continue to provide critical field support during mussel deployment and retrieval along the greater Puget Sound coast. Data from the latest round of mussel monitoring (2015/16) is currently being analyzed and a final report will be released in the summer of 2017. The next deployment of mussels will occur in the winter of 2017/18. Groups interested in participating in Washington State's mussel monitoring are encouraged to contact the lead author of this study at WDFW.





(A) concentrations of organic contaminants detected in mussels and % of sites where contaminants were detected; (B) concentration of 42 summed PAHs in mussels increased with % impervious surface ($p < 0.0001$), dots represent sites, solid curve is a regression, dotted curves are 95% confidence intervals.

Cadmium in oysters from the Salish Sea

SFU

Leah Bendell

Simon Fraser University

- BC Oysters contain high levels of cadmium (1-4 ug/g wet weight), a toxic element.
- Consumption of BC oysters should be limited to one oyster per week for adults and for children, twelve a year. Vulnerable groups (e.g., those with diabetes, anemia) should not consume any.

Nearly 15 years ago, research scientists in the federal department of Fisheries and Oceans Canada (DFO) were alerted to the presence of high levels of cadmium, a toxic metal, in the Pacific oyster cultured in the Salish Sea, British Columbia, Canada (Kruzynski et al., 2002). The discovery was a result of several shipments of oysters being rejected from the Hong Kong Food and Environmental Hygiene Department as being in excess of their 2 µg/g cadmium (ppm) wet weight limit. A subsequent survey conducted by the Canadian Food Inspection Agency (CFIA 2003) revealed that on average BC oysters contained 2.63 µg/g cadmium wet weight, an amount which also exceeded the European Commission export market guideline of 1 µg/g wet weight.

Oysters are known as “hyper-accumulators” of trace metals largely due to their ability to generate metallothioenein (MT) and MT-like proteins that bind cadmium to both gill and internal organs (reviewed in Bendell 2010). Accumulation can occur directly (uptake by the gill epithelium from the dissolved state) or by food. Hence, the question “What was the source of cadmium to BC oysters?” became central. If remedial strategies were to be applied to lower cadmium concentrations within the oyster to below export market guidelines such that access to international markets could be again be realized then the source of the cadmium to the oyster needed to be known.

Bendell (2010) recently reviewed the various studies that were generated to address the sources of cadmium to BC oysters: 1) DFO in collaboration with the University of British Columbia and Odyssey Shellfish Ltd. (Lekhi et al. 2008) 2) Oregon State University and the Hong Kong University of Science and Technology in collaboration with the Pacific Shellfish Institute, Integral Consulting, Northern Economics and Pyron Environmental Inc. (USDA 2008), 3) Simon Fraser University in collaboration with the DFO and the provincial government of British Columbia (Bendell and Feng 2009), and 4) Simon Fraser University (Widmeyer and Bendell-Young 2008, Christie and Bendell 2009). A workshop held at Simon Fraser University in May of 2010 sought to bring all researchers together to summarize their finding with respect to cadmium in BC shellfish and to identify potential sources of cadmium to BC shellfish (Bendell et al. 2010). The workshop concluded that on average BC oysters contained 1-4 µg/g wet weight of cadmium depending on region with no point source of cadmium identified. To ensure that the population in general does not expose themselves via food to amounts of cadmium of toxicological concern, the workgroup recommended that adults only ingest one oyster per week and children twelve a year. Vulnerable groups (e.g., those with diabetes, anemia) should not consume any BC oysters.

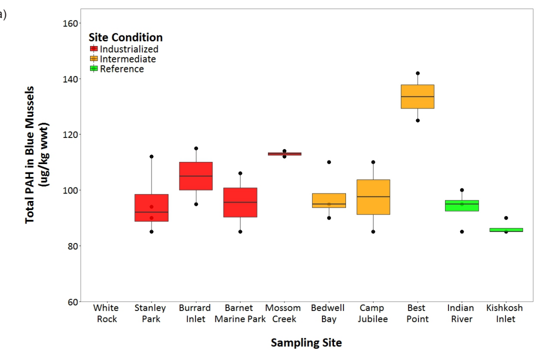
Spatial variation in polycyclic aromatic hydrocarbon exposure in Barrow's Goldeneye (*Bucephala islandica*) in Burrard Inlet and Indian Arm, BC

Megan Willie[1], Dan Esler[2], Sean Boyd[3], Phillip Molloy[4], Ron Ydenberg[1]
1. Centre for Wildlife Ecology, Simon Fraser University; 2. US Geological Survey, Alaska Science Center; 3. Science and Technology Branch, Environment and Climate Change Canada; 4. Stantec Consulting Ltd.

- Elevated PAH concentrations in blue mussels were associated with elevated EROD activity in Barrow's goldeneyes wintering in southern British Columbia.

Barrow's goldeneyes (*Bucephala islandica*) are sea ducks that winter in coastal British Columbia (BC), across a range of intensity of industrial development. Their winter diet is primarily composed of blue mussels (*Mytilus* spp.). Since blue mussels accumulate PAHs, goldeneyes are susceptible to PAH exposure through bioaccumulation (Eadie et al. 2000). Hence, goldeneyes serve as an upper trophic-level indicator of PAH exposure in coastal ecosystems in BC. In 2015, we compared the degree to which Barrow's goldeneyes wintering in industrialized and undeveloped coastal areas in Burrard Inlet and Indian Arm, BC, exhibited contemporary exposure to PAHs. 7-Ethoxyresorufin-O-deethylase (EROD), an enzyme produced by goldeneyes in response to exposure to PAHs and other contaminants, was measured in liver tissue of captured wintering goldeneyes as a proxy of PAH exposure. To examine spatial patterns in dietary PAH availability, ∑PAH (or the sum of 17 individual constituents) concentrations were measured in blue mussels collected from the same wintering areas. Across all developed sites in White Rock and Burrard Inlet (i.e., Stanley Park, Burrard Inlet, Barnet Marine Park, and Mossom Creek) and intermediate or undeveloped sites in Indian Arm (i.e., Bedwell Bay, Camp Jubilee, Best Point, and Indian River), PAH concentrations were higher than from a relatively pristine reference site sampled in northern BC, Kiskosh Inlet (reported separately; median [IQR] µg/kg wwt = 85.0 [85.0, 86.3]; n = 8; Willie et al. 2016). In mussels, ∑PAH was similar among sites (median [IQR] µg/kg wwt = 95.0 [91.0, 111.5]; n = 22; Figure a). ∑PAH was highest at Best Point (median [IQR] µg/kg wwt = 133.5 [129.2, 137.8]; n = 2) and lowest at Indian Arm near the Indian River (median [IQR] µg/kg wwt = 95.0 [92.5, 96.3]; n =4), Bedwell Bay (median [IQR] µg/kg wwt = 95.0 [93.8, 98.8]; n = 4), and Stanley Park (median [IQR] µg/kg wwt = 92.0 [88.8, 98.5]; n = 4; Figure a). In goldeneyes, median EROD activity was 2.12 pmol/min/mg protein, IQR = 1.21, 3.80; n = 41). EROD activity was highest for a single goldeneye sampled from White Rock (13.20 pmol/min/mg protein). For remaining sites, median EROD activity was lower, ranging from 1.85 pmol/min/mg protein (IQR = 0.98, 3.74; n = 25) at Best Point to 2.33 pmol/min/mg protein (IQR = 1.74, 5.14; n = 8) in Bedwell Bay (Figure b). Notably, birds from Best Point demonstrated high variability and the highest individual activity levels, with EROD activity in four birds exceeding all others in the study. Mussels from this site also had the highest PAHs, suggesting a relationship between exposure to PAHs and EROD activity. As with mussels, median EROD activity for all sites sampled in this region was higher than at Kiskosh Inlet (median [IQR] pmol/min/mg protein = 0.70 [0.60, 0.87]; n = 3). Our results suggest that goldeneyes wintering in southern BC were exposed to a higher magnitude and frequency of PAHs through diet compared to our pristine reference site in northern BC (Willie et al. 2016). Considering radio-based telemetry of goldeneye movements, measured EROD reflects exposure within a small area (e.g., 10 km); hence goldeneyes using highly industrialized coastlines have reduced capability of moderating hydrocarbon exposure through inter-site movements. Our data provide a contemporary reference point of hydrocarbon exposure and potential vulnerability. These results are useful for guiding response planning, long-term monitoring, and informing recovery endpoints in the event of a future oil spill.

a)



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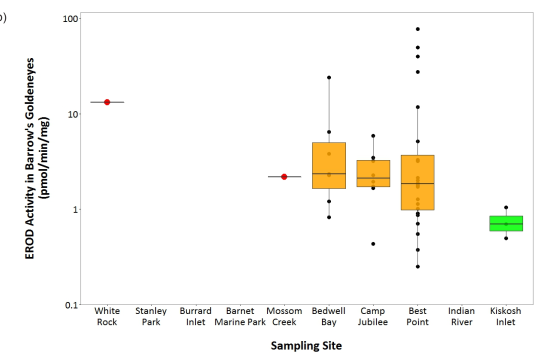
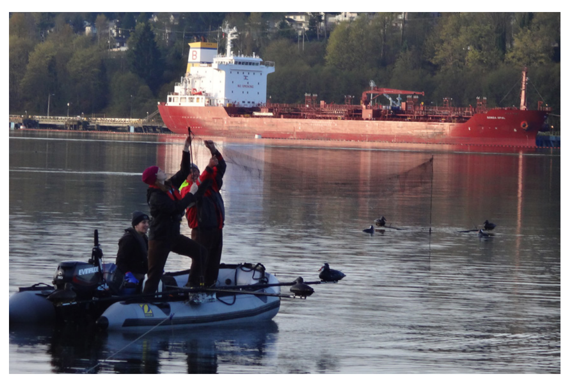


Total PAH (ΣPAH; µg/kg wet weight tissue (wwt]) in blue mussels and EROD activity (pmol/min/mg protein) in Barrow's goldeneyes from sampling sites in southern BC. Box plots show median values (solid horizontal line), 50th percentile values (box outline); whiskers represent 1.5 * interquartile range; data points are shown as solid black circles (●).



Mist-netting Barrow's goldeneye in Burrard Inlet, British Columbia to sample for biomarker activity of PAH exposure from wintering birds

For more information: Megan Willie, Megan.Willie@Stantec.com http://www.sfu.ca/biology/wildberg/CWESeaducksfolder/BAGOwebpage/BAGOMigrationHome.html

Human health evaluation of contaminants in Puget Sound Dungeness crab *(Metacarcinus magister)* and spot prawn *(Pandalus platyceros)*

F Joan Hardy[1], David McBride[1], Laurie Niewolny[2], Jennifer Lanksbury[2], and James West[2]

1. Washington Department of Health; 2. Washington Department of Fish and Wildlife

- Puget Sound Dungeness crab and spot prawn were sampled to determine contaminant levels and develop consumption advice.
- Although crab and spot prawn muscle tissue can be safely consumed from most locations, restrictions were developed for crab hepatopancreas and spot prawn heads.

Introduction: Washington State Department of Fish and Wildlife (WDFW) sampled Dungeness crab and spot prawn from Puget Sound during 2011 and 2012 to determine contaminant levels in the two crustacean species.

Contaminants: Concentrations of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides as well as mercury, arsenic, cadmium, copper, lead and zinc were analyzed in crab and prawn tissues.

Sampling: Sampling was conducted in nine WDFW Marine Areas (MA; fishery management areas for marine recreational fishing - WAC 220-56-185) and three urbanized embayments. All crab and prawn met size, sex, and shell hardness criteria set by fishing regulations. Two hundred forty Dungeness crab specimens were collected at 54 stations, generating 56 crab muscle and 19 crab hepatopancreas composited samples. Seven hundred seventy-seven spot prawn specimens were collected at 42 stations, generating 43 spot prawn muscle (tail) and 16 spot prawn head tissue (containing the hepatopancreas) composited samples.

Health Assessment: Washington State Department of Health (Health) evaluated contaminant concentrations in Dungeness crab muscle and hepatopancreas, and spot prawn muscle and head tissues for potential public health concerns. This evaluation compared tissue concentrations with established screening level values based on non-cancer and cancer health end-points. Values exceeding screening levels were further evaluated. Health calculated meal restrictions to ensure seafood consumers do not exceed safe contaminant levels. Meal limits are meant to guide people toward making informed decisions when selecting seafood.

Findings: With the exception of a few metals, all contaminant concentrations in hepatopancreas of Dungeness crab and head tissue of spot prawn were greater than corresponding muscle tissues. PCBs were detected in Dungeness crab from all marine areas and were highest in samples from urban areas. DDT, PAHs and PBDEs were detected in crab but not at levels to impact human health. DDT was rarely detected in any spot prawn, while PBDEs and PAHs were detected but at low levels. Most metal concentrations were evenly distributed in Dungeness crab from all marine areas and urban bays. Mercury was the only metal that occurred in significantly greater levels in urban compared to non-urban areas in Dungeness crab.

Recommendations (See Table)

Dungeness Crab from Puget Sound: Based on tissue concentrations, frequency of detection, and toxicity, Health concluded that Dungeness crab muscle tissue can be safely consumed at unrestricted rates from most Marine Areas with some exceptions. Consumption guidance for crab hepatopancreas was determined; advice ranges from no consumption to four 8-ounce servings per month.

Spot Prawn from Puget Sound: Health concluded that spot prawn tails can be safely consumed at unrestricted rates from all Marine Areas except:

- No more than eight meals of spot prawn tails per month in Elliott Bay, Sinclair Inlet, and Commencement Bay.
- Elevated levels of PCBs, cadmium, and mercury were found in spot prawn heads leading to a range of restrictions.

Puget Sound meal advisory for Dungeness crab (muscle tissue and hepatopancreas) and spot prawn (muscle tissue and heads).

Recreational Marine Area		Consumption Guidance for Dungeness Crab Muscle Tissue (Spot Prawn Muscle Tissue is Unrestricted for all Marine Areas, with exceptions to the right)	Exceptions for Crab Muscle Tissue	Consumption Guidance for Dungeness Crab Hepatopancreas	Exceptions for Spot Prawn Muscle Tissue	Consumption Guidance for Spot Prawn Heads from Puget Sound
6	East Juan de Fuca Strait	Unrestricted	Port Angeles Harbor: 4 crab per month	MA 6: 4 per month Port Angeles: No hepatopancreas	None	No more than eight meals with heads per month
7	San Juan Islands	Unrestricted	None	4 per month	None	No restrictions
8.1	Deception Pass, Hope Island, and Skagit Bay	Unrestricted	None	4 per month	None	No consumption of heads
8.2	Port Susan and Port Gardner	Unrestricted	None	1 per month	None	No consumption of heads
9	Admiralty Inlet	Unrestricted	None	2 per month	None	No consumption of heads
10	Seattle-Bremerton Area	8 meals per month	Elliott Bay: 2 crab per month Sinclair Inlet: 2 crab per month	No hepatopancreas	Elliott Bay: 8 meals per month Sinclair Inlet: 8 meals per month	No consumption of heads
11	Tacoma-Vashon Area	Unrestricted	Commencement Bay: 4 crab per month	2 per month	Commencement Bay: 8 meals per month	No consumption of heads
12	Hood Canal	Unrestricted	None	2 per month	None	No more than eight meals with heads per month
13	South Puget Sound	Unrestricted	None	1 per month	None	No consumption of heads

NOTE: Meal size equals eight ounces of uncooked shellfish for an average-sized adult (60 kg female and 70 kg male)

Toxic contaminants pose a threat to early marine survival of Chinook salmon from Puget Sound

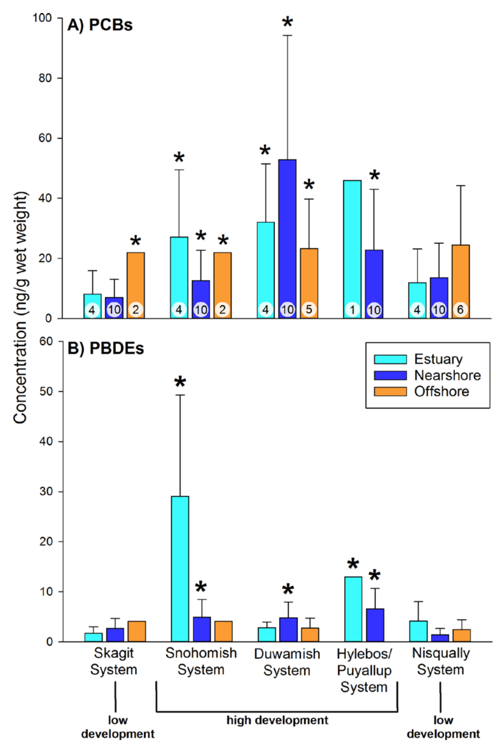
Andrea Carey[1], Jennifer Lanksbury[1], Laurie Niewolny[1], Gina Ylitalo[2], Lyndal Johnson[2], James West[1], Sandra O'Neill[1]

1. Washington Department of Fish and Wildlife; 2. NOAA, Northwest Fisheries Science Center

- A third of juvenile Chinook salmon migrating through Puget Sound estuary, nearshore and offshore habitats accumulated contaminant concentrations high enough to impair their health.

Human development and urbanization of Puget Sound over the past 100 years has led to the loss and modification of salmonid habitat, and has resulted in inputs of toxic contaminants and impairment of water quality (Meador et al. 2014). Salmonids may be exposed to contaminants in fresh, estuarine, and marine waters (Cullon et al. 2009; O'Neill and West 2009); however, the health and ultimately the marine survival of juveniles migrating from freshwater into Puget Sound en route to the Pacific Ocean are more likely to be reduced by contaminant exposure as this life stage also undergoes tremendous physiological stress associated with smolting. Juvenile Chinook salmon are especially vulnerable to contaminant exposure because they spend considerably more time than other salmonid species feeding in estuaries (Quinn 2005) where contaminant inputs may be quite high. This study was designed to provide a synoptic assessment of contaminant exposure for major populations of Puget Sound juvenile Chinook salmon as they migrate from freshwater to marine habitats.

Fish were sampled in spring and summer of 2013 from five major Puget Sound river systems and three associated marine basins in Puget Sound. In each river system, sampling sites included locations in the lower estuary and adjacent nearshore marine shorelines, while the offshore marine basins included Whidbey, Central, and South Basins. Whole-body juvenile Chinook were analyzed for persistent organic pollutants, including polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and several organochlorine pesticides.



The mean concentrations (+95% confidence intervals) of PCBs (A) and PBDEs (B) measured in juvenile Chinook salmon whole bodies. The star indicates some or all samples exceeded the adverse effects threshold for that contaminant. Sample sizes are in located within the bars of Figure A.

Approximately one third of the juvenile Chinook salmon sampled from estuary, nearshore marine, and offshore habitats of Puget Sound had contaminant concentrations associated with adverse effects (O'Neill et al. 2015). These effects include reduction in growth and disease resistance, and altered hormone and protein levels. Most levels of PCBs and PBDEs measured in salmon from the more developed Snohomish, Green/Duwamish, and Hylebos/Puyallup river systems were high enough to potentially cause these adverse effects. Furthermore, PCBs and PBDEs from these highly developed river systems and other sources are reaching less developed offshore habitats where juvenile Chinook salmon may feed for several months, as evidenced by the higher total mass of these contaminants in their bodies. Moreover, juvenile Chinook salmon migrating from rivers to the offshore habitat of the Whidbey and Central Basins accumulated substantial PCB concentrations, sometimes high enough to potentially impair their health.

Building on these results, WDFW is currently expanding and modifying the sampling design to provide better estimates of contaminant exposure in juvenile Chinook salmon for all populations from each of the major river systems in Puget Sound. This new study will help identify areas where salmon may be at risk of contaminant exposure so that appropriate toxics reduction activities can be implemented.

For more information: Andrea Carey, andrea.carey@dfw.wa.gov http://wdfw.wa.gov/conservation/research/projects/marine_toxics/index.html

Legacy and current-use toxic contaminants in Pacific sand lance throughout Puget Sound, WA

Kathy Conn[1], Marty Liedtke[2], Collin Smith[2], Renee Takesue[3], Rick Dinicola[1]

1. U.S. Geological Survey, Washington Water Science Center; 2. USGS, Western Fisheries Research Center; 3. USGS, Pacific Coastal & Marine Science Center

- PCBs, PBDEs, PAHs, and some organochlorine pesticides were broadly detected in Puget Sound sand lance, a forage fish not studied previously for contaminants.

David Ayers (USGS)

Large sand lance catch from USGS beach seining in Puget Sound, Washington

Forage fish such as herring (*Clupea* sp.), surf smelt (*Hypomesus pretiosus*), and Pacific sand lance (*Ammodytes hexapterus*) are an important component in the marine food web as a food source for birds, fish, and marine mammals. In the Salish Sea, despite ongoing protection and restoration efforts, populations of forage fish appear to be in decline. One potential contributing factor to these declines may be exposure to toxic anthropogenic compounds in the water and sediment of the Salish Sea. Contaminant concentrations previously have been measured in herring, but little is known regarding contaminant body burdens in Pacific sand lance—the focus of this research—or in surf smelt. This is, in part, because little is known of the abundance and movement of sand lance and surf smelt around the Salish Sea. Due to their burrowing habits, sand lance may be susceptible to increased exposure to sediment-bound anthropogenic chemicals by ingestion of and direct contact with contaminated sediments relative to non-burrowing fish like herring.

In support of the USGS Coastal Habitats in Puget Sound program, sand lance were collected during 2010-14 from nine Puget Sound locations ranging from the South Sound (Eld Inlet, Nisqually Reach) to the North Sound (Samish Bay, Lopez Island), including historically contaminated urban areas (Eagle Harbor, Commencement Bay). Composites of whole-body fish tissue from each site were analyzed for a suite of toxic organic contaminants including current-use chemicals such as polycyclic aromatic hydrocarbons (PAHs) and alkylphenols, as well as banned chemicals such as polybrominated diphenyl ether (PBDE) flame retardants, polychlorinated biphenyls (PCBs), and organochlorine pesticides. Preliminary results indicate that 200 to 250 (of 330) individual chemicals were detected in each composite sample despite differences in location (low to high embayment urbanization), fish size (sub-yearling to two years old), activity and season (schooling in spring and summer or buried in winter), and lipid content (1 to 7 percent).

Compounds that were preliminarily detected in all composite samples included PCBs (sum of 209 congeners), PBDEs (sum of 40 congeners), PAHs (sum of 46 parent and alkylated compounds), and pesticides including parent and degradate dichlorodiphenyltrichloroethanes (DDTs, sum of 6), chlordanes (sum of 8), dieldrin, and hexachlorobenzene (Table). Though these chemicals were ubiquitously detected in all samples, chemical concentrations were variable, likely reflecting differences in nearshore and basin land use, fish characteristics, and physio-chemical properties of each toxic chemical. Fish collected from urbanized embayments had higher concentrations of PCBs, PBDEs, and PAHs than fish collected near less urbanized embayments. The ubiquitous occurrence of toxic contaminants in sand lance tissue is consistent with previous studies detecting contaminants in other Puget Sound biota, marine sediment, nearshore sediment, and river suspended sediment, suggesting persistent exposure of Puget Sound biota to urban toxic contaminants.

Relative contaminant levels measured in whole-body tissue composites of sand lance, Puget Sound, Washington, 2010-14.

[For each compound, a relative contaminant level is shown for the nine Puget Sound locations. Yellow = one to two times higher than green; Red = greater than two times higher than green (based on wet weight concentrations). PCBs, sum of 209 polychlorinated biphenyls; PBDEs, sum of 40 polybrominated diphenyl ethers; PAHs, sum of 46 parent and alkylated polycyclic aromatic hydrocarbons; DDTs, sum of six parent and degradate dichlorodiphenyltrichloroethanes, 4-NP1EO, 4-nonylphenol monoethoxylate; naf, not analyzed for.]

Puget Sound location	Compound				
	PCBs	PBDEs	PAHs	DDTs	4-NP1EO
Lopez Island	Green	Green	Green	Green	Green
Nisqually Reach	Yellow	Green	Green	Green	Yellow
Agate Pass	Yellow	Yellow	Green	Green	Yellow
Liberty Bay	Yellow	Yellow	Green	Green	Red
Point Monroe	Yellow	Yellow	Green	Yellow	Yellow
Samish Bay	Green	Yellow	Green	Red	Green
Eld Inlet	Red	Red	naf	Yellow	naf
Eagle Harbor	Red	Red	Red	Yellow	Red
Commencement Bay	Red	Red	naf	Yellow	naf

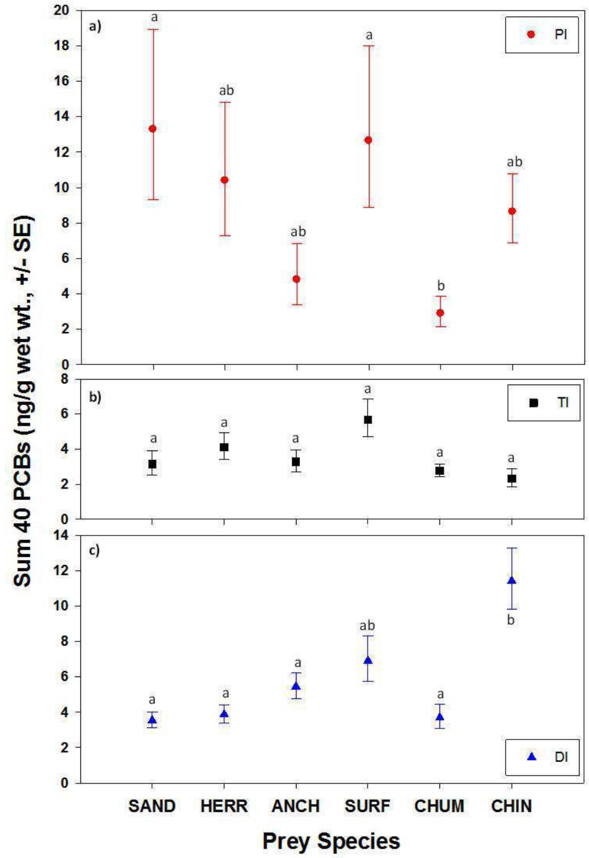
Persistent organic pollutants in forage fish preyed upon by rhinoceros auklets breeding in Puget Sound and the northern California Current

Thomas P. Good[1], Scott F. Pearson[2], Peter Hodum[3], Daryle Boyd[1], Bernadita F. Anulacion[1], Gina M. Ylitalo[1]

1. NOAA, Northwest Fisheries Science Center; 2. Washington Department of Fish and Wildlife; 3. University of Puget Sound

- POP levels (PCBs & PBDEs) in fish differed between inland water and outer coast locations and were generally greatest in fish from Puget Sound colonies.
- POP burdens for pre-fledging auklet chicks are considerable, and, because of site differences, are greatest for chicks in Puget Sound colonies.

Organochlorine contaminants in upper trophic-level consumers (Pacific salmon, harbor seals, killer whales) inhabiting Puget Sound are consistently higher than in those consumers inhabiting other west coast locations. While toxins in Pacific herring and Pacific salmon have been assessed in Puget Sound and other estuaries, breeding seabirds and other fish upon which they rely have not been assessed for persistent organic pollutants in Washington's inland and outer-coast waters. Stark differences in the diets of rhinoceros auklets (*Cerorhinca monocerata*) exist among inland-water and outer-coast breeding colonies, with inland water colony diets comprised almost entirely of Pacific sand lance (76% by weight) and Pacific herring (16%), while outer coast colony diets are more diverse. Differences in contaminant levels among these prey species may lead to differences in contaminant burdens experienced by birds in the different regions. We analyzed the most common fish prey (Pacific sand lance, Pacific herring, northern anchovy, surf smelt, Chinook salmon, and chum salmon) obtained from rhinoceros auklets breeding on Protection Island (Puget Sound), Tatoosh Island (WA coast), and Destruction Island (WA coast) for a variety of industrial compounds, organochlorine pesticides, and flame retardants, including polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethan (DDT), polybrominated diphenyl ethers (PBDEs), chlordanes, hexachlorocyclohexanes (HCHs), and hexachlorobenzene (HCB). We compared individual and composite levels of persistent organic pollutants in fish prey from the three locations using parametric and non-parametric analyses. Overall, concentrations of PCBs (Fig. 1), DDTs, and PBDEs in fish from the Puget Sound location were 2-4 times higher and had similar contaminant profiles compared to fish from the two outer coast locations. Elevated PCB and PBDE concentrations in Chinook salmon from the outer coast likely reflected Columbia River influences. Contaminants delivered by adults to auklet nestlings via prey were calculated from POPs levels of fish prey species and observed diets at the three colonies. The reliance on prey species with relatively greater POPs levels (Pacific herring and sand lance) at the Protection Island colony resulted in even greater differences in contaminant burdens experienced by nestlings between inland water and outer coast locations. The consequences of such ingestion levels for rhinoceros auklet nestlings are unknown, but potential sub-lethal effects include reduced chick growth, fledging success, and post-fledging survival. Breeding auklets, their fish prey, and other resident marine birds are not presently assessed for contaminants, and monitoring of these upper trophic-level consumers is needed to assess biomagnification impacts in the Puget Sound marine ecosystem.



Concentration of 40 PCBs (polychlorinated biphenyls) in prey fish collected from rhinoceros auklets on a) Protection Island (PI; Puget Sound), b) Tatoosh Island (TI; WA Coast), and c) Destruction Island (DI; WA Coast) breeding colonies on the outer coast and inland waters of Washington. Data are geometric means +/- SE for Pacific sand lance (SAND), Pacific herring (HERR), surf smelt (SURF), Northern anchovy (ANCH), chum salmon (CHUM), and Chinook salmon (CHIN). Letters denote significant post-hoc differences ($p<0.05$ using Bonferroni tests) among species at each site. Stepwise GLM testing found significant differences in Σ_{40}PCBs among species ($F_{5,69} = 4.1$, $p = 0.002$) and among sites ($F_{2,69} = 9.7$, $p < 0.001$).

Peter Hodum

Rhinoceros auklet with bill load of Pacific sandlance (Protection Island, WA)

For more information: Thomas P. Good, tom.good@noaa.gov https://www.nwfsc.noaa.gov/research/divisions/cb/ecosystem/marinemammal/seabirds/organic_pollutants.cfm

Toxic contaminant patterns in Chinook salmon and southern resident killer whales provide insights into whale foraging habitat

Sandra M. O'Neill[1], James E. West[1], Gina M. Ylitalo[2]

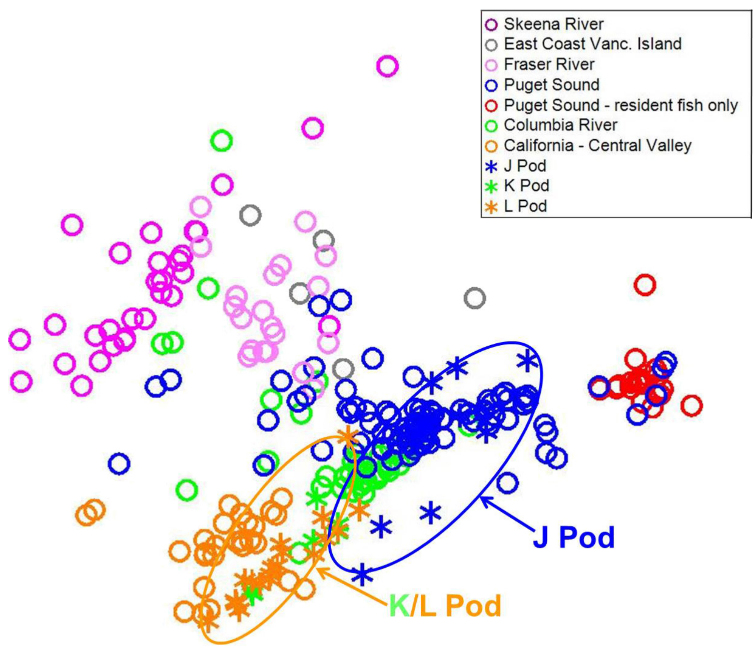
1. Washington Department of Fish and Wildlife; 2. NOAA Fisheries

- Comparison of contaminant patterns in southern resident killer whales and their prey suggests spatial segregation of whale pods in their foraging habitats.

Knowledge of the diet and foraging habitats of endangered southern resident killer whales (SRKW; *Orcinus orca)* is necessary to define and protect their critical habitat, but such information is lacking for this highly mobile species. SRKW spend much of the summer foraging in the Salish Sea where they feed primarily on Pacific salmon (especially Chinook, *Oncorhynchus tshawytscha*), based on observed feeding events (Ford and Ellis 2006, Hanson et al. 2010) and analysis of whale fecal material (Ford et al. 2016). The coastal distribution of SRKW outside of the summer months is known to extend south to Pt. Reyes, California but their preferred foraging habitats are unknown.

Persistent organic pollutants (POPs) can serve as chemical tracers to infer foraging habitats of marine species. Marine environments have distinct POP patterns based on historic inputs, and animals foraging for extended periods of time can accumulate POPs in proportion to their availability in those environments. We used multi-dimensional scaling to analyze the relative proportions of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), dichlorodiphenyltrichloroethane (DDTs), and hexachlorobenzene (HCB), hereafter referred to as POPs fingerprints, in whole-body Chinook salmon from known marine distributions and foraging habitats along the west coast of North America. The POPs fingerprints from chinook were compared with POPs fingerprints in blubber samples of SRKW to infer SRKW foraging habitats.

The relative abundance of four POP classes in Chinook salmon populations revealed unique chemical fingerprints consistent with their known marine distribution, confirming that POP patterns can be used as chemical tracers that reflect time spent foraging in specific marine regions. We observed higher levels of DDTs compared to other POPs in Chinook populations originating from California that migrate northward and feed off the coast of California and Oregon (Weitkamp 2010), reflecting greater historical use of DDT in California. Likewise, higher concentrations of PCBs and PBDEs were observed in salmon that reside in Puget Sound, where the pelagic food web has elevated concentrations of these contaminants relative to the other regions of the west coast (West et al. 2008, O'Neill et al. 2009). A comparison of POPs fingerprints of three pods of SRKW and Chinook salmon populations (Figure) revealed that J pod whales overlapped most with salmon from Puget Sound and the Columbia River, suggesting that J pod foraged substantially in habitats used by these salmon populations (i.e., a more northerly distribution, along the Oregon coast northward to the west coast of Vancouver Island). In contrast, fingerprints of K and L pod whales overlapped more with those of salmon from California and the Columbia River, indicating they spend a substantial portion of time foraging in habitats frequented by these salmon populations (i.e., a more southerly distribution, along the coastal waters of northern California and the Oregon coast). Collectively, these data suggest that SRKW foraged in coastal waters from the northern coast of California, northward to the west coast of Vancouver Island, as well as in the Salish Sea, but that J pod was spatially segregated from K and L pods in their foraging habitats.



Comparison of persistent organic pollutant (POP) patterns in seven Chinook salmon populations (○) and three pods of southern resident killer (*) whales reveals segregation among salmon populations and whale pods associated with distinct sources of POPs in their foraging habitats. Nonmetric multidimensional scaling (MDS) was used to represent relative abundances of 4 POP groups in low-dimensional (2-D) space. MDS analysis was carried out using Primer version 6.0. Axes surround a unitless space within which samples were placed according to the degree of similarity in the relative abundance of four POP groups. Similarity in POP patterns determined the distance between points in the space: samples with similar contaminant POPs patterns were placed close together and dissimilar patterns further apart. The observed patterns are statistically different from a random configuration of points (stress = 0.07). The Puget Sound Chinook salmon are represented by two populations: 1) fish caught in Puget Sound during the typical adult migration window (April –September) when marine distribution is unknown (i.e., Puget Sound) and 2) fish caught in Puget Sound outside this timeframe when their residency in Puget Sound can be inferred.

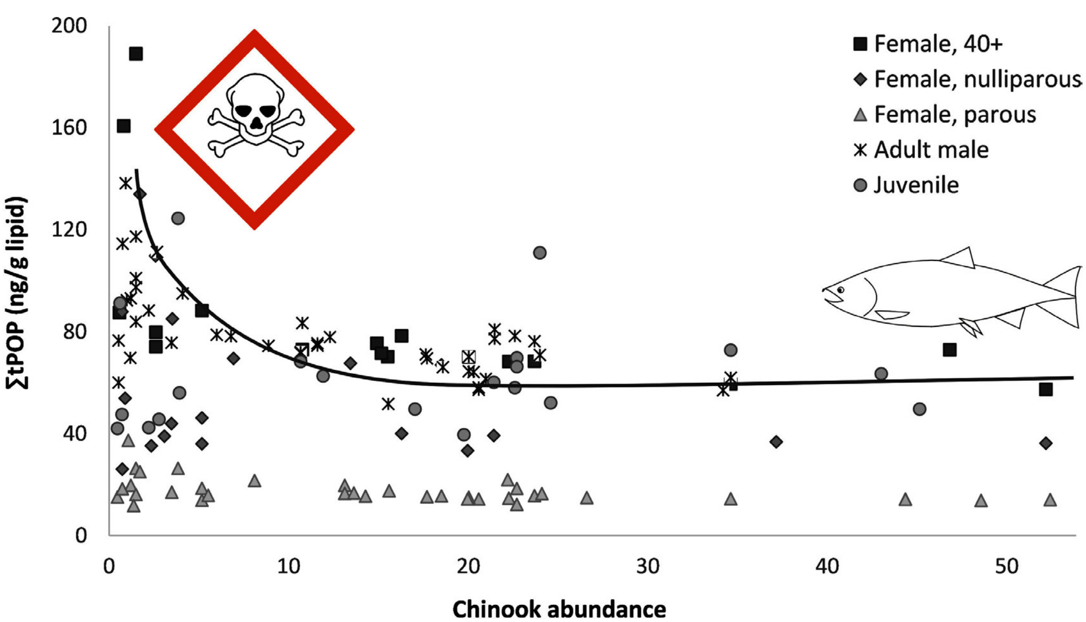
Modulation in persistent organic pollutant concentration and profile by prey availability and reproductive status in southern resident killer whale scat samples

Jessica Lundin[1], Samuel K. Wasser[2], Rebecca K. Booth[2], Elizabeth Seely[2], Gina M. Ylitalo[1], Bernadita Anulacion[1], Jennifer A. Hempelmann[1], Kim M. Parsons[1], M. Bradley Hanson[1], Candice K. Emmons[1], Deborah A. Giles[3]

1. National Oceanic and Atmospheric Administration; 2. University of Washington; 3. Center for Whale Research

- Highest concentrations of POPs in scat occurred with low prey abundance; congener profiles suggested releases from endogenous stores.
- Bioaccumulation increased with age, excepted by known maternal transfer and possible unobserved neonatal loss in presumed nulliparous females.

Persistent organic pollutants (POPs), specifically PCBs, PBDEs, and DDTs, in the marine environment are well documented, however accumulation and mobilization patterns at the top of the food-web are poorly understood. This study broadens the understanding of POPs in the endangered southern resident killer whale population by addressing modulation by prey availability and reproductive status, along with endocrine disrupting effects. A total of 140 killer whale scat samples collected from 54 unique whales across a 4 year sampling period (2010−2013) were analyzed for concentrations of POPs. Toxicant measures were linked to pod, age, and birth order in genotyped individuals, prey abundance using open-source test fishery data, and pregnancy status based on hormone indices from the same sample. Toxicant concentrations were highest and had the greatest potential for toxicity when prey abundance was the lowest. In addition, these toxicants were likely from endogenous lipid stores. Bioaccumulation of POPs increased with age, with the exception of presumed nulliparous females. The exceptional pattern may be explained by females experiencing unobserved neonatal loss. Transfer of POPs through mobilization of endogenous lipid stores during lactation was highest for first-borns with diminished transfer to subsequent calves. Contrary to expectation, POP concentrations did not demonstrate an associated disruption of thyroid hormone, although this association may have been masked by impacts of prey abundance on thyroid hormone concentrations. The noninvasive method for measuring POP concentrations in killer whales through scat employed in this study may improve toxicant monitoring in the marine environment and promote conservation efforts.



tPOP (ng/g lipid) in killer whale scat with respect to Fraser River Chinook abundance (n=133 samples, 2010-2013); line represents trend for adult males

Jessica Lundin collecting a killer whale scat sample.

For more information: Jessica I. Lundin, Jessica.lundin@noaa.gov http://conservationbiology.uw.edu/

CECs in marine biota: Presence of estrogenic chemicals in bile of English sole (*Parophrys vetulus*) from Puget Sound, WA

Denis da Silva[1], Sandra O'Neill[2], Lyndal Johnson[1], James West[2], Penny Swanson[1], and Gina Ylitalo[1]

1. NOAA, Northwest Fisheries Science Center; 2. Washington Department of Fish and Wildlife

- Estrogenic chemicals measured in bile of English sole at 10 Puget Sound sites revealed fish from urbanized sites had elevated levels of Bisphenol A and tert-octylphenol and Elliott Bay fish had the highest estrogen exposure.

Marine waters near urban centers receive frequent inputs of chemicals that are emerging as threats to ecological and human health referred to as chemicals of emerging concern (CECs). Priority lists of CECs include some estrogenic chemicals (ECs) such as natural and synthetic estrogens; 17β-estradiol (E2), estrone (E1), estriol (E3), and 17α-ethynylestradiol (EE2), as well as industrial phenolic compounds [e.g., bisphenol A (BPA), octylphenol (OP) and nonyphenol (NP)]. Recent information on the levels of these ECs in water indicates that they may pose a risk due to their widespread occurrence and their potential estrogenicity, affecting growth, development and reproduction of marine fish. Although limited data are available on exposure concentrations of ECs in biota of marine ecosystems, recent studies (da Silva et al. 2013) in Puget Sound have reported measurable levels of selected ECs in bile of male English sole at levels that are correlated with abnormal reproductive cycles and elevated in-plasma vitellogenin levels in this benthic species (Johnson et al. 2008). To improve the understanding on EC levels of contamination in Puget Sound and ultimately provide monitoring of ECs for assessing the Toxics in Fish Vital Sign (PSP, 2016), we applied our method for analysis of ECs in bile of male and female English sole collected at 10 different sites, including low, moderate and high development sites (Figure 1, O'Neill et al. 2015). The results indicate that BPA and tert-OP (tOP) levels were significantly higher in English sole collected from the most highly developed sites compared to those collected at sites classified with either medium or low development (Figure 2). Moreover, the concentrations of natural hormones and nonsteroidal xenoestrogens detected indicate that sole from Elliott Bay had the highest estrogen exposure. The median total estradiol equivalent concentrations (EEQ) in female and male sole from Elliott Bay were 3000 and 410 ng/mL bile (Figure 3). These results suggest that Puget Sound fish are being exposed to elevated levels of ECs, particularly from highly-developed urbanized habitats, such as Seattle Waterfront/Elliott Bay and Sinclair Inlet. The chronic exposure to these ECs may cause endocrine disrupting effects such as reproductive impairment.

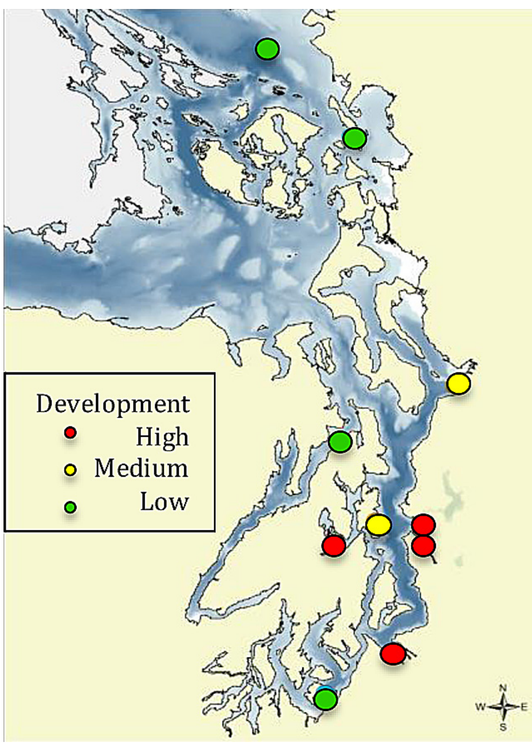


Figure 1: English sole were collected from 10 locations throughout Puget Sound which were classified as either high, medium, or low development basins. (Classifications were based on surrounding land use)

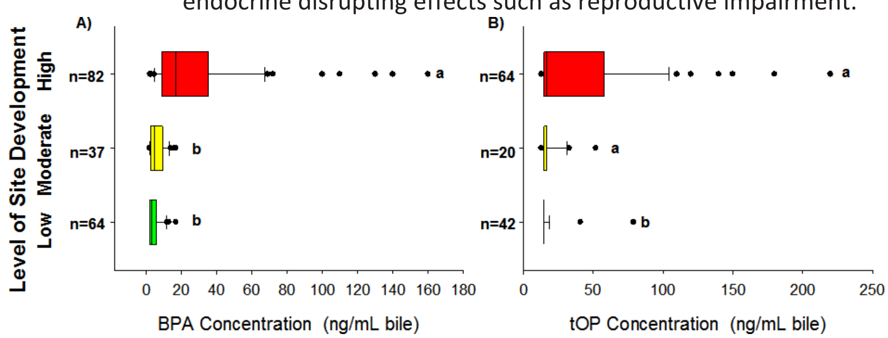


Figure 2: Bisphenol A (BPA) and tert-octylphenol (tOP) are higher in males and females from high development sites.

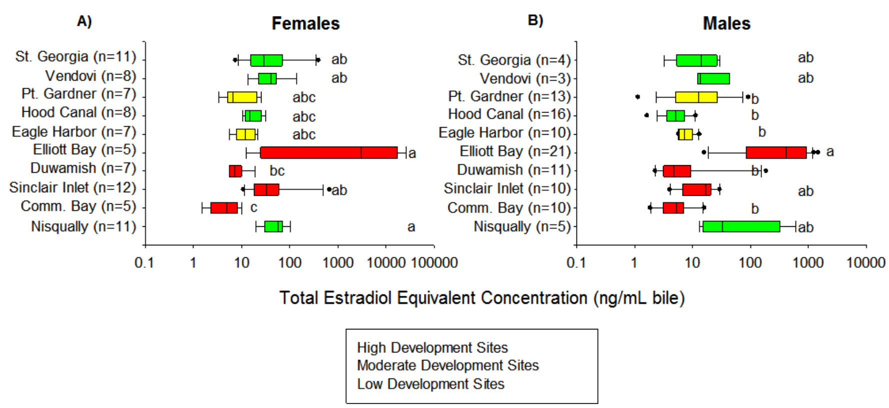


Figure 3: Concentrations of natural hormones and nonsteroidal xenoestrogens detected indicate that English sole from Elliott Bay had the highest estrogen exposure.

Microplastics in wild and cultured shellfish in British Columbia

Sarah Dudas[1], Katie Davidson[1], Garth Coverton[2], Brenna Collicutt[2]

1. Vancouver Island University; 2. University of Victoria

- Microplastics were found to be present at similar levels in both wild and cultured clams in Baynes Sound, B.C.

Increased use of plastic has driven corresponding increases in plastic debris in the ocean, more than 18% of which can be sourced to fisheries and aquaculture equipment (Andrady 2011). As scientists investigate plastics at smaller and smaller scales, research has shown microplastics (particles <5 mm) are ubiquitous in aquatic environments. Microplastics have been found in marine organisms from several phyla (GESAMP 2015) including seafood consumed by humans, particularly shellfish (Mathalon & Hill 2014, Li et al. 2015, Davidson & Dudas 2016). Consumers and farmers alike have become increasingly concerned about microplastic contamination of seafood and the implications for food safety and security. While potentially impacted by this contaminant, the aquaculture industry likely contributes to this pollution source due to the extensive use of plastics in culturing systems (Baluyut 1989). We conducted a study to determine the quantity of microplastics present in wild and cultured Manila clams (*Venerupis philippinarum*) on three active shellfish farms and three reference beaches (i.e., non-shellfish farm sites) in Baynes Sound, British Columbia. There was no significant difference ($F = 1.29$; $df = 1,4$; $p = 0.289$) between microplastic concentrations in cultured and wild clams. Microplastic concentrations ranged from 0.07 to 5.47 particles/g of tissue, from reference beach and shellfish farm clams, respectively. Fibers were the dominant microplastic (90 %); colourless and dark gray fibers were the most common colours observed (36 and 26%, respectively). Although this indicates microplastics are definitely present in seafood consumed by humans, shellfish aquaculture operations do not appear to be increasing microplastic concentrations in farmed clams in this region. A larger, more comprehensive study is currently being conducted in British Columbia spanning sites throughout the Strait of Georgia and Clayquot Sound. That study will examine microplastic concentrations in wild and cultured Manila clams, Pacific oysters (*Crassostrea gigas*), and the surrounding water and sediment, and investigate potential sources of plastic pollution.

Plastic ingestion by Pacific sand lance (*Ammodytes personatus*) in the Salish Sea

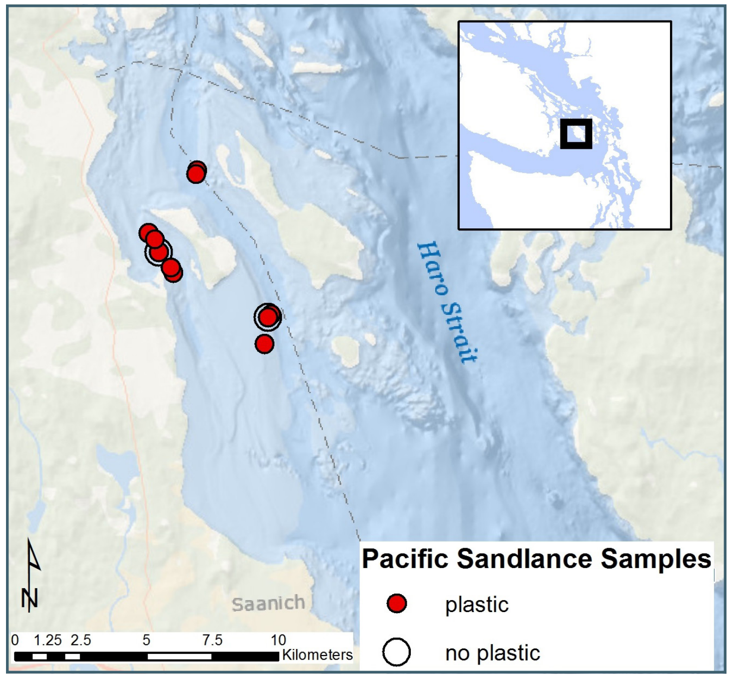
Environment and Climate Change Canada / Environnement et Changement climatique Canada

D.F. Bertram[1], C.L.K. Robinson[2], M. Hennekes[3], M. Galbraith[3], N. Dangerfield[3], S. Gauthier[3], K. Woo[1]

1. Environment and Climate Change Canada; 2. Poseidon EcoService; 3. Department of Fisheries and Oceans Canada

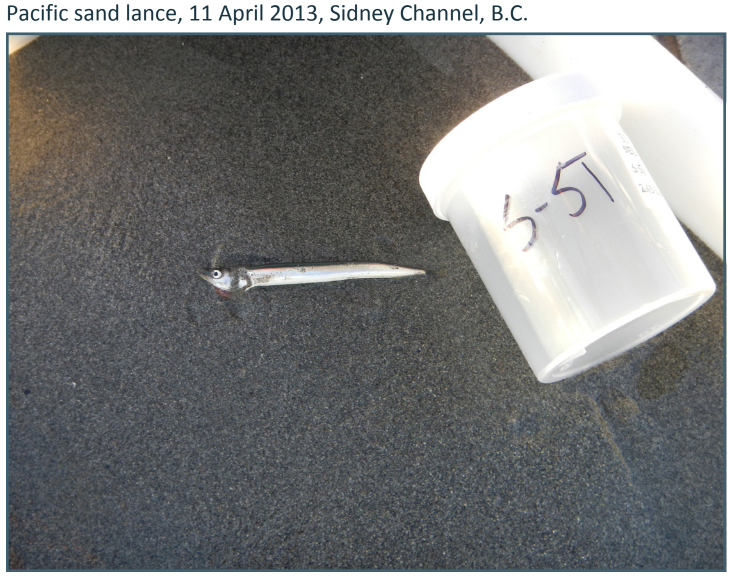
- Eighty five percent (17/20) of Pacific sand lance fish contained coloured plastic filaments.
- High concentrations in forage fish indicate large potential for transfer of microplastics to upper trophic levels of the food web.

We report on microplastic concentrations in the guts of Pacific Sand Lance (*Ammodytes personatus*) captured in an internationally Important Bird Area (IBA) within the Salish Sea, Canada. We collected fish (65 – 117 mm) buried in subtidal habitats in the Sidney Channel IBA during 2013-2015. Eighty five percent (17/20) of the fish contained coloured (black, red, and blue) plastic filaments that ranged in length from 0.59 to >10 mm with an average of 2.14 mm (subsample, n = 38 pieces). Individual fish with plastics had between 1 and 63 pieces in their guts, for a grand total of 211 filaments. The fish fed primarily on copepods and cirripedes, which ranged in size from 0.3 – 3.8 mm. The diet composition differed from historical sand lance samples from Saanich Inlet and the Strait of Georgia (1966-1968; Hipfner and Galbraith 2014), but only the recent samples contained plastic fragments. Recent broad-scale sampling of microplastics on the BC coast (Desforges et al. 2014) showed large concentrations of plastic filaments (2877/m^3) in the surface waters near our study site, with most pieces of the size class 0.1 - 0.5 mm (42%), and roughly equal representation of size fractions 0.5 – 1 mm (27%) and pieces >1 mm (31%). We suspect that a key source of the plastic filaments in the forage fish could be the Saanich Peninsula Wastewater treatment outflow, which empties into our study area from a large urban area. It is likely that Pacific Sand Lance mistake the plastics for zooplankton prey and ingest them directly from the water. The high densities of plastic pieces in the guts of a key forage fish in an IBA indicates the large potential for transfer of microplastics into upper trophic levels of the marine food web.



Location of grab samples of Pacific sand lance containing plastic filaments.

Pacific sand lance, 11 April 2013, Sidney Channel, B.C.



For more information: D.F. Bertram, Douglas.bertram@dfo-mpo.gc.ca

The incidence of microplastics in juvenile Chinook salmon and their nearshore environments

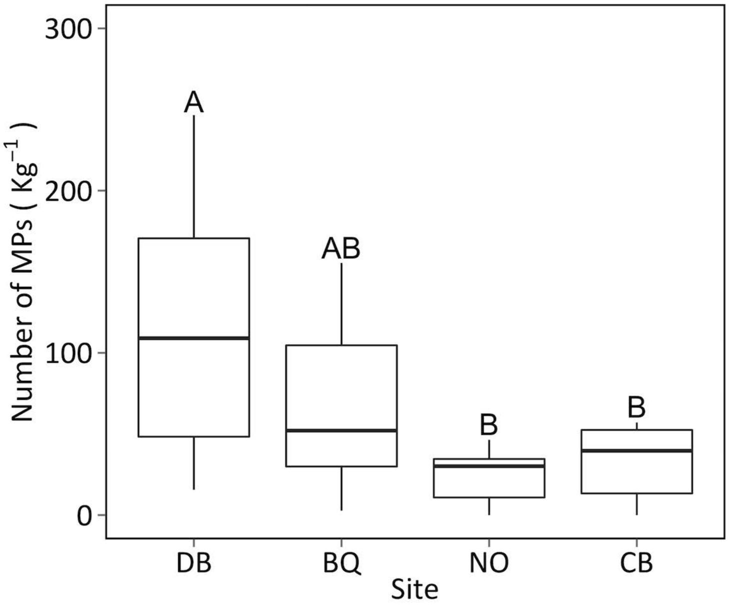
Brenna Collicutt[1], Sarah Dudas[2], Francis Juanes[1]

1. University of Victoria; 2. Vancouver Island University

- Juvenile Chinook salmon are ingesting microplastics at low levels along the east coast of Vancouver Island.

Microplastics (plastic particles <5 mm in size) have been identified as a global threat to the marine environment and have been found in Salish Sea waters, sediment, zooplankton, and bivalves (Desforges *et al.* 2014, 2015; Cluzard *et al.* 2015; Davis and Murphy 2015; Davidson and Dudas 2016). Although microplastics have been observed in various fish species worldwide (Lusher 2015), we have yet to examine those in the Salish Sea. Chinook salmon (*Oncorhynchus tshawytscha*) are of particular importance in the Salish Sea as an ecologically, culturally, and commercially important species. Furthermore, juvenile Chinook salmon are particularly vulnerable and experience high mortality during their early marine nearshore residency (Parker 1968; Beamish and Mahnken 2001), therefore, factors potentially influencing their survival are important to investigate. Our objectives were to determine the incidence of microplastic particles in juvenile Chinook salmon and their nearshore environment along the east coast of Vancouver Island. We beach seined for juvenile Chinook, and collected water and sediment samples at four sites including Deep Bay, Big Qualicum, Nanaimo Harbour and Cowichan Bay. Across all sites 59% of juvenile Chinook salmon contained at least one microplastic particle (MP) with an average of 1.15 $\pm$ 1.41 MPs/individual. In water and sediment samples, we found 659.88 $\pm$ 520.87 MPs m^{-3} and 60.2 $\pm$ 63.4 MPs kg^{-1} dry weight, respectively. We found no differences in microplastic concentrations in Chinook and water samples among sites, however, we found significantly higher levels in sediment from Deep Bay compared to the Nanaimo ($p = 0.020$) and Cowichan ($p = 0.045$) sites. These inconsistencies may be the product of differences in site morphology and exposure, i.e. Deep Bay is a more sheltered area compared to other sites, allowing microplastics to settle there more readily. In addition, the Deep Bay site is located on a shellfish aquaculture tenure and near a marina, which may increase sediment microplastic concentrations through the high use of plastic materials such as ropes, netting, trays, and floats. We did not find relationships between microplastic concentrations in juvenile Chinook and their environment, suggesting different mechanisms may affect microplastic exposure and environmental samples may not be indicative of what fish are ingesting. Furthermore, fish and water are mobile and may be exposed to microplastics over larger areas, whereas sediment is relatively stationary and may concentrate microplastics. Overall, microplastic abundances in juvenile Chinook salmon were relatively low and seem unlikely to cause negative impacts, however further studies on plastic retention time and health implications in juvenile Pacific salmon are necessary to confirm this assumption.

Fish collection.



Average number of microplastics (MPs) Kg^{-1} of sediment at four sample sites including Deep Bay (DB), Big Qualicum (BQ), Nanaimo (NO) and Cowichan Bay (CB). Boxes represent interquartile ranges with medians (black line) and the whiskers are minimum and maximum values. Different letters represent significant differences among sites.

Polybrominated diphenyl ethers (PBDE) and their hydroxylated and methoxylated derivatives in blood from E-waste recyclers, commercial fisherman and office workers in the Puget Sound

Pacific Northwest NATIONAL LABORATORY
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Irvin R. Schultz[1], Sara Cade[1], Li-Jung Kuo[1]

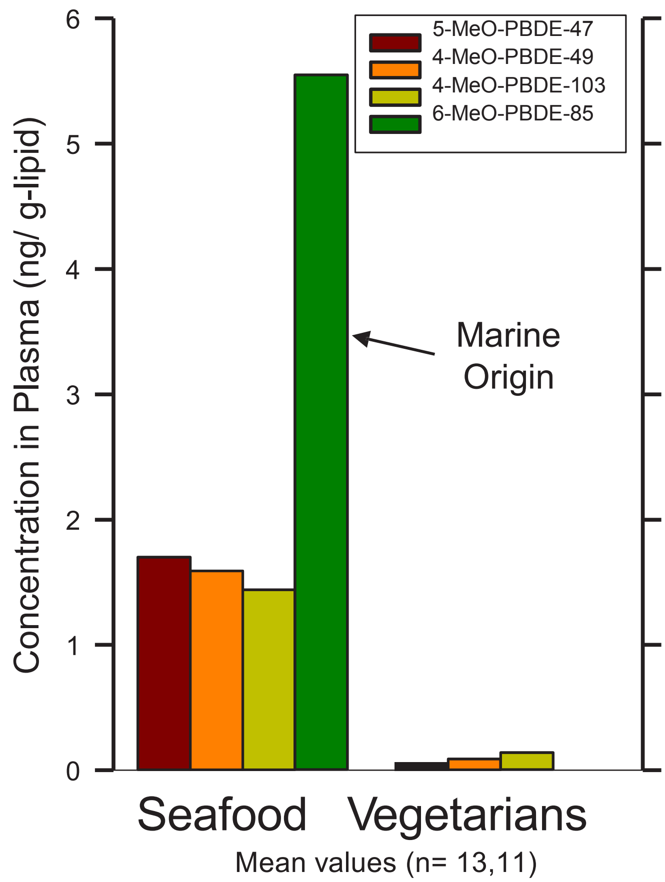
1.Pacific Northwest National Laboratory, Marine Sciences Lab

- Seafood eaters generally had higher levels of PBDEs than low or non-seafood eaters.
- Dust collected from E-waste sites was highly enriched with BDE-153 and 209.

Synthetic polybrominated diphenyl ethers (PBDEs) have been widely used as flame retardants in many consumer products including electronic devices. Important routes of human exposure are contaminated food and contact with dust found in households and workplaces. Structurally related derivatives of PBDEs are the hydroxylated (OH-PBDEs) and methoxylated (MeO-PBDEs) forms. Humans can metabolize some PBDEs into the OH-PBDE derivatives, which is a concern due to greater health risks associated with OH-PBDEs. However, certain OH-PBDEs and MeO-PBDEs are also marine natural products which can bioaccumulate in marine fish and shellfish. It is unclear, although likely, if this serves as a vector for human exposures through seafood consumption. In this study, we compared approximately 30 different PBDEs, OH-PBDEs, and MeO-PBDEs in household / workplace dust and blood plasma samples provided by 113 volunteers living in the Puget Sound region of Washington State and working in the commercial fishing, electronic recycling, or non-specific office occupations. Prior to blood sampling, a two-week food consumption diary was obtained from each volunteer.

Results indicate PBDE levels varied between < 0.03 - 3 ng/ml wet-weight of plasma (5 – 157 ng/g-lipid). The OH-PBDEs were detected in all volunteers varying between < 0.005 – 0.7 ng/ml wet weight (2.5 -101 ng/g-lipid). The MeO-PBDEs were detected in most, but not all volunteers, varying between 0 – 1000 ng/ml wet weight. For the large majority of volunteers, the PBDE levels exceeded the combined OH-PBDE and MeO-PBDEs. Exceptions to this observation were individuals that consumed the highest amounts of seafood (more than 5 and up to 18 servings / week). Electronic waste recyclers generally consumed low amounts of seafood and had PBDE, OH-PBDE and MeO-PBDE blood levels that were intermediate between seafood consumers and non-E-waste office workers. Dust samples from E-waste sites were particularly enriched with BDE-209 and BDE-153 relative to non-E-waste businesses and homes. We did not observe detectable levels of BDE-209 in any samples, but BDE-153 was significantly elevated in E-waste workers relative to office workers. This finding suggests BDE-153 might be a useful marker of PBDE exposure from dust in those individuals consuming similar amounts of seafood. In contrast, some marine origin MeO-PBDEs, such as 6-MeO-PBDE-85 appear to be useful markers of PBDE exposure from seafood. For example, the figure shows the plasma levels of four different MeO-PBDEs in volunteers consuming > 9 servings / week compared to vegetarians. Note the very low or complete absence of MeO-PBDEs in vegetarians.

Supported by NIOSH Grant 1R21OH010259-01A1.



Select MeO-PBDE congeners in plasma collected from high seafood eaters (> 9 servings / week; *n*=13) and vegetarians (*n*=11). Mean values shown. Note that 6-MeO-PBDE-85 is known to be produced in the marine environment and bioaccumulate in fish; it may be a potential marker of PBDE exposure from seafood.

For more information: Irvin R. Schultz, irv.schultz@pnnl.gov

Polybrominated diphenyl ethers and their hydroxylated and methoxylated derivatives in seafood obtained from Puget Sound, WA

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Sara E. Cade[1], Irvin R. Schultz[1], Li-Jung Kuo[1]

1. Pacific Northwest National Laboratory, Marine Sciences Lab

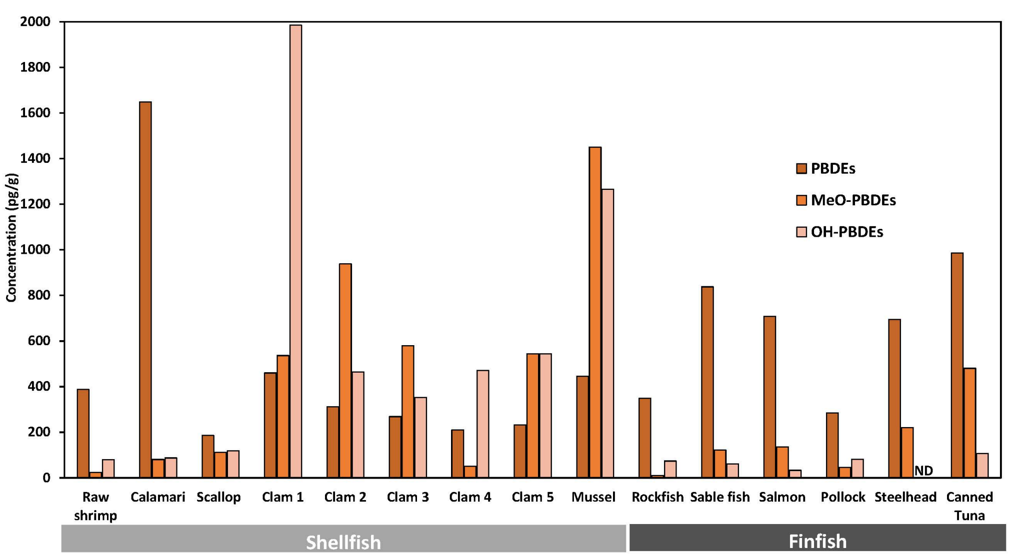
- The congener profile in seafood is dominated by BDE-47, 99 and 100. BDE-209 was un-detectable in all seafood samples.
- Shellfish have relatively high levels of MeO- and OH-PBDEs in comparison to PBDE levels in the seafood sampled.

Polybrominated diphenyl ethers (PBDEs) are a class of additive flame retardants that were widely used until their gradual phase out beginning in 2004 and ending in 2013. PBDEs are ubiquitous environmental contaminants and have been detected in sediments and a variety of biota and marine mammals in the Puget Sound. Structurally related derivatives of PBDEs are the hydroxylated (OH-) and methoxylated (MeO-) forms. Some MeO- and OH-PBDEs are believed to be of natural origin, while others are thought to be products of biotransformation or environmental degradation (Montano, Gutleb, and Murk 2013).

There are human health concerns associated with PBDEs and particularly OH-PBDEs, which appear to be more potent endocrine disrupters and neurotoxic agents (Montano, Gutleb, and Murk 2013). Humans are primarily exposed to PBDEs through diet and contact with contaminated dust (Johnson-Retrepo and Kannan 2009). Previous market basket studies have shown seafood to be a significant source of persistent organic chemicals, including PBDEs (Schechter et al. 2010). We measured 12 PBDEs, 16 MeO-PBDEs and 16 OH-PBDEs in marine fish and shellfish collected from grocery stores and seafood markets in Sequim and Seattle, Washington. Additionally, several fish samples collected from Southeastern Alaska were donated for comparison. The raw tissues were composited, homogenized and assayed with an adapted Hovander et. al method and analyzed using GC-MS (NCI) and GC-ECD for BDE-209 (Hovander et al. 2000).

The total PBDE burden for seafood was largely comprised of three congeners: BDE-47, 99 and 100. Levels of MeO- and OH-PBDEs varied between finfish and shellfish with shellfish often containing more MeO- and OH-PBDEs than PBDEs (Figure). In shellfish, MeO- and OH-PBDE congeners likely to be of natural origin were significantly higher than the MeO- and OH-PBDE congeners that were of probable anthropogenic origin. A similar observation can be made for finfish and MeO-PBDEs, however, a different pattern was observed for OH-PBDEs. In finfish, OH-PBDEs of natural origin represented a much smaller fraction of the total. No BDE-209 was detected in any of our samples. The differences between the PBDE signature for finfish and shellfish, particularly in regards to PBDE derivatives, suggests biotransformation and/or differences in bioaccumulation and trophic transfer may be important (Dahlgren et al. 2016).

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Science Undergraduate Laboratory Internship



Total PBDEs, MeO-PBDEs and OH-PBDEs in finfish and shellfish sampled. A composite of 6-7 samples were used from each location. The following is the labeled origin of the seafood items purchased: raw shrimp - the U.S. Gulf Coast, calamari and scallops - China, clam 1 - Dabob Bay, clam 2 - Hammersley Inlet, clam 3 - Sequim, clam 4 - British Columbia, clam 5 - Puget Sound, mussel - Whidbey Island. The rockfish, sable fish and salmon were all caught in Southeastern Alaska. The pollock (frozen and breaded) - Alaska, steelhead trout - Columbia River, and canned tuna - Thailand.

Fraser River Ambient Environmental Monitoring Program

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

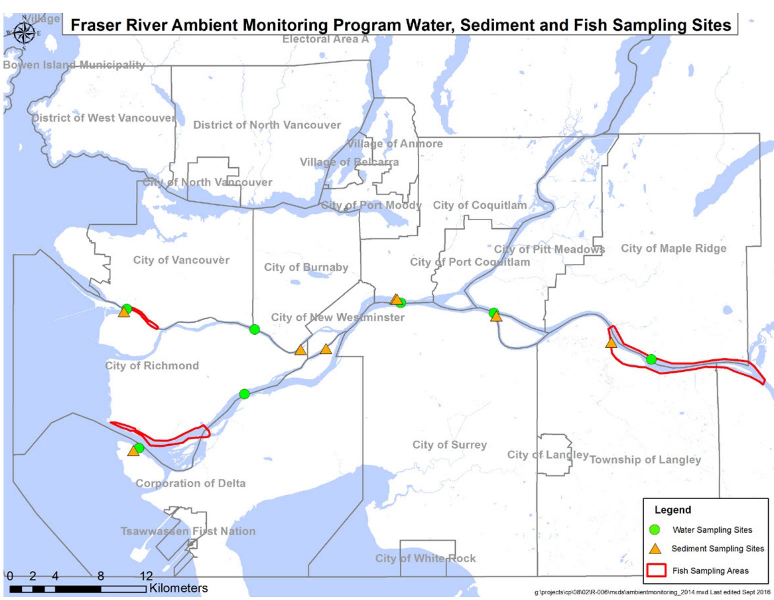
Lynn Landry[1], Annette Smith[2], Les Swain[3], Francisco Perello[4]

1. Metro Vancouver, Vancouver, BC.; 2. Enkon Environmental Ltd, Surrey, BC.; 3. Tristar Environmental Consulting, Malahat, BC.; 4. Keystone Environmental Ltd., Burnaby, BC.

- Water Quality Index including water, sediment and fish results indicate that ambient conditions in the Fraser River are good.

Metro Vancouver's Fraser River Ambient Monitoring Program was initiated in 2003. The program is designed to operate on a five-year cycle, and includes three components: water column, sediment and fish. Ambient water quality monitoring occurs at seven sites on an annual basis, while sediments are monitored every five years at seven sites, and fish tissues and health are monitored every five years in three areas. The objectives of the Fraser River Ambient Monitoring Program are to: provide baseline environmental quality data; characterize changes in water, sediment and biota quality parameters in the Fraser River; evaluate long term temporal and spatial trends within the monitoring area; identify 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.

Monitoring and assessment were targeted to parameters that are potential indicators of wastewater discharges. Results are compared to site specific objectives and applicable environmental quality guidelines. Additionally, a Water Quality Index (WQI) rating based on the Canadian Council of Ministers of the Environment WQI tool was calculated for separate river reaches and for the river as a whole.



Water – In 2015, of the 87 measured parameters, 18 had applicable site specific objectives and guidelines, of these 15 (83%) were met. Parameters measured above objectives or guidelines include copper, manganese, and iron associated with TSS during high river flows. On average concentrations of specific conductance, total ammonia, nitrate, fecal coliforms, total suspended solids, total phosphorus and total metals (copper, iron and zinc) increased from upstream to downstream. No temporal trends were observed.

Sediment - In 2011, for the 370 parameters measured, there were 40 applicable objectives and guidelines, of these 34 (85%) were met. Parameters measured above objectives or guidelines included arsenic, chromium, copper, nickel, dioxin/furan TEQs, and PBDE-99. The applicable nickel and arsenic guidelines were exceeded at all sites. PCBs and nonylphenols were detected in all samples and concentrations generally increased from upstream to downstream. Copper and total PAH concentrations decreased since 2006.

Fish – In 2012, Peamouth chub and Largescale sucker were surveyed. For 241 monitored parameters, there were 22 applicable site specific objectives and guidelines, of these 14 (63%) were met. In whole bodies, methylmercury in all samples, and DDT in one sample exceeded the applicable guidelines. Other parameters measured above the objectives or guidelines, but within the limits of analytical precision include DDT and PCB TEQ in two samples, and dioxin and furan TEQ in one sample. In muscle, penta-BDE-99 exceeded the guideline in one sample, and total mercury in one sample was measured above the guideline, but within the limits of analytical precision. Arsenic concentrations in muscle appear to have increased since the 1980s. Mercury, tetrachloro-dioxin and furan, and total PCBs appear to have decreased since the 1990s.

The three year average Water Quality Indices for the whole river since 2008 which include water, sediment and fish results indicate ambient conditions in the river are good.

For further information see: ENKON Environmental (2014), Keystone Environmental (2011), and Tri-Star Environmental (2015).

Burrard Inlet Ambient Environmental Monitoring Program

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

Lynn Landry[1], Annette Smith[2], Les Swain[3]

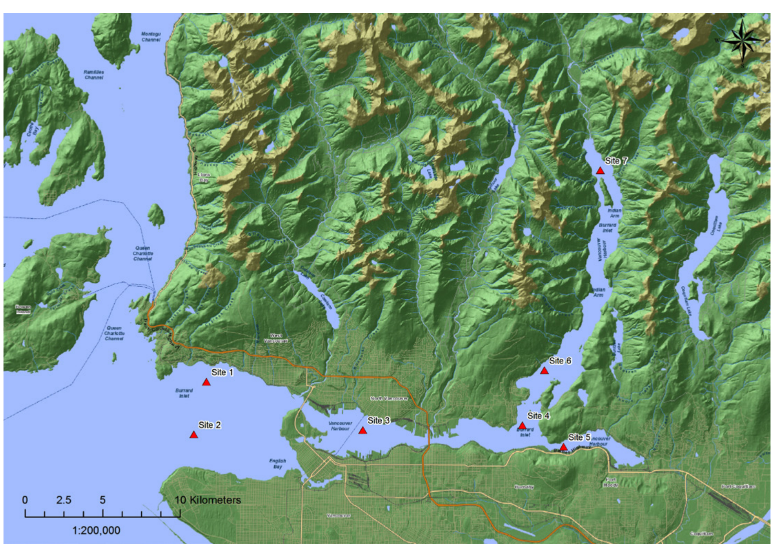
1. Metro Vancouver, Vancouver, BC.; 2. Enkon Environmental Ltd, Surrey, BC.; 3. Tristar Environmental Consulting, Malahat, BC.

- Water Quality Index including water and sediment results indicate that ambient conditions in the Burrard inlet are fair.

Metro Vancouver's Burrard Inlet Ambient Monitoring Program was initiated in 2007. The program is designed to operate on a five-year cycle, and includes three components: water column, sediment and fish. Ambient water quality monitoring occurs at seven sites (Figure) and two depths on an annual basis, while sediments are monitored every two-to-three years, and fish tissues and health are monitored once every five years at the same seven sites. The objectives of the Burrard Inlet Ambient Monitoring Program are to: provide baseline environmental quality data; characterize changes in water, sediment and biota quality parameters in Burrard Inlet; evaluate long term temporal and spatial trends within the monitoring area; identify 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.

Monitoring and assessment were targeted to parameters that are potential indicators of wastewater discharges. Results are compared to site specific objectives and applicable environmental quality guidelines. Additionally, a Water Quality Index (WQI) rating based on the Canadian Council of Ministers of the Environment WQI tool was calculated for separate sub-basins and the overall inlet.

Burrard Inlet Ambient Monitoring Sites



Water – In 2014 for 78 monitored parameters, 25 had applicable site specific objectives and guidelines, of these 22 (88%) were met. The exceptions were copper, boron and dissolved oxygen. Boron concentrations are consistent with background levels in Canadian coastal waters. Historically dissolved oxygen has been below the minimum objective throughout the inlet, especially in deeper waters and periodically in surface waters. No temporal trends were observed.

Sediment – In 2013, for 248 monitored parameters, 46 had applicable site specific objectives and guidelines; of these 26 (57%) were met. Parameters measured above objectives or guidelines included chromium, copper, lead, mercury, nickel, zinc, indeno(1,2,3-cd)pyrene, 2-methylnaphthalene, dioxin/furan toxic equivalency (TEQs), polybrominated diphenyl ether-99 (PBDE-99), aldrin, chlordane, dichlorodiphenyldichloroethane (DDD), dichlorodiphenyltrichloroethane and hexachlorobenzene. All sites had at least three parameters above objectives or guidelines. Concentrations of copper, lead, mercury, zinc and total polycyclic aromatic hydrocarbons (PAHs) are generally decreasing over time (metals 30 years, PAHs 20 years).

Fish – In 2012, English Sole were surveyed. For the 263 monitored parameters, there were 29 applicable site specific objectives and guidelines; of these 19 (65%) were met. In whole bodies, methylmercury, dioxins/furans, polychlorinated biphenyls (PCBs), PBDE-99 and total DDT did not meet objectives or guidelines to protect wildlife at some or all sites. In muscle tissue, only PBDE-99 at one site failed to meet the applicable objectives and guidelines. In liver, concentrations of 2,3,7,8-tetrachlorodibenzofuran (TCDF), PCBs and DDT were significantly positively correlated with cytochrome P450 1A (CYP1A) induction. In plasma, vitellogenin was detected in 80% to 100% of male fish at most sites. Concentrations of vitellogenin in male fish were significantly positively correlated with concentrations of 2,3,7,8-TCDF in whole bodies and DDT in whole bodies and livers.

The three-year average WQI for the whole inlet since 2008, which include water and sediment results, indicate ambient conditions are fair.

For further information see: ENKON Environmental (2014, 2015, 2016) and Tri-Star Environmental (2016)

Boundary Bay Ambient Monitoring Program - water quality monitoring results

metrovancouver
SERVICES AND SOLUTIONS FOR A LIVABLE REGION

Helia Yazdanpanah[1], Les Swain[2], Lauren Petersen[3]

1. Metro Vancouver, Vancouver, BC.; 2. Tristar Environmental Consulting, Malahat, BC.; 3. City of Surrey, Surrey, BC.

- Water Quality Index indicates that ambient conditions in the Boundary Bay are marginal.

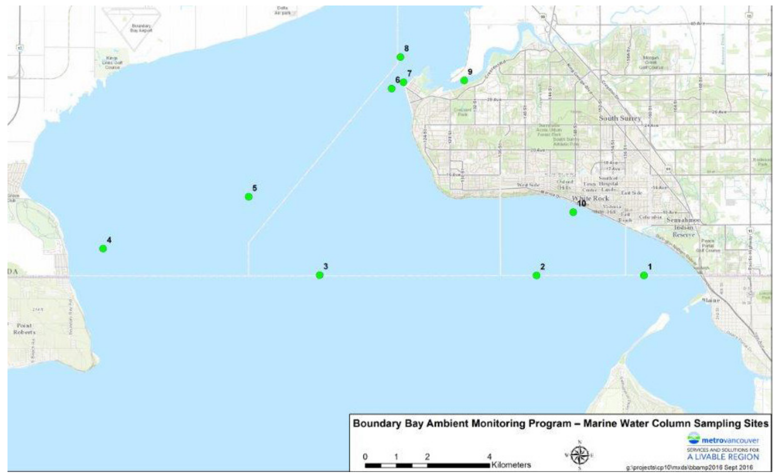
The Metro Vancouver region's Integrated Liquid Waste and Resource Management Plan (ILWRMP) includes a requirement to conduct ambient monitoring programs to assess, forecast and evaluate the effects of wastewater and stormwater discharges to ambient environments. The Boundary Bay Ambient Monitoring Program was initiated in 2009, and is currently continuing as a partnership between the City of Surrey and Metro Vancouver. The City of Surrey conducts the monitoring of the upland fresh water in tributaries and rivers that discharge into the bay, and Metro Vancouver conducts the monitoring of the marine water in Boundary bay. Monitoring is conducted annually in both dry weather and wet weather conditions.

The objectives of the program are to: provide baseline environmental quality data, characterize changes in water quality parameters, evaluate temporal and spatial trends within the monitoring area, identify changes in parameters that might indicate environmental changes, and act as a measure of performance for Metro Vancouver's ILWRMP.

Monitoring was targeted to parameters that are potential indicators of stormwater discharges. Monitored parameters included field measurements such as dissolved oxygen, pH, temperature, conductivity, and turbidity at two depths: one metre below the surface and one metre above the sea floor, and laboratory analyzed parameters such as bacteria, metals, nutrients, total dissolved solids and organic carbon at one metre below the surface. Results are compared to site specific objectives and applicable environmental quality guidelines. Additionally, a Water Quality Index (WQI) rating based on the Canadian Council of Ministers of the Environment WQI tool was calculated for separate tributaries and rivers, and for Boundary Bay as a whole.

Over the past five years, the field tested parameters indicate the water in the bay is usually well-mixed, as no significant differences in these parameters were observed at the two depths. This means that samples collected from the surface during both dry- and wet-weather periods for chemical analyses are representative of the water quality of the bay.

Measured parameters in the marine environment generally met water quality objectives and guidelines. On occasion metals such as nickel, copper, chromium (VI), cadmium, and zinc exceeded objectives or guidelines. Boron consistently exceeded the guidelines; however, this parameter is naturally occurring, and the concentrations observed are typical of Canadian coastal waters. As a source to the bay, boron originating from the tributaries is insignificant. Also, occasionally, water quality objectives for minimum concentrations of dissolved oxygen were not met.



Boundary Bay Ambient Monitoring Program – Marine Water Column Sampling Sites

Temporal trends observed for the Boundary Bay sites include: higher pH values during the dry season, and higher salinity, turbidity, conductivity, total dissolved solids, nitrites and nitrates during the wet season.

The assessment of water quality using the WQI showed that the latest rating for Boundary Bay (2014) is "fair" (i.e., between 65-79) while the latest three- year cumulative ranking for the bay (2012 to 2014) is "marginal" (i.e., between 45-64).

Full reports are available in Tri-Star Environmental (2013, 2014)

Time trends of three major classes of toxic contaminants in two indicator fish species from Puget Sound

James E. West[1], Gina M. Ylitalo[2], Jennifer A. Lanksbury[1], Laurie A. Niewolny[1], Andrea J. Carey[1], Mariko Langness[1], Robert Fisk[1], and Sandra M. O'Neill[1]

1. Washington Department of Fish and Wildlife; 2. NOAA, Northwest Marine Fisheries Science Center

- PCBs have declined significantly in herring from the low-development basin; they are still elevated in the more-developed central and south Puget Sound basins.
- PCBs have increased or decreased in English sole from 10 index sites.
- PBDEs primarily declined or remained static in herring and English sole in Puget Sound.

Two classes of persistent environmental contaminants, polychlorinated biphenyls (PCBs) and polybrominated diphenylethers (PBDEs) have been monitored in two indicator fish species, English sole (*Parophrys vetulus*) and Pacific herring (*Clupea pallasii*) since 1994 in Puget Sound. English sole, a common and abundant flatfish that reflects sediment contaminant conditions, are currently sampled biennially at ten index sites, ranging from highly developed habitats such as the Seattle waterfront and Tacoma's City Waterway, to less developed habitats in Hood Canal and northern Puget Sound (Southern Strait of Georgia). Pacific herring are a small-bodied, open-water planktivore that reflect contaminant conditions in the pelagic food web. Herring results are summarized for four distinct stocks in southern (Squaxin), central (Port Orchard/Madison), and northern (Semiahmoo and Cherry Point) Puget Sound.

The rate of change of PCBs and PBDEs was modeled by regressing the contaminant concentration of tissue composite samples against time (year), with up to three biological covariates (fish size, tissue lipid concentration, and sex ratio). Rate of change was a significant factor in 18 of the 28 regression models (p>0.05, Table); time explained moderate amounts of contaminant variability (partial r^2 from 0.11 to 0.41) in 13 regressions, and time was a low or trivial factor in five regressions (partial r^2 <0.10; Table). Ten regressions were not significant (p>0.05), indicating no change in contaminants over the monitored time period. Semiahmoo and Cherry Point herring exhibited moderate declines in PCBs (-4.0% and -2.3%), whereas herring from the other two stocks exhibited no change (Squaxin), or a weak decline (Port Orchard, -1.1%). The PCB decline in herring from Port Orchard, however, is indistinguishable from the normal, low variability observed in the analytical method, and so should be interpreted with caution. PCBs increased in English sole from two highly developed sites (Seattle Waterfront, 3.6%; Tacoma City Waterway, 6.2%), two moderately developed sites (Eagle Harbor, 2.9%; Everett, 7.1%), and two low-development sites (Anderson Island, 3.6% ; Hood Canal, 2.8%). PCBs remained static in English sole from the Strait of Georgia and Vendovi Island. PBDEs declined moderately to strongly in all four herring stocks, with rates ranging from -4.3% to -8.1%. PBDEs declined moderately in English sole from Seattle Waterfront (-3.7%), Bremerton (-4.0%), Vendovi Island (-7.2%), and Hood Canal (-3.2%). Five other sites showed no change in PBDEs, and PBDEs increased in English sole from one site, Everett (+5.9%).

These results indicate that although PCBs have declined in herring from the low-development basin, they are still problematic in the more developed central and south Puget Sound, and in English sole from several sites throughout the sound. PCBs appear to persist, especially in the urbanized pelagic food web, despite prohibitions against their production and use. PBDEs declined or remained static widely in both species (except for English sole from one site), suggesting that source controls and mitigation efforts for PBDEs have been somewhat successful.

			PCBs[b]			PBDEs[c]		
	Basin[a]	Land Development	n	Year Range	Rate (%)	n	Year Range	Rate (%)
Pacific Herring								
Cherry Point	NPS	low	40	94-14	**-2.3**	36	94-14	***-4.3***
Semiahmoo	NPS	low	85	99-14	***-4.0***	47	01-14	***-8.1***
Port Orchard	CPS	high	116	99-14	-1.1	78	01-14	***-7.0***
Squaxin	SPS	medium	115	99-14	NC	73	01-14	**-4.5**
English Sole								
Str. Georgia	NPS	low	55	97-15	NC	33	05-15	NC
Vendovi Is.	NPS	low	55	97-15	NC	36	05-15	**-7.2**
Everett	WB	medium	55	97-15	***7.1***	34	05-15	5.9
Hood Canal	HC	low	57	97-15	2.8	41	98-15	-3.2
Eagle Harbor	CPS	medium	31	98-15	**2.9**	19	05-15	NC
Duwamish River	CPS	high	26	07-15	NC	26	07-15	NC
Seattle Waterfront	CPS	high	56	97-15	**3.6**	35	05-15	**-3.7**
Bremerton	CPS	high	52	97-15	NC	37	98-15	**-4.0**
Tacoma City Wway	CPS	high	56	97-15	**6.2**	31	05-15	NC
Anderson Is.	SPS	low	57	97-15	3.6	36	05-15	NC

[a] oceanographic basins as follows: NPS (north Puget Sound), CPS (Central Puget Sound), SPS (south Puget Sound), HC (Hood Canal), and WB (Whidbey Basin)

[b] estimate of total PCBs based on an algorithm using 17 selected congeners; Lauenstein, G. G. and A. Y. Cantillo, Eds. (1993). Sampling and analytical methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects. 1984-1992. Silver Spring, MD, National Oceanic and Atmospheric Administration Technical Memorandum NOS ORCA 71.

[c] sum of detected values of 11 selected PBDE congeners

Rate of change of two contaminant groups in benthic English sole and pelagic Pacific herring over various time periods from 1994 to 2015, and across a wide range of land development levels. Bolded rates indicate moderately significant changes (partial $r^2 \geq 0.10$, <0.42); unbolded rates are statistically significant but weak (partial r2<0.10). NC indicates no significant change.

For more information: James E. West, james.west@dfw.wa.gov

Persistent pollutants in Puget Sound juvenile Chinook salmon: Changes after 25 years

Lyndal Johnson[1], Daniel Lomax[1], Sean Sol[1], Gina Ylitalo[1], James West[2], Sandra O'Neill[2]

1. NOAA, Northwest Fisheries Science Center; 2. Washington Department of Fish and Wildlife

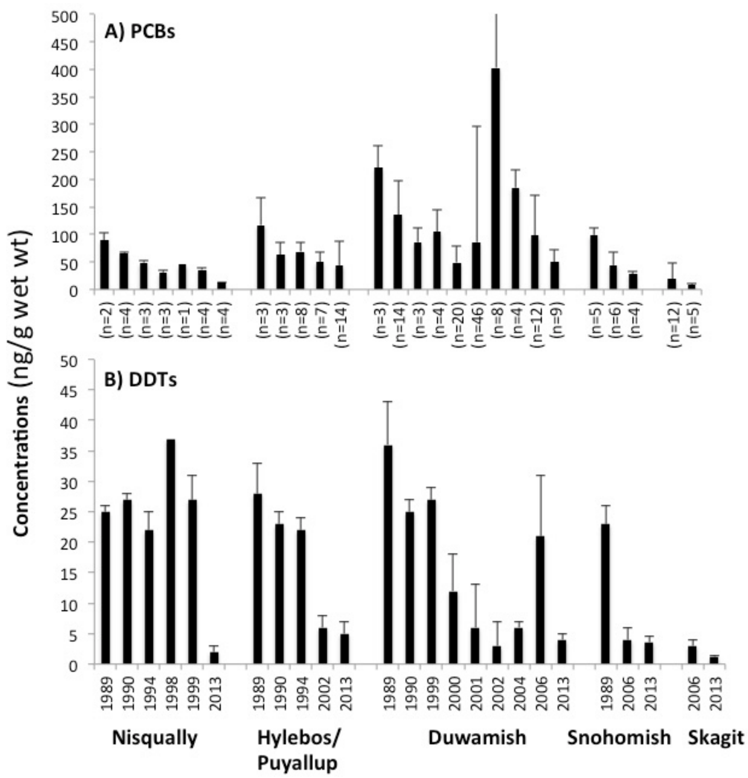
- Over the past 25 years, concentrations of PCBs, DDTs, and PAHs have declined in juvenile Chinook salmon from several urban embayments in Puget Sound.

Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) have been listed as a threatened species under the Endangered Species Act since 1999. Factors contributing to their decline include overharvest, hatchery impacts, and loss and modification of salmon habitats, including reduced habitat quality due to contaminant inputs. Since the late 1980s, NOAA Fisheries has been measuring concentrations of persistent organic pollutants (POPs) in juvenile salmon from Puget Sound, WA. Initial studies in 1986 and 1989 revealed unexpectedly high concentrations of polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethanes (DDTs), and polycyclic aromatic hydrocarbons (PAHs) in juvenile Chinook salmon or their prey from urban areas in the Sound (McCain et al. 1990; Stein et al. 1995). Over the following 25 years, there have been numerous efforts to reduce contamination in Puget Sound, including remediation and restoration of superfund sites in Elliott Bay (Seattle, WA) and Commencement Bay (Tacoma WA), with associated assessment of contaminant exposure in juvenile salmon and other trust resources.

In 2013, the Washington Department of Fish and Wildlife and NOAA Fisheries conducted a joint study to measure concentrations of contaminants, including POPs, in juvenile salmon from five Puget Sound river-estuary systems: Skagit, Snohomish, Green/Duwamish, Puyallup/Hylebos, and Nisqually (O'Neill et al. 2015). We compared these current data to concentrations measured in salmon from the same locations in previous studies conducted from the late 1980s to 2006 (McCain et al. 1990; Stein et al. 1995; Stehr et al. 2000; Olson et al. 2008; Meador et al. 2010).

Results indicate declines in exposure to DDTs and PCBs (shown in the Figure), as well as PAHs, in juvenile Chinook salmon from several estuary systems. Concentrations of DDTs declined in both urban and non-urban esturaries, while PCBs showed the greatest declines in urban systems. Contaminant concentrations in the Duwamish system, while generally declining, showed increases in the mid-2000s, probably because of dredging activities occuring in the Duwamish Waterway as part of sediment cleanup at that time (EcoChem 2005).

Our findings suggest that efforts to reduce inputs of persistent pollutants to the Sound have had some success. A variety of factors, including source control and sediment cleanup, regulatory actions, and improved hatchery practices have likely contributed to declines in persistent pollutants in juvenile Chinook salmon. However, in a significant proportion of salmon, exposure to PCBs and PAHs is still above estimated toxicity thresholds, and other contaminants, including current use pesticides, polybrominated fire retardants, and pharmaceuticals and personal care products, may pose risks.



The mean concentrations (+SD) of PCBs (A) and DDTs (B) measured in juvenile Chinook salmon whole bodies. Sample sizes (number of composite samples) are in parentheses located beneath the bars of Figure A.

These data establish a time series of contaminant conditions in juvenile Chinook salmon in order to measure the effectiveness of past and current toxics reductions strategies and actions, inform future pollution reduction efforts, and enhance the recovery of Chinook salmon.

2002 to 2014: An evolution in Lake Washington tissue PCB monitoring

King County
Department of
Natural Resources and Parks
Water and Land Resources Division

Richard Jack[1], Jenée Colton[1], Deb Lester[1], Carly Greyell[1]

1. King County Department of Natural Resources and Parks

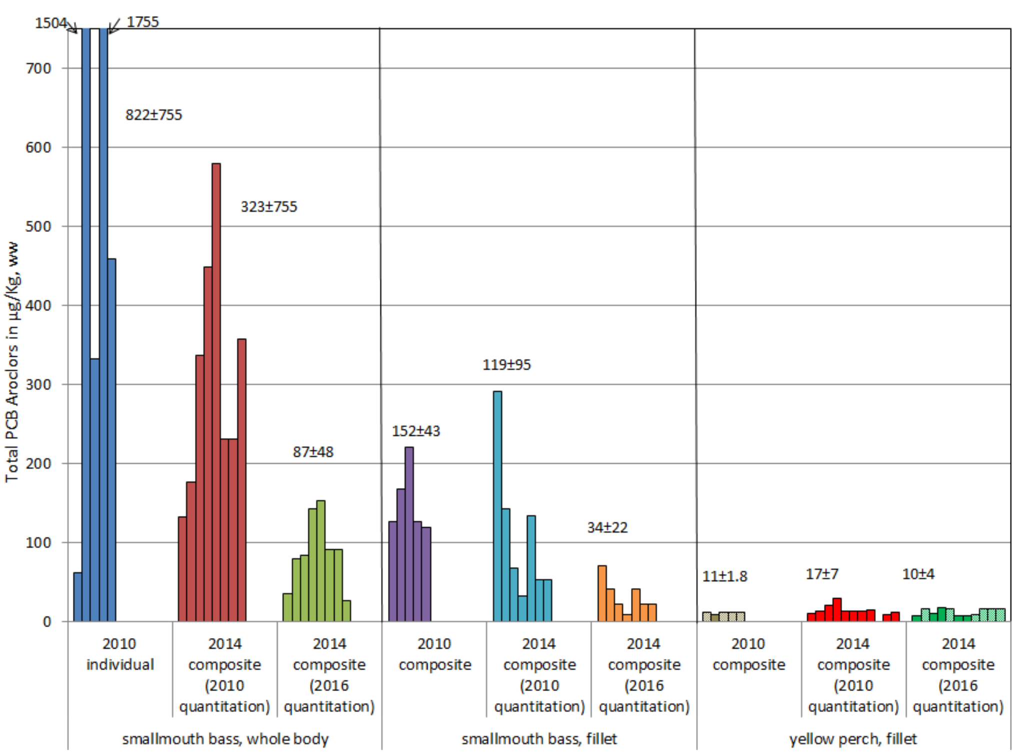
- Comparison of two quantitative methods for PCB analysis revealed lower reported concentrations utilizing newer methods for the same sample.

King County's fish tissue monitoring efforts in Lake Washington began as a one-time project in 2002. Monitoring was re-initiated in 2010 and 2014. Between 2002 and 2014, the monitoring goals, species and sizes sampled, field methods, and analytical instruments and methods have changed. These changes combined have made polychlorinated biphenyl (PCB) and other contaminant trend analysis challenging.

Many changes in PCB analytical methods occurred, including changing from sonication to Soxhlet extraction. Extraction solvents also changed from methylene chloride and hexane to hexane and acetone. Changes to sample cleanup procedures influenced results over time as well; the addition of silica gel cleanup procedures produced cleaner chromatograms which enhanced the resolution of key PCB peaks. In particular, three peaks more representative of Aroclor 1254 are now resolved. These improvements have most strongly influenced reported Aroclor 1254 concentrations, especially for tissues with relatively high levels of total PCBs (> 1,000 ppb, ww).

Total Aroclor results from 2010 to 2014 initially showed a marked decrease. To help understand the change, the 2014 samples were re-quantified using both the 2010 and 2016 quantitation methods. The figure illustrates that the 2010 quantitation method consistently reported higher concentrations than the 2016. Also illustrated are apparent downward PCB trends in Lake Washington's smallmouth bass and yellow perch. The magnitude of these trends are highly dependent on the analytical changes, including quantitation changes, that have occurred since 2002.

Inconsistent sample collection in the early years of King County's fish tissue monitoring program combined with evolving analytical methods limit the usefulness of present data to track and quantify PCB trends; it is especially challenging to retrospectively address the impacts of analytical changes. Despite these constraints, recent PCB concentrations in Lake Washington appear to be: 1) lower than 2002 historical highs, and 2) potentially slowly declining. King County's current [2016] analytical methods for PCBs are much more refined than those employed in 2002. These improved methods are now combined with new funding commitments to track tissue contaminants in Lake Washington. Additionally, valuable knowledge has been gained to guide projects intending to show trends over time. Thus, over the coming decade, King County will continue to refine our understanding of PCB trends in Lake Washington fish tissues.



Washington fish tissue concentrations by species over time. Mean and standard deviations shown. Each bar represents one composite. Samples were extracted, then reported using both the 2010 quantitation and the 2016 quantitation methods. While there appear to be downward trends in PCB concentrations in Lake Washington's smallmouth bass and yellow perch from 2010 to 2014, the magnitude of the trend is highly dependent on the analytical changes, including the quantitation changes, which have occurred since 2002.

Changes in Puget Sound sediment quality measured over a quarter century

DEPARTMENT OF ECOLOGY State of Washington

Sandra Weakland[1], Valerie Partridge[1], Margaret Dutch[1], Carol Maloy[1]

1. Washington State Department of Ecology

- While sediment chemistry generally meets or exceeds the PSP target, and areas with the highest contamination are improving, benthic community health is declining.
- New methods of investigation are being explored to help understand these trends.

The Washington State Department of Ecology (Ecology) has monitored sediments since 1989 as part of the Puget Sound Ecosystem Monitoring Program (PSEMP). Ecology recently completed a study of sediment quality changes over time, based on long-term stations sampled annually and regional stations sampled less often (Weakland et al., 2017; Partridge et al., 2017). The ten long-term stations represent different sediment habitat types in Puget Sound with distinct biological communities. The regional stations are randomly chosen and distributed over multiple scales including eight regions, six urban bays, and five cross-region strata defined by waterbody type and human use.

Sediment quality was determined by evaluating measures of chemical contamination, laboratory tests of sediment toxicity, and measures of benthic (sediment-dwelling) invertebrate community health. The regional programs weight sample results by area to arrive at weighted mean values. Results are presented for:

- Chemical contaminants and the Chemistry Index – The mean ratio of 39 chemical concentrations to established Washington State Sediment Cleanup Objectives (SCO), scaled from 0 to 100, or worst to best condition. The Chemistry Index is used as a Vital Sign by the Puget Sound Partnership (PSP), with a target value of 93.3, indicative of minimally contaminated sediments.
- Toxicity Index (regions and urban bays only) – Combined results of two laboratory bioassays, amphipod survival in solid phase sediments and sea urchin fertilization in sediment porewater, with values ranging from *non-toxic* to *high toxicity.*
- Benthic invertebrate community measures of abundance and diversity.

Chemistry

In general, the majority of Puget Sound did not have elevated levels of chemical contaminants. The highest concentrations were found near population and/or industrial centers including Bellingham, Everett, Seattle, Tacoma, and Bremerton. Metals were detected in almost all samples.

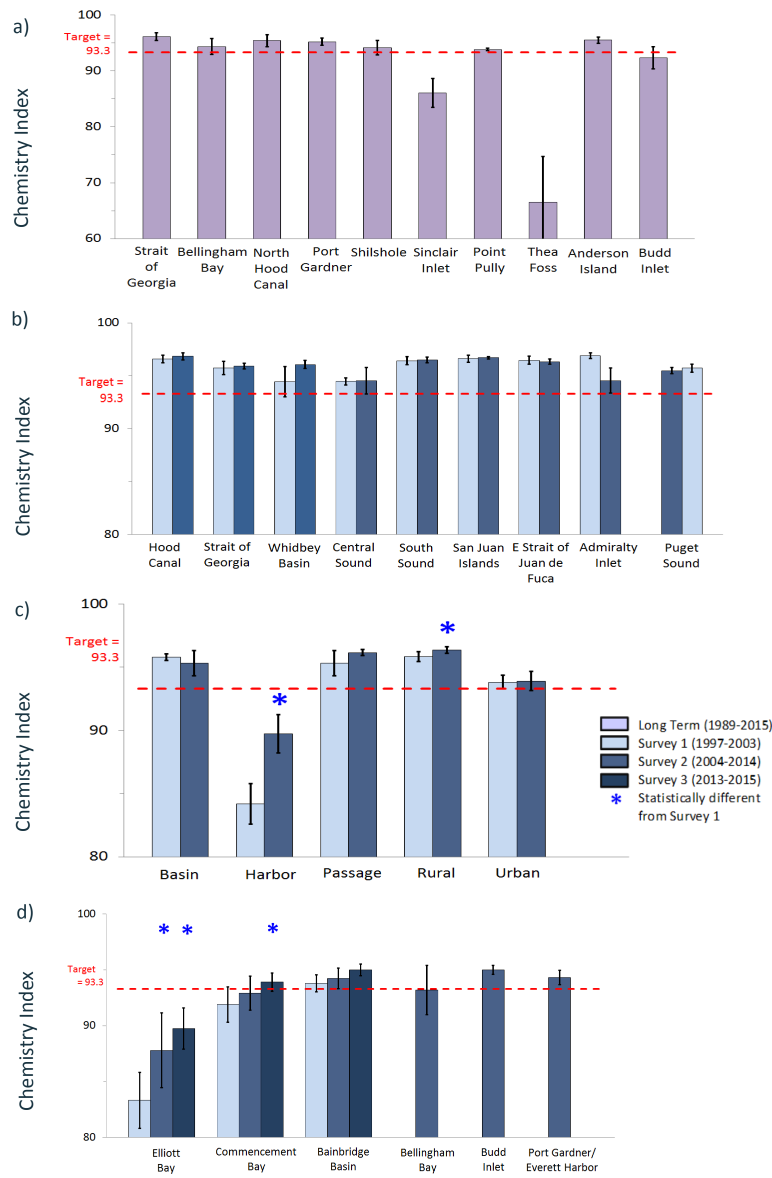


Figure 1. Weighted mean *Chemistry Index* values (0-100) calculated for a) long-term stations, averaged over all years; b) eight geographic regions and all Puget Sound; c) five strata; and d) six urban bays.

Survey 1 is indicated by the lightest color bar; subsequent surveys are successively darker bars. Dashed line indicates target value. Error bars = 95% confidence intervals.

Polycyclic aromatic hydrocarbon (PAH) detection climbed over time to nearly 100%. Other organic compounds were rarely detected, even as analytical detection limits improved.

The Chemistry Index scores were relatively good at most long-term stations (Figure 1a) and did not change over time. The exceptions were the more urban Thea Foss and Sinclair Inlet stations, which had much lower index scores. The Thea Foss station had multiple years of poor scores with no consistent trend (Partridge et al., 2017).

Taking a broader view, the Chemistry Index scores surpassed the target value of 93.3 in all eight regions and for the entire Sound (Figure 1b), indicating that sediments had minimal exposure to chemical contaminants. All strata also met the target except the Harbor stratum (industrialized nearshore areas), though the Harbor stratum improved significantly between the two decadal sampling periods (Figure 1c). Four of the six urban bays met the target in the most recent surveys. Elliott Bay had the lowest scores, though showed continual improvement (Figure 1d).

Toxicity

The spatial distribution of all regional and the most recent urban bay results for the Toxicity Index indicate that 88% of the Puget Sound sampling area had *non-toxic* sediments. Greater levels of toxic response, indicated by *moderate* or *high* toxicity categories (3% and 1% of the area, respectively) were measured primarily in sediments from terminal inlets and/or areas known to have poor water circulation, in both non-urban and urban areas. *Low* toxicity (8% of the area) was found between higher levels of toxicity and *non-toxic* sediments and elsewhere, including areas suspected of low dissolved oxygen and/or high sulfides (Figure 2, full map).

Sediment toxicity in urban bays was less than anticipated, particularly near the industrialized centers of Port Gardner, Elliott Bay, and Commencement Bay (Figure 2, insets). Toxicity index values remained statistically unchanged over the last decade in Elliott and Commencement Bays.

Benthos

Benthic invertebrates were identified and counted for all samples. Multiple community measures were calculated, including total abundance (number of organisms), taxa richness (number of species), and abundance of each of five major taxonomic groups. Annelids (worms) made the largest contribution to total abundance in most stations and sampling frames, followed by molluscs (clams and snails), arthropods (crabs and shrimp), echinoderms (sea stars and sea urchins), and miscellaneous taxa (Figure 4).

Taxa richness and total abundance are generally higher in northern Puget Sound and lower in South Sound and southern

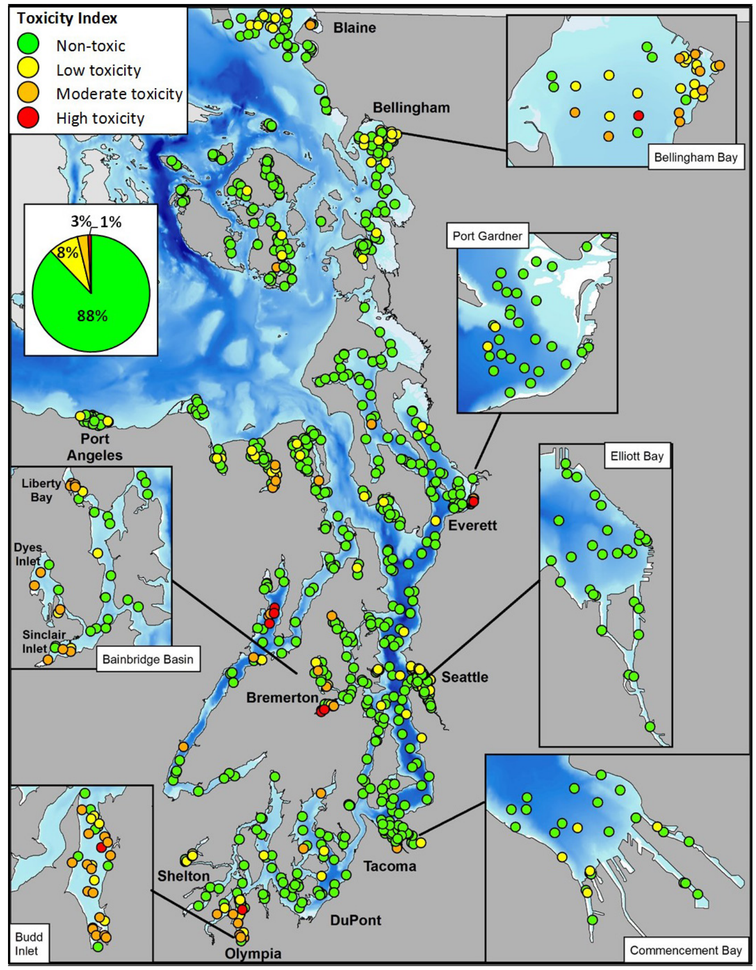


Figure 2. Spatial patterns for the Toxicity Index categories for Puget Sound sediments. Base map = Regional Program (1997-2014), inset maps = Urban Bays (2010-2015). Pie chart displays percent of area representing Toxicity Index categories for the Regional Program.

Hood Canal (Figures 4a, 4b). Among the strata, deep Basins had the lowest abundances, and Harbor and Urban the highest, due to the presence of large numbers of stress-tolerant polychaete worms (Figure 4c). Among the urban bays, abundances were highest in Commencement Bay and lowest in Budd Inlet and Port Gardner (Figure 4d).

Significant declines in abundance and richness were seen in the Strait of Georgia and Admiralty Inlet regions (Figure 4b) and in Elliott Bay, Commencement Bay, and Bainbridge Basin (Figure 4d). These declines were also reflected in the Urban, Harbor, Passage, and Rural strata (Figure 4c). At the long-term stations, which are distinguished by habitat characteristics (Figure 3) and have distinct benthic communities, some declines were also seen. Abundance and richness declined over the years at the Sinclair Inlet and Anderson Island stations, and since 2000 at the North Hood Canal station (Partridge et al., 2017).

Program Synthesis, Reflection, and Revisions

The PSEMP Sediment monitoring program was originally designed to monitor the effects of point-source discharges. Twenty-eight years later the program faces an interesting paradox: While chemical concentrations observed are generally not expected to harm benthos, and areas with harmful contaminant levels such as urban bays and harbor strata have largely improved, sediment toxicity has increased in non-urban areas and the condition of the benthic invertebrate communities has worsened throughout Puget Sound.

Because no significant correlation was found between the chemistry, toxicity, and benthos, it is hypothesized that additional factors are at play. The quality and quantity of nutrients and carbon, sedimentation flux, nutrient cycling and sediment diagenesis, and levels of dissolved oxygen and pH all influence sediment quality and the community structure. Shifting from the point-source discharge focus, to a more comprehensive understanding of the biogeochemical attributes of the benthic ecosystem, particularly in light of climate change and ocean acidification, is needed.

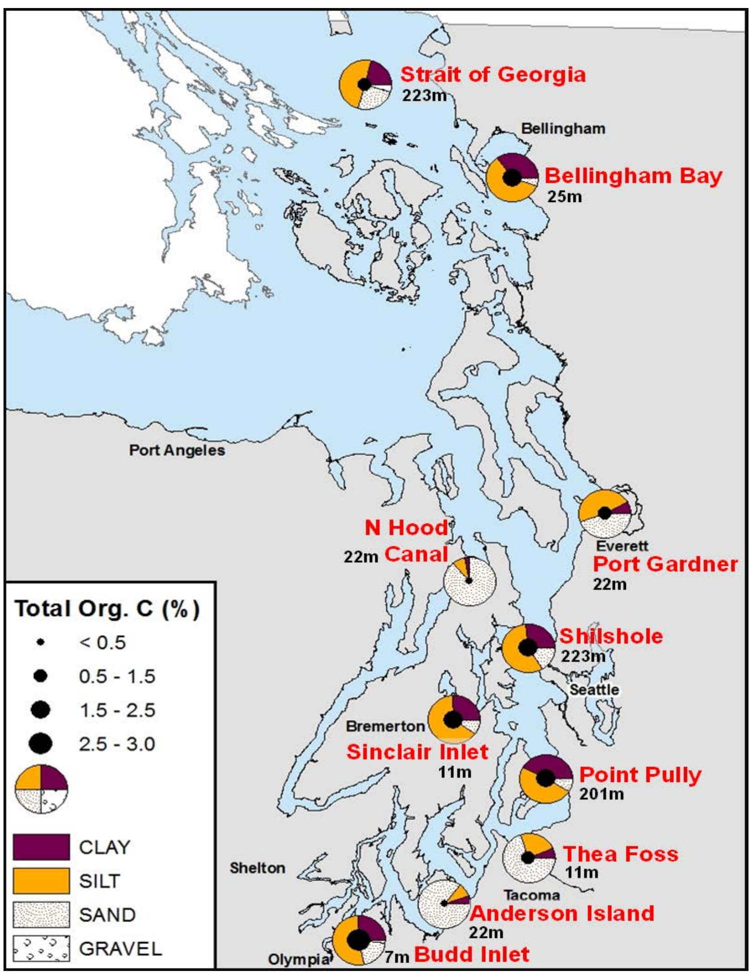


Figure 3. Ten long-term sediment monitoring stations which have been sampled every year since 1989. The map displays station depth, mean sediment grain size (pie chart), and mean organic carbon content (size of black dot), distinguishing habitat characteristics of each site.

The PSEMP Sediment monitoring program is currently undergoing revision. Ecology will continue the program into the future by annual sampling of an expanded set of long-term stations, designed to estimate the spatial extent of sediment quality over time, as well as keeping a focus on urban bays (Dutch et al., in prep.). Those interested are encouraged to contact the study authors.

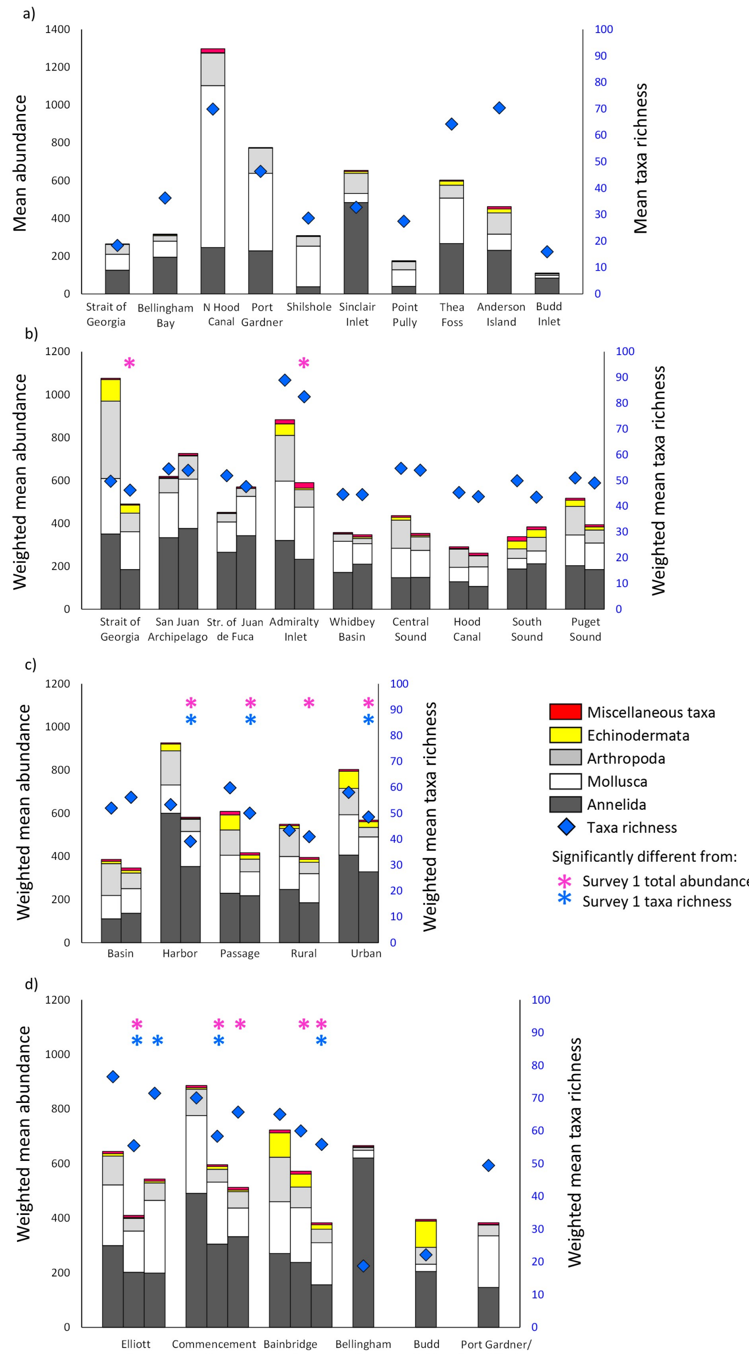


Figure 4. Weighted mean total abundance and taxa richness for a) long-term stations, averaged over all years; b) eight regions and Puget Sound; c) five strata; and d) six urban bays. Survey 1 = first bar; subsequent surveys are successive bars. Statistically significant changes from Survey 1 to subsequent samplings are marked.

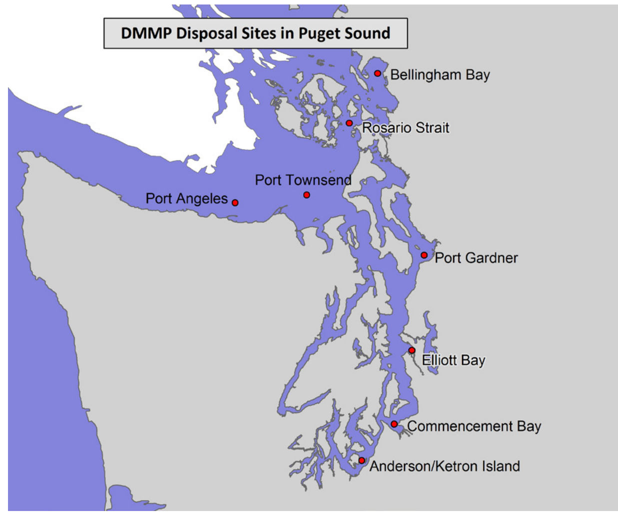
Dredged Material Management Program (DMMP) long-term monitoring of dredged material disposal sites in Puget Sound

Heather Fourie [1], Erika Hoffman[2], Celia Barton[3], Laura Inouye[4]

1. U.S. Army Corps of Engineers, Dredged Material Management Office (DMMO) 2. US. EPA Region 10, 3. WA Department of Natural Resources, 4. WA Department of Ecology

- The DMMP has extensive physical, chemical, and biological data from over 30 monitoring events between 1988 to present at eight open-water disposal sites around Puget Sound.

The Dredged Material Management Program (DMMP) manages eight open-water sites within Puget Sound for the disposal of approved dredged material (map). The sites range in depth from 96 to 560 feet and range from as far south as Olympia (Anderson/Ketron) northward to Bellingham (Bellingham Bay site). Over 17 million cubic yards of material have been disposed at the Puget Sound sites since 1989. To ensure site management objectives are being met, the DMMP has regularly conducted a range of monitoring activities at the disposal sites, including physical, chemical, and biological analyses. Physical studies include multibeam bathymetric surveys, sediment profile imaging, side-scan sonar surveys, and remotely-operated vehicle inspections. Sediment chemistry testing includes collection of surface grab samples from on-site, perimeter and benchmark stations and analysis of the DMMP chemicals of concern (COCs) and sediment conventional parameters (grain size, % total organic carbon). Samples are collected using a van Veen grab sampler. The COCs include polycyclic aromatic hydrocarbons (PAHs) and other semivolatile organics; metals; pesticides; polychlorinated biphenyls (Aroclor PCBs); tributyltin (TBT); and dioxins. The COC list is subject to revisions and updates made through the DMMP annual review process, and monitoring sometimes includes special interest chemicals (e.g., emerging chemicals of bioaccumulative concern). Biological analyses include acute-exposure laboratory bioassays (amphipod mortality, bivalve larval development, and polychaete growth), benthic tissue chemistry analysis, benthic community analysis, and benthic trawl surveys. A full list of studies can be found in the table. Based on site monitoring conducted to date, dredged material disposal has not caused adverse impacts at or adjacent to any of the non-dispersive sites, and the program site management objectives continue to be met to adequately protect and preserve the disposal sites for continued use. Monitoring at several of the sites located in highly urban embayments (Elliott Bay and Commencement Bay) have demonstrated that disposal of sediment over the long term has improved the sediment quality on the disposal site itself relative to the surrounding area. A more complete description of the studies from any given year can be found in the Biennial Reports at the website address listed below. Full datasets are managed by the Dredged Materials Management Office (DMMO) of the U.S. Army Corps of Engineers. Data are entered into the Washington Department of Ecology's Environmental Information Management system and are also available upon request from DMMOteam@usace.army.mil.



Puget Sound Disposal Site Monitoring History

Year	Disposal Site	Type of Survey
1988	Port Gardner, Elliott Bay, Commencement Bay	Initial Baseline Surveys: Full
1989	Bellingham Bay, Anderson/Ketron Island	Initial Baseline surveys: Full
1990	Bellingham Bay	Dungeness Crab Density Study
1990	Port Gardner	Full
1990	Elliott Bay	Partial
1991	Rosario Strait	Bathymetric Survey
1991	Port Gardner, Bellingham Bay	Special Study: new PG benchmark station Special Study: tissue chemistry protocol PG/BB
1992	Elliott Bay	Full
1993	Bellingham Bay	Partial, Side-Scan Sonar Survey
1994	Port Gardner	Tiered-Full
1994	Rosario Strait	Bathymetric Survey
1995	Elliott Bay	Side-Scan Sonar Survey (debris evaluation)
1995	Commencement Bay	Tiered-Full (new baseline)
1996	Commencement Bay	Tiered-Partial
1998	Commencement Bay	SPI Survey
1999	Rosario Strait	Bathymetric Survey
2000	Elliott Bay	Full, special PCB Congener Study, 45-day bioaccumulation
2001	Commencement Bay	Full + Bathymetric Survey
2002	Elliott Bay	Tiered-Full, BCOC special study
2003	Commencement Bay	Tiered-Full
2004	Commencement Bay	Tiered-Partial + Bathymetric Survey
2005	Commencement Bay	SPI Survey + Special Phenol Study
2005	Anderson/Ketron Island	Full (new baseline)
2005	Elliott Bay	Special Onsite Chemistry Study
2006	Port Gardner	Full, Dioxin Baseline
2006	Commencement Bay	Mulitbeam bathymetric survey (MBS)
2007	Commencement Bay, Bellingham Bay, Elliott Bay,	Full + MBS @ CB site, dioxin baseline at all 3 sites
2008	Anderson/Ketron Island	Dioxin/furan post-disposal special survey (offsite disposal evaluation): OSV Bold Survey
2009	Rosario Strait	Multibeam Bathymetric Survey
2010	Port Gardner	Tiered-Full
2010	Puget Sound Dispersive Sites	Fate & Transport Study
2013	Commencement Bay	SPI Survey + Multibeam Bathymetric Survey
2013	Elliott Bay	Partial + Multibeam Bathymetric Survey
2014	Anderson/Ketron Island	Fate & Transport Study
2014	Anderson/Ketron Island	Multibeam Bathymetric Survey
2014	Elliott Bay	ROV Inspection
2014/15	Anderson/Ketron Island	Benthic Trawl Survey

SPI = Sediment Profile Imagery Survey
BCOC = bioaccumulative chemicals of concern
Partial = Answers 1st 2 Monitoring Questions (hypotheses 1-4)
Full = Answers all 3 Monitoring Questions (hypotheses 1-6)

PG = Port Gardner
BB = Bellingham Bay
S = Sediment
T = Tissue

For more information: Heather Fourie, Heather.W.Fourie@usace.army.mil http://www.nws.usace.army.mil/Missions/Civil-Works/Dredging/Disposal/

SECTION 2:
WHY IS IT HAPPENING?
(PROCESSES AFFECTING STATUS AND TRENDS)

Biomagnification, oceanographic processes, and the distribution of toxic contaminants in Puget Sound's pelagic food web

James E. West[1], Christopher Krembs[2], Jennifer A. Lanksbury[1], Gina M. Ylitalo[3], Sandra M. O'Neill[1]

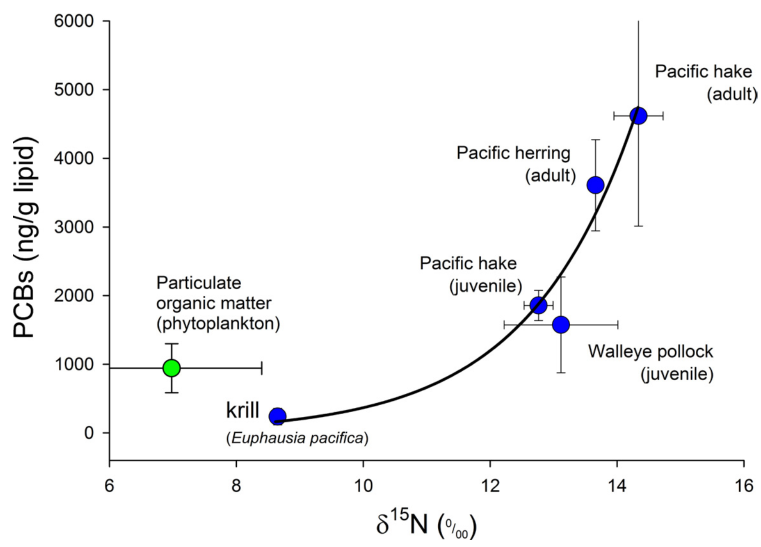
1. Washington Department of Fish and Wildlife; 2. Washington Department of Ecology; 3. NOAA, Northwest Marine Fisheries Science Center

Puget Sound's pelagic food web is characterized by high concentrations of polychlorinated biphenyls (PCBs) in its apex predators, including killer whales (*Orcinus orca*; Ross et al. 2000) and harbor seals (*Phoca vitulina*; Ross et al. 2004), and in the pelagic fish and invertebrate prey that make up the base of this food web (West et al. 2008, O'Neill and West 2009, West et al. 2011a, 2011b). In a 2010 central Puget Sound study, PCBs increased exponentially with trophic level, from primary producers (phytoplankton, represented as particulate organic matter) through primary consumers (krill, *Euphausia pacifica*), secondary consumers (juvenile forms of predatory pelagic fish), and tertiary consumers (adult Pacific hake, *Merluccius productus).* PCB concentration in this range of species varied from approximately 300 to over 5000 ng/g lipid weight (Figure, data from West et al. 2011a, 2011b). High PCB levels in particulate organic matter suggest PCBs concentrate at the base of the pelagic food web as these contaminants enter surface waters. This notion of a direct pelagic food web pathway challenges the paradigm that particulate PCBs sink quickly, accumulate primarily in sediments, and enter pelagic biota primarily via a benthic-to-pelagic food web linkage (or via resuspension).

Puget Sound exhibits five characteristics that may increase the availability of PCBs for uptake by pelagic biota:

- strong stratification related to high freshwater inputs may slow the sinking rate of PCB-laden particles, resulting in their aggregation at the density gradient, where particulates may stimulate grazing by microplankton,
- abundant pelagic micro-grazers promote remineralization and recycling of organic material in surface waters, which competes with the benthic-pelagic coupling,
- deep, fjord-like basins support vertically migrating macrozooplankton such as krill, which intercept and feed on sinking particles; krill break up particles during feeding and reduce their sinking rate, promoting retention of particle-bound PCBs in mid- and surface waters,
- a relatively long pelagic food chain, including vertically migrating zooplankton, increases the probability of pelagic biomagnification, and
- a complex microbial community, characterized notably by abundant and potentially increasing populations of positively buoyant heterotrophs like Noctiluca scintillans, may increase recycling of biota-bound PCBs in surface waters.

Elliott Bay is a particularly suitable area to test these concepts because it is deep enough to support resident populations of vertically migrating macrozooplankton, it regularly exhibits strong density-stratification, and it receives some of the greatest inputs of PCBs of any location in Puget Sound. A comparison of Elliott Bay biota with those from a shallower, less stratified, yet similarly PCB-contaminated embayment such as Sinclair Inlet could provide valuable information regarding best actions to reduce PCBs in Puget Sound's pelagic food web.



Biomagnification model of PCBs in the pelagic food web of the Puget Sound's central basin. Mean PCB concentration (ng/g lipid, 95% confidence intervals) in six pelagic species or groups representing a wide range of trophic levels. Trophic levels represented by the abundance of the rare but stable isotope of nitrogen, ^{15}N, expressed as a ratio to its more abundant ^{14}N isotope, measured in whole bodies of the organisms. Particulate organic matter, representing primary producers, were size-selected plankton samples targeting phytoplankton blooms, and were dominated by centric and pennate diatoms and dinoflagellates. Consumer groups were Pacific krill (*Euphasia pacifica*), Pacific herring (*Clupea pallasii*), Pacific hake (*Merluccius productus*), and walleye pollock (*Theragra chalcogramma*).

Puget Sound Regional Toxics Model: Evaluation of PCBs, PBDES, PAHs, copper, lead, and zinc

Greg Pelletier[1], David J. Osterberg[1], Dale Norton[1]

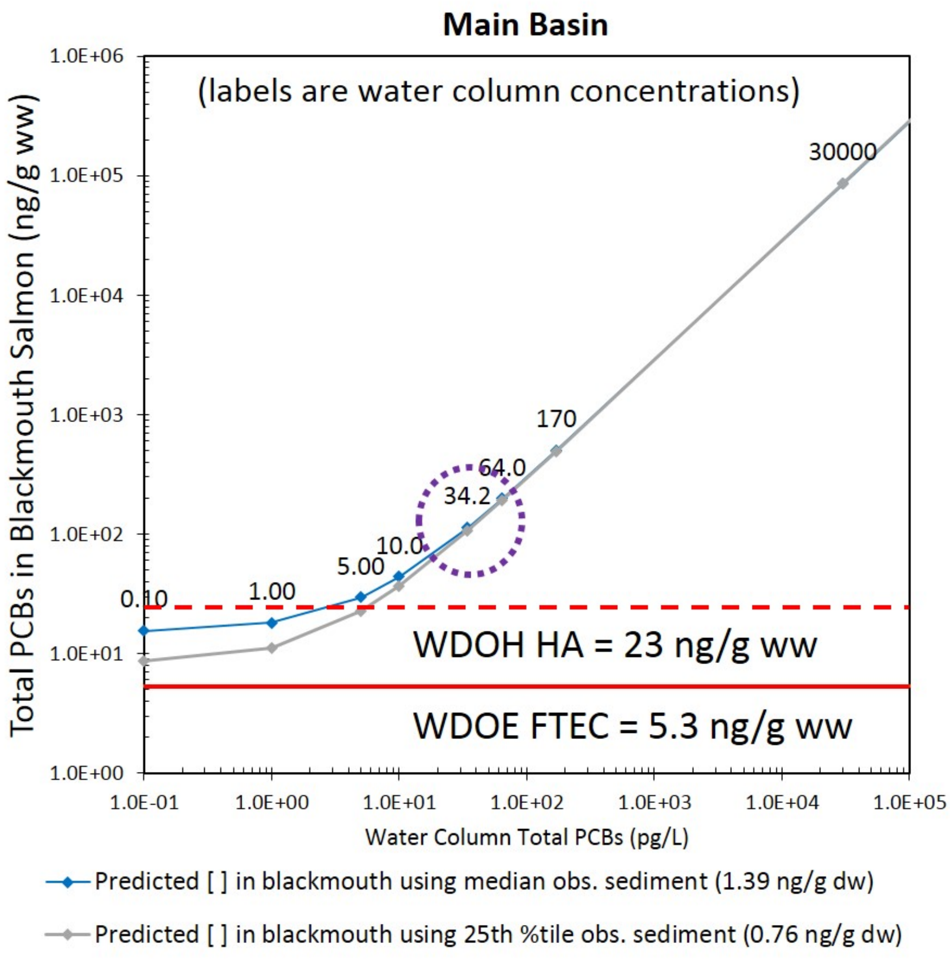
1. Washington Department of Ecology

- Biota concentrations are more sensitive to contaminants in water than in sediments in most regions (except for urban bays).
- Urban bay PCBs exceed adverse effects thresholds. Up to 50% to 80% reduction is needed in water and sediment PCBs.

The Puget Sound Regional Toxics Model is a model of contaminant fate, transport, and bioaccumulation in Puget Sound. In this study, Ecology (1) incorporated recent data and loading estimates and (2) expanded the model to simulate PCBs, PBDEs, PAHs, copper, lead, and zinc (Osterberg and Pelletier, 2015).

Fate and transport modeling results suggested that current estimates of contaminant loading from the watershed, the ocean, or both, may be too low. Such uncertainties limited the utility of the model for evaluating contaminant source-control strategies.

The updated bioaccumulation model had good skill for predicting PCB and PBDE concentrations in Puget Sound biota. The model identified areas where organisms would be expected to bioaccumulate contaminants to harmful levels, and then estimated how low sediment and water concentrations would need to be at these locations to ensure that contaminants in biota do not exceed harmful-effects thresholds.



The purple dashed circle is the current water concentration and current concentration of PCBs in resident chinook. As hypothetical concentrations in water are reduced, the fish concentration decreases but reaches a plateau that is supported by the concentration in the sediment. The blue line is for the median of current sediment data for the main basin. The gray line is the 25th percentile of current sediment data for the main basin. The solid red line represents the Fish Tissue Equivalent Concentration used by the Department of Ecology to list impaired water bodies. The dashed line indicates the Health Action level, above which a species and location specific fish consumption advisory is issued by the Washington Department of Health. In other words, the concentration of PCBs in water would need to be decreased far below the current concentration of 34.2 pg/L, and the sediment concentration would also need to be reduced below the 25th percentile of current levels before the PCBs in the fish would be below the FTEC.

Sewage in the Strait of Georgia: How big is the problem and what can we achieve with treatment?

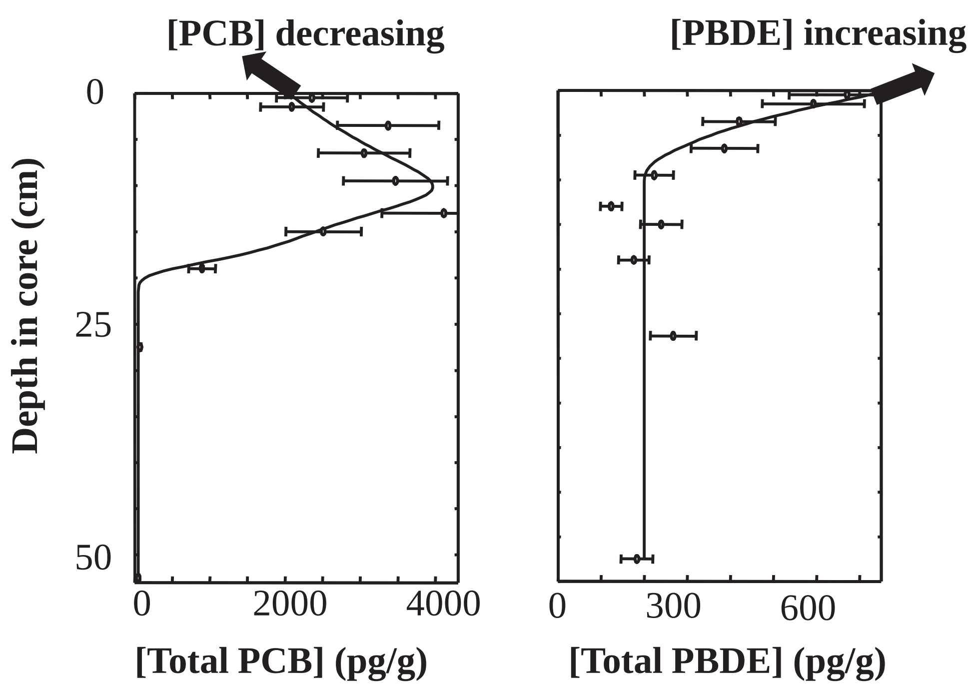
Fisheries and Oceans Canada Pêches et Océans Canada

Sophia Johannessen[1]

1. Fisheries and Oceans Canada, Institute of Ocean Sciences

- Wastewater to the Strait of Georgia contributes negligibly to regional budgets for substances with large natural cycles (C, N, O2, metals), but is a major conduit of PBDEs.

The discharge of primary-treated or screened municipal wastewater from Vancouver and Victoria into the coastal ocean is controversial. The controversy stems in part from a lack of a common understanding of the scope of the problem and of what might be achieved by further treatment. A decade of geochemical research in the Strait of Georgia (Johannessen et al., 2015) indicates that wastewater contributes negligibly to regional budgets of substances that have large natural cycles, e.g. nitrogen, organic carbon, oxygen and metals. Wastewater contributes less than 1% of the nitrogen (Figure), organic carbon and oxygen demand in the Strait and is unlikely to cause eutrophication, harmful algal blooms or hypoxia in this region. Metals (Hg, Pb, Cd) are also dominated by natural cycles, augmented by past mining and urbanization, with 0.3 - 5% of the flux contributed by wastewater. Wastewater contributes about 5-10% of PCBs (polychlorinated biphenyls, previously used as a lubricant in electronics), which have no natural source. Near Vancouver's Iona Island outfall, for example, the discharge of wastewater at 80 m depth appears to have diluted the concentration of PCBs in nearby sediments. The story is different for substances that are still in current or recent use, such as the flame retardant PBDEs (polybrominated diphenyl ethers). As much as 60% of PBDE flux into the Strait is delivered through wastewater, which is likely also an important route of entry for pharmaceuticals, personal care products, microplastics and some pathogens. Despite the minimal contribution of organic carbon flux to regional budgets, the high organic flux has measurable effects on the sediment chemistry and benthic animals in the immediate receiving environment (within ~ 4km at Iona and ~ 400 m at Victoria's Macaulay outfall). Secondary treatment, slated for completion in Vancouver and Victoria over the next 15 years, will reduce fluxes of some contaminants, but will have negligible effect on regional budgets for organic carbon, nitrogen, oxygen and metals. Although secondary treatment will divert some PCBs and PBDEs from the discharged wastewater, it will not break down these or other persistent organic pollutants, but rather will move them mainly into the sludge. The ultimate fate of these chemicals will depend on how the sludge is sequestered. Source control could help to prevent persistent contaminants from entering the marine environment.



Depth profiles of (a) Total PCB and (b) Total PBDE in a sediment core collected near Vancouver, B.C., just north of the Iona Island wastewater outfall.

For more information: Sophia Johannessen, Sophia.johannessen@dfo-mpo.gc.ca http://www.pac.dfo-mpo.gc.ca/science/facilities-installations/ios-ism/index-eng.html

Ocean pollution indicators for the Strait of Georgia

Juan José Alava[1,2], William W.L. Cheung[2], Andrew Day[1], U. Rashid Sumaila[2], Peter S. Ross[1]

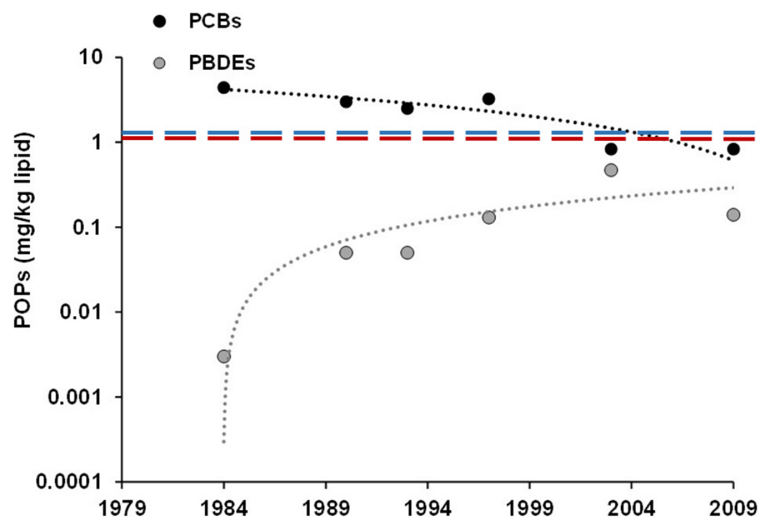
1. Ocean Pollution Research Program, Coastal Ocean Research Institute, Vancouver Aquarium, Marine Science Centre; 2. Institute for the Oceans and Fisheries, University of British Columbia

- Ocean pollution indicators can be developed as practical approaches to monitor and assess the state of marine pollution in the Salish Sea Ecosystem.

In the Salish Sea, chemical pollution represents an anthropogenic pressure which would clearly benefit from a methodical tracking of contaminant types, levels, and trends in the environment and in valued biota. While the lack of rigid, ecosystem-based pollution monitoring efforts presently constrains the ability to track trends in priority pollutants in the Strait of Georgia, datasets for certain pollutants are available from different agencies, reflecting their legislated need to monitor discharges to the environment. In this context, the use of ocean pollution indicators (OPIs) offers an opportunity for multi-institutional efforts aimed to understand and update the state of marine pollution in the Salish Sea Ecosystem. The development of OPIs is a key task for the Ocean Pollution Research Program at the Vancouver Aquarium's new Coastal Ocean Research Institute, and a source of baseline data to support time series observations of environmental contaminant for the North Pacific Ecosystem Status Report and the North Pacific Marine Science Organization.

A well-designed OPI can be categorized as a Marine Ecosystem-Based Management (EBM) indicator to track and assess the state of pollution levels in coastal-marine ecosystems and test the effectiveness of marine pollution regulations and/or guidelines over time (Day et al. 2013). Under this premise, OPIs such as contaminant loads/levels of POPs in marine mammals (e.g., PCBs, PBDEs in harbour seals and killer whales) and contamination in sediments (e.g., mercury levels in sediments), can fall under the definition of either or both: a) Ecological State Indicators and, b) Human Pressure Indicators.

As a study case for the application of OPIs, estimated temporal concentration data (1984-2009; for persistent organic pollutants (POPs), including polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs), were modeled for harbour seal pups from the Strait of Georgia (Figure), based on empirical data measured in live-captured seal pups from the Strait of Georgia in 2003 (Ross et al., 2004) and trends measured in harbour seals from Puget Sound (Ross et al., 2013). Results reveal the history of accumulation by these POPs in this species: while harbour seals exhibited declining concentrations of PCB with 81% reduction from 1984 to 2009, PBDEs show an increase in concentrations of 99% from 1984 to 2003, but



Estimated temporal concentrations of PCBs and PBDEs (log scale in mg/kg lipid) in harbor seals from the Strait of Georgia (BC, Canada), calculated using empiral data for seals sampled from the Strait of Georgia in 2003 and the trend of temporal concentrations observed in harbor seals from Puget Sound, WA, USA (Ross et al., 2013). Blue-dashed line indicates the PBDE-endocrine disruption threshold of 1.5 mg/kg reported for grey seals (Hall et al., 2003) and the red-dashed line represent the total PCB-risk based toxic effect concentration of 1.3 mg/kg lipid for harbor seals (Mos et al 2010).

reached steady state concentrations over time until 2009 when concentration dropped, reflecting the withdrawal of penta- and octa- formulations from the market in 2004. In general, the contaminant data suggest that past and current regulations and source controls have markedly reduced inputs of these pollutants to the Strait of Georgia, consequently reducing the associated health risks to marine wildlife.

Finally, a Marine Pollution Index (MPI) is being developed to track pollutant responses to past or present emissions histories, thereby providing insight into the overall health of food webs and potential risks for human health. MPI trends for a given species or aggregate of species can then be compared against toxic effect thresholds and human consumption guidelines to inform marine pollution policies in Canada. These indicators will then be applied to inform marine and climate policies in Canada.

For more information: Juan José Alava, j.alava@oceans.ubc.ca https://www.vanaqua.org/act/research/ocean-pollution-research-program

SECTION 3:
WHAT IS BEING DONE ABOUT IT?
(MANAGEMENT)

Suspended sediment-bound toxic chemical fluxes from large rivers to Puget Sound

science for a changing world

Kathy Conn[1], Bob Black[1], Mahbub Alam[2], Ron Timm[2]

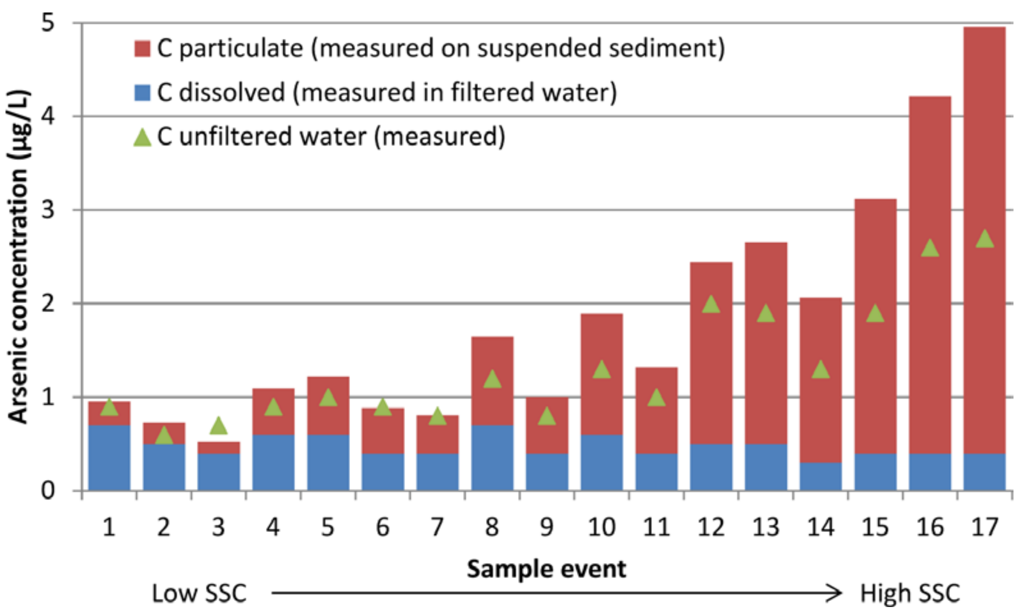
1. U.S. Geological Survey, Washington Water Science Center; 2. Washington Department of Ecology

- River suspended sediment can transport toxic chemicals to Puget Sound.
- Concentrations are highly variable and are affected by many environmental variables.

Rivers can transport land-derived toxic chemicals to receiving nearshore environments in the Salish Sea. Many toxic chemicals preferentially adsorb to fine sediment rather than partitioning into the dissolved water phase or adsorbing to larger-diameter sediment particles that can settle out. Direct measurement of chemical concentrations on suspended sediment is rarely done, as obtaining a sample of sufficient quality and mass for chemical analysis is difficult. Therefore, river suspended sediment is an understudied pathway for toxic contaminant entry into the Salish Sea food web. Chemical flux calculations that do not incorporate the suspended sediment-bound contribution may underestimate total chemical fluxes from rivers to the Salish Sea.

In support of the National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries, the USGS has developed a field-deployable continuous-flow centrifugation technique to collect suspended sediment for chemical analysis. As water is continuously pumped into a spinning centrifuge bowl, sediment is retained. The sediment can be analyzed for nutrients, metals, and organic compounds such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). The resulting suspended sediment-bound chemical concentrations can be used to estimate continuous chemical fluxes to downstream waters when combined with a continuous record of stream discharge.

The centrifugation method has been implemented at several large Puget Sound rivers (Duwamish, Puyallup, Stillaguamish) and nearshore environments (Eagle Harbor, Samish Bay). A suite of toxic chemicals has been regularly detected on suspended sediment, including metals, PCBs, PAHs and other semivolatile compounds. This sediment-bound chemical fraction is important; for example, during high-sediment Duwamish River conditions, the elevated arsenic concentration in water was mostly from sediment-bound arsenic, while the dissolved arsenic concentration remained low. Some compounds, such as PAHs, were detected on suspended sediment even when they were not detected in a co-collected water sample. Sediment-bound chemical concentrations were highly variable between different rivers and sampling events. This is likely owing to complex interacting environmental variables, including the source of sediment, adjacent land uses, river discharge, season, and antecedent precipitation. Concentrations of many chemicals were not simply related to the river streamflow or the amount of suspended sediment in the water. High chemical fluxes can occur not only during storm events but also during dry-weather high-sediment events, such as dam releases, that transport large amounts of low-chemical sediment to the nearshore. These studies will improve estimates of sediment-bound toxic chemical fluxes from rivers to the Salish Sea.



Arsenic concentration (µg/L) measured in river suspended sediment (C particulate), filtered water (C dissolved) and unfiltered water (C unfiltered water) during 17 sampling events from low to high suspended sediment concentration (SSC), USGS 12113390, Duwamish River at Golf Course at Tukwila, WA, 2013-15. [C particulate + C dissolved ≈ C unfiltered water. During high SSC events, most of the total arsenic concentration in the water is sediment-bound.]

For more information: Kathy Conn, kconn@usgs.gov http://wa.water.usgs.gov/projects/riverloads/

Measuring PBDEs from river otter scat using an enzyme-linked immunosorbent assay (ELISA)

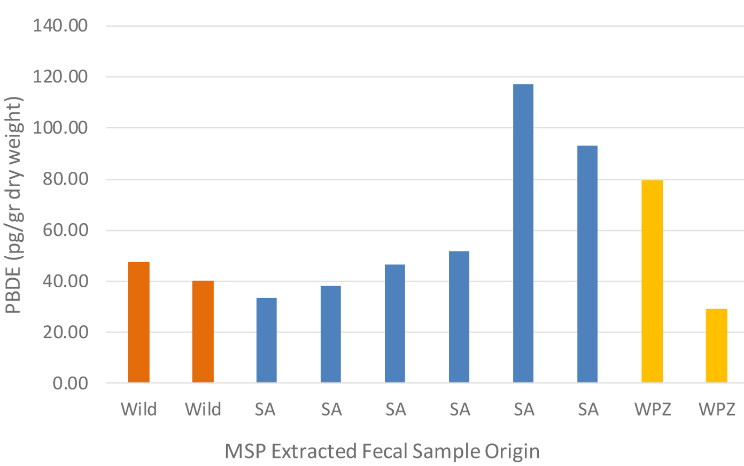
SEATTLE AQUARIUM

Amy Green[1], Shawn Larson[1]

1. Seattle Aquarium

- The Seattle Aquarium is in the process of validating the use of commercially available ELISA kits to measure PBDEs in Northern river otter scat.

Northern river otters (*Lontra canadensis paci ica*) are semi-aquatic, piscivorous mustelids that often inhabit the highly urbanized nearshore of Puget Sound. In the wild they eat a variety of fish, crustaceans, mollusks, insects, birds, and other aquatic invertebrates (Guertin et al., 2010). Concentrations of organic contaminants biomagnify in the aquatic food web and as a top predator river otters are vulnerable to biomagnification. One group of persistent organic pollutants of concern for river otters are polybrominated diphenyl ethers (PBDEs), which are known to cause a variety of adverse health effects in wildlife (Ross, 2000). The Seattle Aquarium cares for three male river otters that are fed restaurant-quality fish and seafood. In 2015 we ran a trial to determine whether we could use commercially available enzyme-linked immunosorbent assays (ELISAs) to characterize PBDEs in the river otter feces. Though contaminants are typically analyzed through chromatography/mass spectrometry, ELISAs offer an alternative approach that is simple in methodology, lower in cost, and can be used in the field if needed. In addition, the Seattle Aquarium already uses an ELISA method for monitoring endocrine steroid hormones in its other marine mammals. In this experiment methanol-extracted river otter fecal samples, collected from both wild and captive river otters, as well as undigested capelin fish (a staple of their diet), were analyzed. By comparing their food source and feces we expect to compare how much PBDEs wild and captive river otters are accumulating. We analyzed two samples of wild river otter feces collected from West Seattle (mean PBDE 43.67 pg/gr dry weight), six samples from male river otters housed in Seattle Aquarium (mean 63.33 pg/gr dry weight), and two samples from a female river otter housed at the Woodland Park Zoo (mean 54.28 pg/gr dry weight). Capelin fish from the Seattle Aquarium had a mean PBDE value of 131.78 pg/gr dry weight (n = 4). Variance between these concentrations may be due to differences in diet type or origin, sex, age-class, as well as individual metabolic rate (time between ingestion and defecation). Although values obtained from feces are an indirect measure of contaminants in diet, ongoing research into these questions may help to improve husbandry practices in zoos and aquariums. Currently we are working towards validating the use of ELISAs through comparison with gas chromatography/mass spectrometry, and we hope to also begin analyzing water and sediment samples from underneath the Seattle Aquarium pier.



Individual PBDE (pg/gr dry weight) values of fecal samples collected from wild river otters (n=2), Seattle Aquarium river otters (n=6) and Woodland Park Zoo river otter (n=2). Wild otters are of unknown sex, Seattle Aquarium otters are males, and Woodland Park Zoo samples were from one female.

Wadaah is one of three Northern river otters at the Seattle Aquarium.

For more information: Amy Green, a.green@seattleaquarium.org

The improved screening and characterization of Contaminants of Emerging Concern in environmental samples with QTOF LC-MS/MS instrumentation

CENTER FOR URBAN WATERS

C. Andrew James[1], Bowen Du[1], Edward Kolodziej[1], Joel Baker[1]

1. University of Washington

- High resolution mass spectrometry approaches are being used to identify novel anthropogenic compounds in wastewater treatment plant effluent and stormwater.

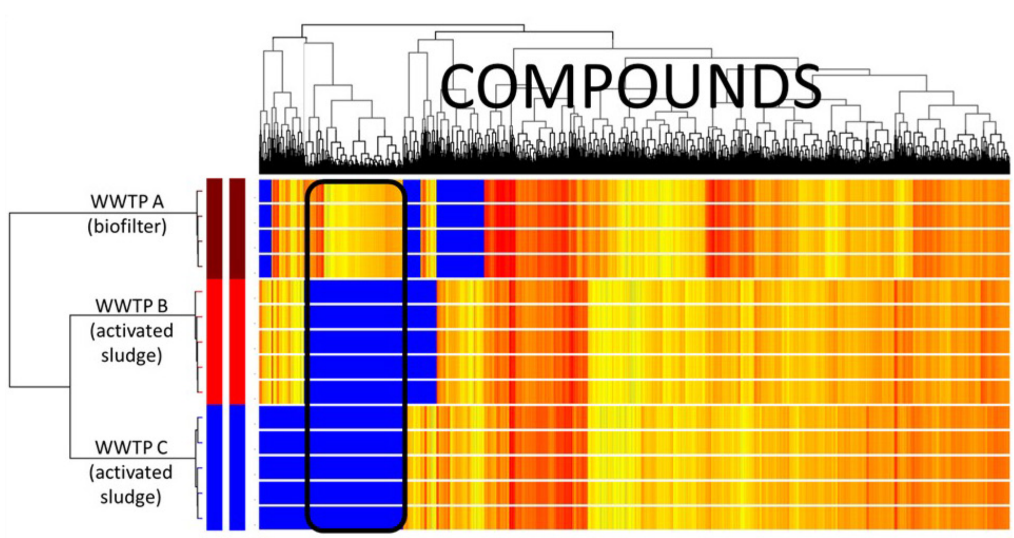
Introduction: Thousands of compounds are used in modern society including pharmaceuticals, personal care products, food additives, and industrial chemicals. There is ample evidence that many of these chemicals, collectively known as Contaminants of Emerging Concern, enter the waters of the Salish Sea. However, there is a lack of occurrence information on many of these compounds.

High resolution mass spectrometry can be utilized in <u>non-targeted approaches</u> to capture occurrence information of a large number of organic compounds in a given sample. Non-targeted approaches do not require the pre-selection of particular analytes prior to the beginning of investigation. A workflow incorporating careful experimental design and data analysis is utilized to explore the compounds in a given sample matrix. Quadrupole Time of Flight Mass Spectrometry systems have the capacity to make accurate mass measurements (< 1 ppm) of compounds, to support high confidence identifications of unknowns.

High Resolution Mass Measurements: A data analysis algorithm combines accurate mass measurements with compound-specific isotopic patterns in the probabilistic identification of compounds with known molecular formula. Additional information such as compound retention time and MSMS fragmentation patterns are used to improve confidence of identification of compound and related degradation products.

Experimental Design: Due to the large number of compounds that are likely to be detected in a given water sample (e.g., WWTP treatment system effluent analyzed in this study had 15,000+ unique features), careful experimental design is important to allow the comparison of data across different conditions or treatments (e.g., light exposed vs dark, influent vs effluent) which may highlight important differences. In the example shown here, effluent samples were collected from three different WWTP facilities. This type of sampling regime allowed the *post hoc* comparative analysis of treatment system removal patterns. Similar approaches are being applied in our group to investigate differences in occurrence patterns in water samples associated with a known biological response (e.g., pre-spawn mortality) compared to those not associated with impacts.

Data Screening: Several different screening strategies can be utilized based on the experimental question. The focus of this example was to 1) compare WWTP removal performance, and 2) identify novel compounds and metabolites in WWTP effluents. Replicate effluent samples from three WWTPs were compared to identify differences in effluent quality. The highlighted box identifies approximately 300 unique compounds present in effluent from WWTP A, but not in either WWTP B or WWTP C. Further, several novel compounds were identified in all samples including potent CYP3A4 enzyme inhibitors and newly approved fungicides. Similar approaches are being adopted to characterize CECs in stormwater and to evaluate potential exposures to marine biota.



Cluster diagram of compounds identified in effluent samples from three different wastewater treatment facilities in Puget Sound. Samples (n=14) are shown in rows; 4-5 replicates were collected from each facility. Compounds (n>15,000) are shown in columns. Red indicates compound abundance; blue indicates compound absence. Area in black box contains compounds detected in effluent from WWTP A (biofilter) but not in effluent from WWTP B or WWTP C (activated sludge).

For more information: C. Andrew James, jamesca@uw.edu

The inclusion of toxic exposures in a population model of Chinook salmon (*Oncorhynchus tshawytscha*) in the Duwamish/ Green River

Jessica Lundin[1], Julann A. Spromberg[1], Lyndal L. Johnson[1], David Baldwin[1], Rebecca Hoff[1], Robert Neely[1], Troy Baker[1], Sandra O'Neill[2], Nathaniel Scholz[1]

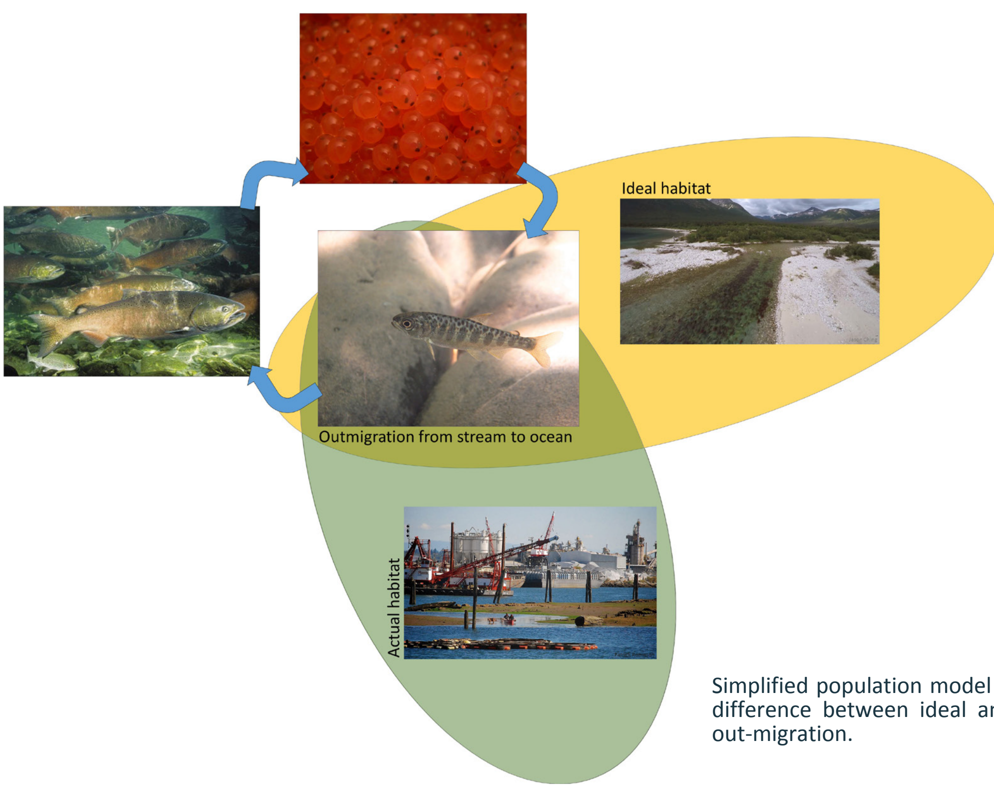
1. National Oceanic and Atmospheric Administration; 2. Washington Department of Fish and Wildlife

- Salmon habitat degradation is widely considered a major cause of salmon declines; yet, the influence of chemical contamination is poorly understood.
- The study will address the impact of sublethal toxic insult at the population scale on Chinook salmon (*O. tshawytscha*) in the lower Duwamish Waterway.

Salmon are a keystone species with a biological foundation that spans from coastal ecosystem health to human economies. Water pollution is becoming an increasingly important salmon conservation issue, particularly in watersheds affected by toxic runoff from urban development, industrial activities, and impervious surfaces such as roads. The physiologic effects of many toxic substances are well studied, however the population-level effects are more challenging to evaluate due to differences in life history strategies.

Toxic exposures are often not included in population abundance evaluations, particularly sub-lethal exposures. The purpose of this study is to quantify the impacts of sublethal toxic insults, such as changes in growth and immune function, on Chinook salmon (*Oncorhynchus tshawytscha*) in the Duwamish/ Green River resulting from exposures to contaminants in the lower Duwamish Waterway. The population model will incorporate information on stage-age structure, reproductive stages, time to reproductive maturity, and life span, as well as proportion of each stage in areas along the study site, based on an extensive review of literature specific to Chinook salmon in the Duwamish/Green River.

Routes, concentrations, and likelihood of exposure will be determined incorporating stage-specific feeding/ rearing locations, and migration habits with contaminant concentration distribution along the study site. Toxicity will be determined by mechanism of action, and sub-lethal effects dose-response relationships. Model scenarios will investigate the impact of toxic insults at specific life history stages on population abundance. Extrapolations of this model can be applied to Chinook salmon populations throughout the Salish Sea to evaluate sound-wide impacts and to track the effectiveness of ecosystem recovery efforts.



Simplified population model of Chinook salmon demonstrating the difference between ideal and actual habitat encountered during out-migration.

For more information: Jessica I. Lundin, Jessica.lundin@noaa.gov https://www.nwfsc.noaa.gov/research/divisions/efs/ecotox/

Coho salmon spawner mortality in Pacific Northwest urban watersheds: lethal stormwater impacts are prevented by soil bioinfiltration

Puget Sound Stormwater Science Team

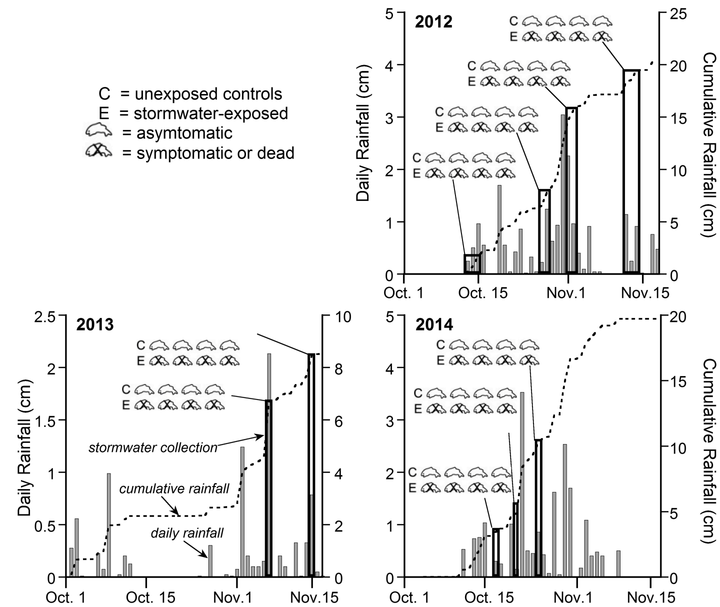
Jay W. Davis[1], Julann A. Spromberg[2], David H. Baldwin[2], Steven E. Damm[3], Jenifer K. McIntyre[4], Michael Huff[5], Catherine A. Sloan[2], Bernadita Anulacion[2], Nathaniel L. Scholz[2]

1. U.S. Fish & Wildlife Service; 2. NWFSC – NOAA Fisheries, 3. Seattle Public Utilities, 4. WSU-Puyallup, 5. Suquamish Tribe

Results indicate the first direct evidence that:

- toxic highway run-off is killing adult coho in urban watersheds, and
- inexpensive stormwater mitigation measures (e. g. Green Stormwater Infrastructure like soil infiltration) can improve water quality and promote salmon survival.

Adult coho salmon (*Oncorhynchus kisutch*) return each fall to freshwater spawning habitats throughout western North America. This migration coincides with increasing seasonal rainfall, which in turn increases stormwater runoff, particularly in urban and urbanizing watersheds in the Pacific Northwest because of the land cover characteristics of these basins (e.g., increasing impervious surfaces with increased urbanization). For more than a decade, field assessments in urban streams in the greater Seattle area have shown that adult coho are dying prior to spawning, often at rates exceeding 50% of the entire fall run. The syndrome is characterized by a loss of orientation and equilibrium, leading to death on a time scale of a few hours. Such high levels of mortality are a significant concern for the long term conservation and recovery of wild coho, particularly those distinct population segments vulnerable to ongoing and future development pressures in the Pacific Northwest. Stressors related to temperature, oxygen, and pathogens have been ruled out based upon extensive forensic data. Although indirect evidence from forensic investigations and geospatial land use analyses has implicated toxic runoff as causing the mortality syndrome, this had not been directly demonstrated. Thus, we exposed otherwise healthy coho spawners to undiluted stormwater collected from a high traffic urban arterial (i.e., highway runoff) and highway runoff that was first treated via bioinfiltration through experimental soil columns to remove pollutants. Results revealed that untreated highway runoff collected during nine distinct storm events over three seasons was universally lethal to adult coho relative to unexposed controls. The mortality syndrome was prevented when highway runoff was treated by soil infiltration. The findings demonstrate that exposure to urban stormwater is sufficient to cause the adult coho mortality syndrome. However, although the causal chemical stressor(s) have not yet been identified, conventional green stormwater infrastructure (GSI or LID technologies) can effectively protect adult spawners from the acutely toxic effects of highway runoff. Finally, integration of these types of infrastructure may protect salmonid habitat in urban watersheds.



Presence or absence of the pre-spawn mortality syndrome in adult coho salmon exposed to unfiltered highway runoff (E) or clean well water (C). Paired exposures spanned three consecutive fall spawning seasons, 2012-14. Shown in each panel are daily rainfall (shaded bars), cumulative rainfall (dotted lines), rainfall collection intervals for each exposure (black rectangles), and the presence or absence of symptomatic (or dead) fish in each individual treatment (4-24 hour durations). Symptoms included lethargy, loss of orientation, or loss of equilibrium.

Below left: The authors filtered toxic highway runoff through experimental soil columns to assess the positive influence of bioinfiltration on coho salmon spawner survival. (Tiffany Royal, NWIFC)

Above: Reproductive failure (i.e. pre-spawn mortality) is most evident in female coho carcasses with nearly 100% egg retention. (NOAA-Fisheries)

For more information: Jay W. Davis, jay_davis@fws.gov

http://www.fws.gov/wafwo/promo.cfm?id=177175807

Confirmation of stormwater bioretention treatment effectiveness using molecular indicators of cardiovascular toxicity in developing fish

Puget Sound Stormwater Science Team

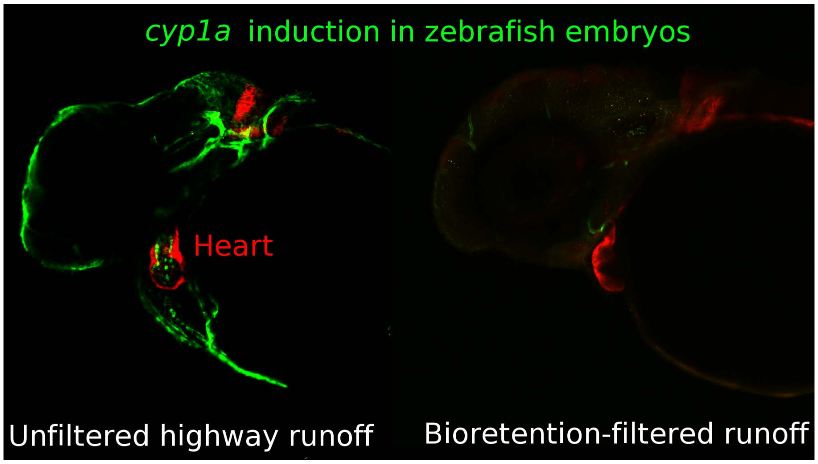
Jenifer K. McIntyre[1], Nathaniel Scholz[2], John P. Incardona[2], Maria Redig[3], Emma Mudrock[1], Richard Edmunds[2], Bernadita Anulacion[2], John S. Stark[1]

1. Washington State University; 2. NOAA, Northwest Fisheries Science Center; 3. The Evergreen State College

Results indicate the first direct evidence that:

- Genes of exposure to aromatic hydrocarbons (*cyp1a*) and cardiotoxicity (*nppb, myl6, myl7*) correlated with visible cardiotoxicity for three separate storm events.
- Bioretention treatment of runoff reduced expression of *cyp1a*, and prevented molecular and visible evidence of cardiotoxicity.

Urban stormwater runoff is a globally significant threat to the ecological integrity of aquatic habitats. Green stormwater infrastructure methods, such as bioretention, are increasingly used to improve water quality by filtering chemical contaminants that may be harmful to fish and other aquatic animals. Ubiquitous examples of toxics in runoff from highways and other impervious surfaces include polycyclic aromatic hydrocarbons (PAHs). Certain PAHs are known to cause functional and structural defects in developing fish hearts. Therefore, abnormal heart development in fish can be a sensitive measure of clean water technology effectiveness.



Immunofluorescence of cyp1a in zebrafish embryo exposed to urban runoff before and after bioretention treatment. Red stain is muscle fibers. Green stain is cyp1a enzyme.

We used the zebrafish experimental model to assess the effects of untreated runoff from three storm events on the expression of genes that are classically responsive to contaminant exposures (*cyp1a*, *mt2*), as well as cardiac-specific genes (*nppb*, *nppa*, *myl6*, *myl7*) that may underpin the familiar cardiotoxicity phenotype. For one of those storms, we assessed the effectiveness of soil bioretention for treating runoff, as measured by the prevention of both visible cardiac toxicity and corresponding gene regulation. Exposure to unfiltered runoff produced a suite of visible cardiotoxicity including atrial regurgitation, edema, pooling of blood in the common cardinal vein, looping defects, and bradycardia. The genes that scaled best with cardiovascular toxicity across storm events included cyp1a, nppb, myl6, and myl7. To test whether toxicity was associated with particulates, we experimentally filtered the most concentrated runoff through a glass fiber filter (0.7 µm). We found that contaminants in the dissolved phase of runoff produced cardiotoxicity (looping defects) at rates equal to that of the whole runoff. Particulates reconstituted in control water were not associated with any significant cardiotoxicity. Expression of contaminant exposure genes was not affected by removal of particulates, although some of the molecular indicators of cardiotoxicity were less expressed in the dissolved phase than in unfiltered runoff.

Bioretention treatment of unfiltered runoff prevented all visible cardiotoxicity and reduced the expression of cardiac-specific genes to control levels. Expression of *cyp1a* – an indicator of exposure to planar aromatic chemicals including many PAHs – was still present in fish exposed to runoff filtered through the bioretention. Immunofluorescence of *cyp1a* confirmed some residual *cyp1a* activity in the peripheral vasculature, but showed an unequivocal loss of *cyp1a* activity in the fish skin and endocardium following the bioretention treatment.

For more information: Jenifer K. McIntyre, jen.mcintyre@wsu.edu

Stormwater Action Monitoring* (SAM): Toxics in sediment of small streams in Puget Sound

Brandi Lubliner[1]

1. **Washington Department of Ecology, RSMP/SAM Coordinator**

* *Note: The Regional Stormwater Monitoring Program (RSMP) changed its name to Stormwater Action Monitoring (SAM) in 2017 .*

- In 2016, long-term analyses for a regional status assessment of small streams were initiated by SAM that included water quality variables, habitat, macroinvertebrates, periphyton, and a variety of contaminants.

Stormwater Action Monitoring (SAM) is a new collaboration of Western Washington Phase I and II Municipal Stormwater Permittees, and state and federal agencies to monitor and assess the condition of small streams and to commission studies to assess the effectiveness of stormwater management actions. SAM's emphasis on the regional scale (western Washington) satisfies the monitoring requirements in the municipal stormwater permits and replaces stormwater outfall monitoring required in prior permits. Sites for SAM status and trends monitoring are selected using the EPA's randomized sample design so that results from individual sites can be summarized to reflect the conditions at the regional scale. Four environmental monitoring studies will be conducted under the Status and Trend component of SAM from 2014-2018: freshwater small streams, marine nearshore sediment, marine mussels, and review of fecal bacteria indicators. The SAM marine sediment and mussel contaminant studies are described under their own entries in the Puget Sound Ecosystem Monitoring Program Toxics review.

For SAM Puget lowland small streams, the area of selection was the intersection of the Puget Sound lowland ecoregion and salmon recovery region. Two distinct strata were sampled: outside the urban growth area (OUGA) and within the urban growth areas (WUGA). In 2015, 30 streams per stratum were sampled for monthly water quality (metals, conventionals, PAHs, and discharge).

SAM Site 21-WUGA Johnson Creek

A target of 50 streams per strata were sampled once for summer watershed health characterization that included habitat, macroinvertebrates, periphyton and fine sediment (metals, conventionals, PCBs, PBDEs, PAHs, phthalates, and pesticides). A multi-agency team approach was needed to conduct field monitoring for SAM Puget Lowland small stream sites. Another multi-agency team is conducting the data analysis and will write the final report. A modest effort was made to compare results of split water and sediment samples from the two main labs used for SAM streams, King County Environmental Laboratory (KCEL) and Manchester Environmental Laboratory (MEL). Results showed the two labs generated comparable, high quality data for all evaluated parameters. The Department of Agriculture contributed to the effort by analyzing for landscape and agricultural pesticides in the sediments at most of the SAM small streams sites. USGS also contributed by comparing stage-discharge at a few of the SAM small streams sites.

Initial analytical results are anticipated in . The goal is to share these early findings with the PSEMP Freshwater Work Group and provide a final report in 2017.

For more information: Brandi Lubliner, brandi.lubliner@ecy.wa.gov http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp/status.html

Stormwater Action Monitoring (SAM): Toxics in sediment of Puget Sound along the urban marine nearshore

Brandi Lubliner[1]
1. Washington Department of Ecology, RSMP/SAM Coordinator

** Note: The Regional Stormwater Monitoring Program (RSMP) changed its name to Stormwater Action Monitoring (SAM) in 2017*

- In 2016, SAM began a long-term sampling program of urban nearshore sediments for characterization of metals and organic chemistry constituents.
- These site locations are used for SAM-funded, WDFW-led caged marine mussel monitoring.

The Stormwater Action Monitoring (SAM) is a new collaboration of Western Washington Phase I and II Municipal Stormwater Permittees and state and federal agencies to monitor and assess the condition of small streams and commission studies to assess the effectiveness of stormwater management actions. The SAM's emphasis on the regional scale (western Washington) satisfies the monitoring requirements in the municipal stormwater permits and replaces stormwater outfall monitoring required in prior permits. Sites for SAM status and trends monitoring are selected using the EPA's randomized sample design so that results from individual sites can be summarized to reflect the conditions at the regional scale. Four environmental monitoring studies will be conducted under the Status and Trend component of the RSMP from 2014-2018: freshwater small streams, marine nearshore sediment, marine mussels, and review of fecal bacteria indicators. The SAM small streams and mussel contaminant studies are described under their own entries in the Puget Sound Ecosystem Monitoring Program Toxics review.

In 2016, environmental monitoring of fine sediment from the Puget Sound marine nearshore along urban shorelines will occur. For this study, the sole strata area of selection was sub-tidal nearshore along defined urban growth areas lining the Puget Sound. A target of 40 sites will be sampled once for sediment in the summer of 2016. Parameters for analysis will include metals, conventionals, PCBs, PBDEs, PAHs, and phthalates. USGS is funding an evaluation of micro-plastics in these 40 nearshore sediment samples.

A multi-agency team approach will be used for monitoring and data analysis. A modest effort is planned to compare results of split sediment samples from the two main labs used for SAM, King County Environmental Laboratory (KCEL) and Manchester Environmental Laboratory (MEL). Initial analytical results are anticipated in early 2017 and a final report in late 2017.

For more information: Brandi Lubliner, brandi.lubliner@ecy.wa.gov http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp/status.html

Western Washington NPDES Phase 1 Stormwater Permit: Final data characterization 2009-2013

William Hobbs[1], Brandi Lubliner[1], Nathaniel Kale[1], Evan Newell[1]

1. Washington State Department of Ecology

- Commercial and industrial areas discharged stormwater with the highest levels of metals, hydrocarbons, phthalates, nitrogen and phosphorus and PCBs.
- Nutrients, turbidity, metals, and hydrocarbons were frequently detected, while volatile hydrocarbons and some pesticides were infrequently detected.

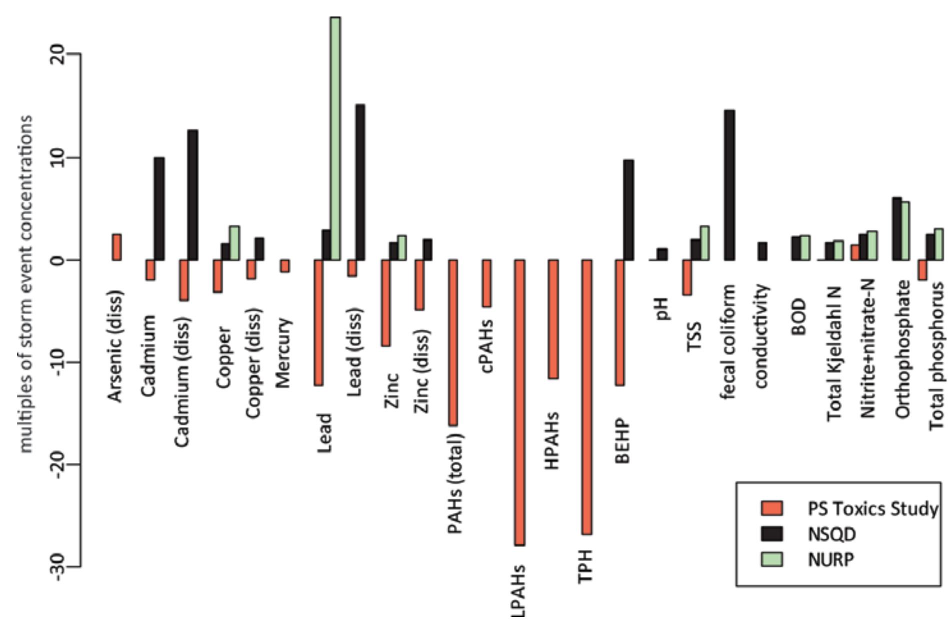
Stormwater and storm sediment discharge data were collected by NPDES Phase I Municipal Stormwater permittees, under Special Condition S8.D, between 2007 and 2013. This study is a summary of the data. The Phase 1 permittees, all located in western Washington, collected highly representative storm-event data under a prescribed monitoring program that represented multiple land uses, storm characteristics, and seasons. The main goals of the study were to (1) compile and summarize the permittees' data using appropriate statistical techniques and (2) provide a western Washington regional baseline characterization of stormwater quality.

These findings are based on the analysis of 44,800 data records representing 597 storm events. Up to 85 parameters were analyzed in stormwater samples, and 67 parameters were analyzed in stormwater sediments. Metals, hydrocarbons, phthalates, total nitrogen and phosphorus, pentachlorophenol, and PCBs were detected more frequently and at higher concentrations from commercial and industrial areas than from residential areas. Residential areas exported stormwater with the highest dissolved nutrient concentrations.

For context, data were compared to previous stormwater studies and the Washington State water quality criteria. Stormwater pollutant concentrations were lower than those reported by EPA in the mid-1980s, but higher than stream and river concentrations draining to Puget Sound during storms (see Figure). Across all land uses, copper, zinc, and lead were found to not meet water quality criteria for the protection of aquatic life in 58%, 40%, and 28% of the samples, respectively. Mercury and total PCBs exceeded criteria in 17% and 41% of the samples, respectively. For most parameters measured in both stormwater and stormwater sediments, concentrations in stormwater sediments paralleled the trends found in water samples across all four land uses.

The statistical analyses used in this study have produced reliable statistical summaries and allowed for robust comparisons of the impacts of land use and seasons on contaminant concentrations and mass loads. The statistical summaries form a baseline for contaminant concentrations in stormwater that will allow for future comparisons.

Summary of S8.D median stormwater concentrations relative to median concentrations reported in other studies. The Y-axis displays the ratio (multiples) of the median concentrations reported elsewhere to the median concentrations in the S8.D study. Bars show the magnitude of difference as less than (negative) or more than (positive) the S8.D results. Many parameters were not measured in the previous studies. PS Toxics Study = Control of Toxic Chemicals in Puget Sound: Phase 3 Data and Load Estimates (Herrera, 2011); NSQD = National Stormwater Quality Database (Maestre and Pitt., 2005); NURP = Nationwide Urban Runoff Program (EPA, 1983). Note: PS Toxics Study sampled receiving waters and not stormwater directly.



Remediation and restoration as drivers of an environmental cleanup

Emily Duncanson[1], Jason Stutes[1], Jessica Blanchette[1], Maria Sandercock[1]

1. Hart Crowser, Edmonds, WA

- This describes a rare opportunity to implement meaningful restoration of a contaminated industrial waterfront as part of broader site-wide cleanup action.

Hart Crowser is leading a comprehensive effort in Anacortes, Washington to remediate and restore productive habitat at the former Custom Plywood Site. Designated as a Puget Sound Initiative site, this Ecology-directed project provided a rare opportunity to implement meaningful restoration of a contaminated industrial waterfront as part of broader site-wide cleanup action. The upland and aquatic areas were phased interim cleanup actions. Extensive wood waste deposits, creosote-treated piles, petroleum hydrocarbon, and metal contamination impaired existing habitat for nearly a century. Wide-spread dioxin in adjacent marine sediment created a human health risk through seafood consumption exposure.

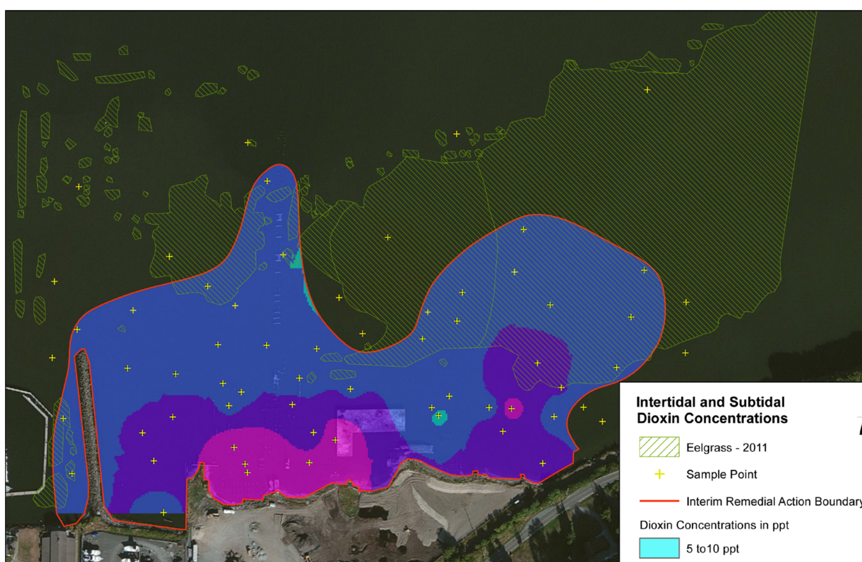
The cleanup was separated into upland and aquatic cleanup actions. Phase I was upland based and involved demolition of derelict concrete structures, pilings and removal of contaminated soil to substantially reduce the risk to human health and the environment. Phase I also included consolidation of existing low quality isolated wetlands into a functional wetland complex that is actively tidally inundated. Phase II focused on aquatic habitat and was one of the first sediment remediation projects within Puget Sound that had dioxin as the driver of the cleanup. Dredging was performed on areas where sediment contamination concentrations of dioxin were greater than 25 ppt (approx. 45,000 cy). In-water structures and over 1,400 creosote treated piles were removed.

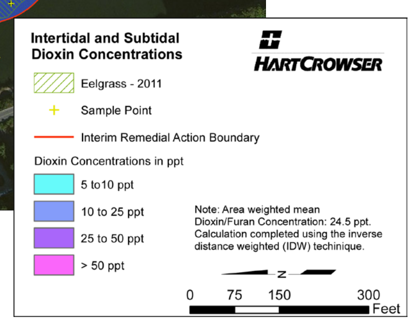
As part of these Phase I and Phase II cleanup activities, Hart Crowser assisted in the design of a soft beach face that was not only protective of residual contamination remaining in the upland's deep subsurface portion of the site, but also restored historical ecological function to the nearshore. The beach design promoted forage fish spawning and use by outmigrating salmonids, as well as restored emergent nearshore/wetland plants as part of a pocket estuary. Performance surveys over the past two years have quantitatively examined beach slope, salmonid use, epibenthic zooplankton productivity, forage fish spawning occurrence/success, and wetland plant recruitment. The monitoring results show a significant increase in use, activity and productivity along the beach and within the estuary compared to an adjacent reference site.

Not only did we remove contamination that posed potential human health and environmental risk, we also restored the physical and ecological processes of the shoreline, which enhances the overall ecological function to the Fidalgo Bay system.

Hun Seak Park

Hun Seak Park





Map of dioxin/furan concentrations measured at Custom Plywood Site prior to remediation activities. Concentrations were based on analytical results of sediment core samples and analyzed for dioxin/furan, PAH, metals. Sediments with concentrations > 25 ppt were dredged.

For more information: Emily Duncanson, Emily.Duncanson@hartcrowser.com https://fortress.wa.gov/ecy/gsp/Sitepage.aspx?csid=4533

In situ treatment of PCB contaminated sediments with reactive amendments effectively reduced PCBs in the benthic food web of an active harbor

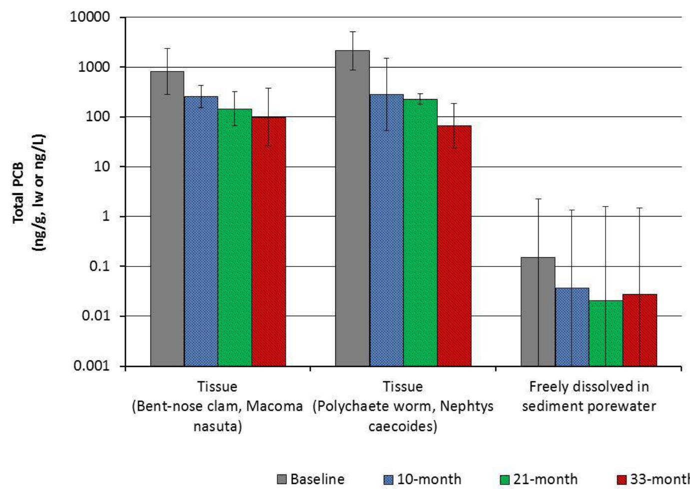
Victoria Kirtay[1], Bart Chadwick[1], Gunther Rosen[1], Robert Johnston[1], Marienne Colvin[1], Melissa Grover[2], Joe Germano[3], Rob Webb[4], Victor Magar[5]

1. Space and Naval Warfare Systems; 2. Geosyntec; 3. Germano and Associates; 4. Dalton, Olmstead and Fuglevand; 5. Ramboll Environ

- In situ treatment of sediments with reactive amendment significantly reduced PCBs in associated pore water and benthic species.
- Amendment placement did not adversely affect the benthic community.

In this study, in situ remediation of surface sediment contaminated with hydrophobic organic compounds was demonstrated by placing a reactive amendment consisting of powdered activated carbon (PAC) at a site (Pier 7) contaminated with polychlorinated biphenyls (PCBs) located at the Puget Sound Naval Shipyard & Intermediate Maintenance Facility, Bremerton, WA. Sediments adjacent to and beneath Pier 7 lie within an area subject to Superfund cleanup but because of the presence of infrastructure (i.e., piers and bulkheads), remediation of PCB contaminated sediments by in situ treatment methods was evaluated as an alternative method to dredging in achieving cleanup goals. An aggregate core coated with PAC held in a bentonite clay binder, AquaGate+PAC™ (AquaGate, AquaBlok, Limited, Toledo, OH) was successfully placed on the seafloor of a half-acre target site to sorb PCBs in sediments. Over a short period of time (days), the PAC coating of the AquaGate releases from the aggregate and becomes mixed with the underlying sediment. Natural mixing via bioturbation, incorporates the PAC into the surface sediments over time. AquaGate was placed with conveyor belt-type equipment, which demonstrated the ability to rapidly and evenly place the material both in open water and areas under structures such as piers and between pilings.

This project demonstrated the effective use of reactive amendments to remediate PCB contaminated sediments in an active harbor where associated infrastructure (i.e., piers and bulkheads) make traditional dredging and capping remediation challenging. Within 10 months of placement of the AquaGate, concentrations of total PCBs in clam tissue, worm tissue and pore water were 68, 87, and 75% lower relative to baseline concentrations, on a site-wide average. Continued improvement was observed over time with statistically significant (paired t-tests on log transformed data, α level of 0.05) reductions of 82, 89, and 86% (21-month) and 88, 97, and 81% (33-month) time points (Figure). In addition to harbors, ports and shipyards with developed infrastructures, in situ remediation may be suitable in areas where dredging will cause destruction of sensitive habitat or where contaminant concentrations do not warrant removal. Also, conventional sand capping may not be possible at sites where water depths must be maintained for navigational channels and berthing areas as well as where there are concerns with propeller wash. Implementation of remedies in deep water and active areas present cost and logistical challenges for many remedies. Prior to this project, the majority of in situ sediment amendment efforts have been small, pilot-scale efforts in areas without significant limitations to access and generally targeted to low velocity waters with minimal vessel traffic or harbor activities. This project demonstrated the placement and quantitative integration of a suite of common and novel monitoring tools to evaluate amendment stability and performance in deep water (15 m) at an active Naval shipyard with high vessel traffic. This study extended pilot-scale efforts to a larger scale footprints in an active Department of Defense (DoD) harbor area, demonstrating that reactive amendments are a viable tool for solving contaminated sediment challenges at DoD sites (Kirtay et al. 2016).



Significant reductions in concentrations of Total PCBs in tissue and sediment porewater relative to baseline conditions (88%, 97% and 81%, respectively) 33-months after treatment with in situ reactive amendments. Results are shown as mean ± 95% Confidence Level (CL).

Amendment application method at Pier 7 showing barge staged with "Super Sacks" of product that were loaded into the hopper mixing prior to deployment with a truck mounted conveyor system that distributed the product in the berthing and under pier areas.

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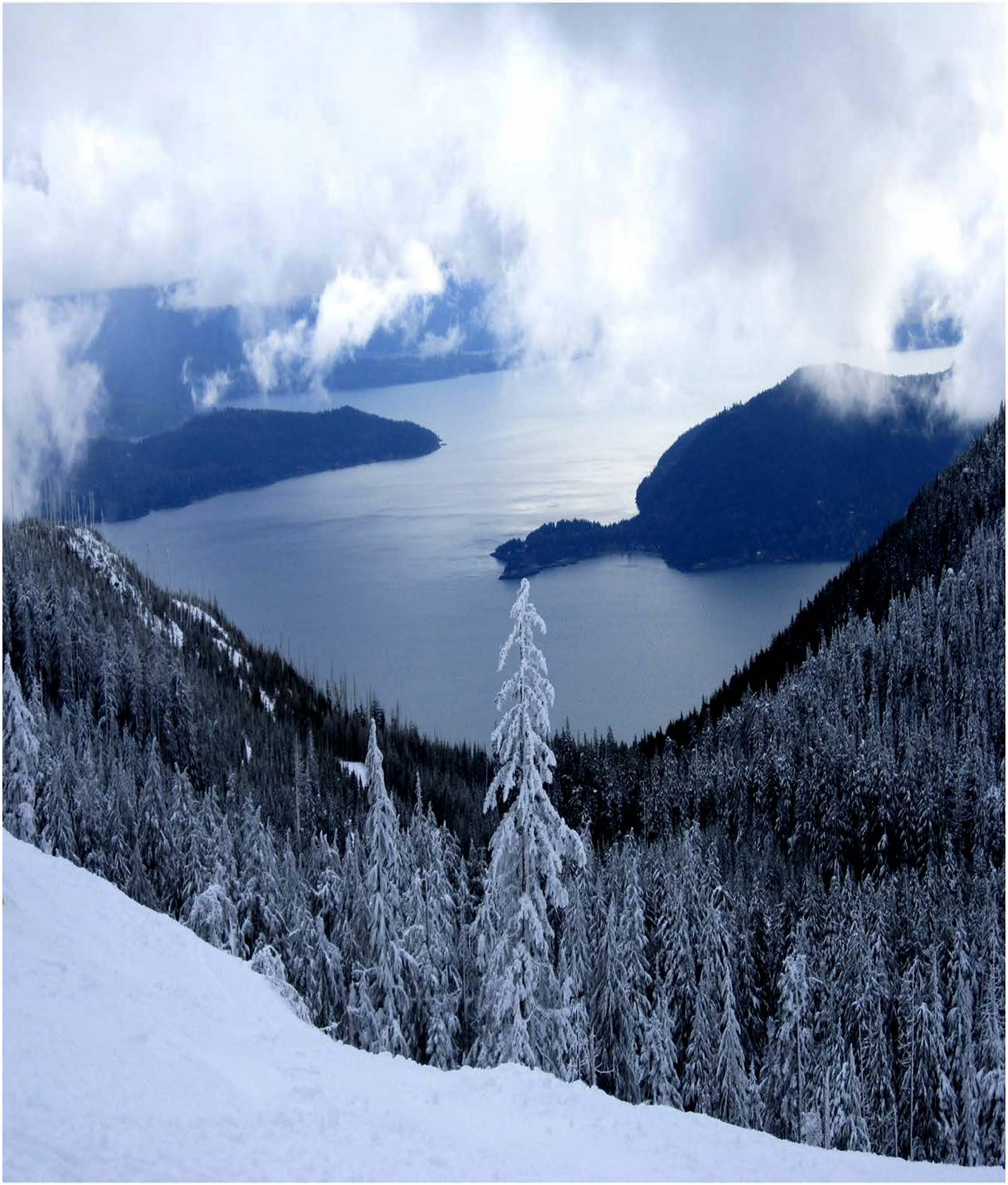

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