October 2003 **FINAL**

Status, Trends and Effects of Toxic Contaminants in the Puget Sound Environment:

Recommendations

PREPARED FOR:

Puget Sound Action Team
Olympia, WA

PREPARED BY:

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STATUS, TRENDS AND EFFECTS OF TOXIC CONTAMINANTS IN THE PUGET SOUND ENVIRONMENT:

RECOMMENDATIONS

FINAL

Prepared for

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LIST OF ACRONYMS

CSO	Combined sewer overflow
ECC	Environmental Cooperative Council
EDC	Endocrine disrupting compound
EOF	Emergency overflow
EVS	EVS Environment Consultants
FAO	Food and Agriculture Organization
GBCWWG	Georgia Basin Clean Water Work Group
GIS	Geographic information system
MSMP	Marine Sediment Monitoring Program
NOAA	National Oceanic and Atmospheric Administration
PAH	Polycyclic aromatic hydrocarbons
PBDE	Polybrominated diphenyl ethers
PBT	Persistent bioaccumulative toxic
PCB	Polychlorinated biphenyl
PPCP	Pharmaceuticals and personal care products
PSAMP	Puget Sound Ambient Monitoring Program
PSAT	Puget Sound Action Team
PSGBITF	Puget Sound Georgia Basin International Task Force
PSTWG	Puget Sound Toxics Work Group
SMIC	Sea-surface microlayer
USFWS	United States Fish and Wildlife Service
WDOE	Washington Department of Ecology
WDFW	Washington Department of Fish and Wildlife
WWTP	Wastewater treatment plant

GLOSSARY

biliary FAC	A measure of the metabolites of polycyclic aromatic hydrocarbons (PAH) found in the bile of vertebrates, used as a surrogate for exposure to PAHs
bioaccumulation	A general term, meaning that an organism stores within its body a higher concentration of a substance than is found in its environment. Includes uptake of substances from water (=bioconcentration) and from food.
bioavailable	The fraction of the total chemical in the surrounding environment which can be taken up by organisms. The environment may include water, sediment, suspended particles, and food items.
bioconcentration	Accumulation of a chemical by an aquatic organism directly from the water, to a higher concentration than is found in the water. The bioconcentration results from simultaneous processes of uptake and elimination.
biomagnification	The result of processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through the food chain. The term implies an efficient transfer of chemical from food to consumer, so that residue concentrations increase systematically from one trophic level to the next.
biomethylation	The process by which microbes add a methyl group to a compound, often a metal.
carcinogen	A substance or chemical which induces cancer in living organisms.
DNA adduct	Damaged segments of DNA.
fecundity	Refers to the number of offspring produced by a female organism.
vitellogenesis	The production of vitellogenin, a protein synthesized by the livers of female fish in preparation for reproduction.

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This document is a companion to an earlier review of the status, trends and effects of toxic contaminants in the Puget Sound environment (EVS 2003), and makes recommendations for research based on what is currently known about contaminant sources and pathways, the effects of contaminants in water, sediment, and biota, and identified monitoring and data gaps.

The review of the available data highlighted concerns at both a broader scale such as identifying/quantifying sources and trophic transfer of persistent, bioaccumulative toxics (PBTs) in Puget Sound, to more specific questions such as what are the potential ecological effects of the elevated lead concentrations observed in Sinclair Inlet fish. To answer both kinds of questions, continued monitoring is imperative. Further recommendations are summarized below.

Contaminant Sources and Pathways

To assist in tracking the sources and effects of toxic contaminants in the Puget Sound marine ecosystem, it is recommended that contemporary sources such as industrial and municipal wastewater discharges, combined sewer overflows and stormwater discharges be identified and quantified.

Water Quality

Limited data were available for an assessment of toxic metals and organics in the water column of Puget Sound. The data that were available suggested that contaminant concentrations in the water column are highest in urban/industrial embayments, however, they have decreased during the last two decades as a result of contaminated-site cleanup and source control efforts. Continued monitoring of the water is important to track changes in environmental health and identify source control needs in the future. Because of the complex behavior of contaminants in seawater, monitoring efforts need to be focused at locations where the contaminants may occur in measurable concentrations and where effects may occur, such as in the vicinity of point-source discharges and at the sea-surface microlayer.

Sediment Quality

Many contaminants have an affinity for the organic or inorganic components of sediment particles. As a result, sediments often act as a contaminant sink with substantially higher concentrations than in the overlying water. In Puget Sound “hot spots” of toxic contaminants have been shown to alter and reduce benthic invertebrate communities and cause disease in aquatic organisms closely associated with the sediments. Sediments also contribute metals and organic compounds to higher trophic level organisms through food chain transfer. Continued monitoring of sediment chemistry will assist in identifying sources of contaminants to aquatic organisms and in tracking the environmental health of Puget Sound.

Invertebrates

The National Oceanic and Atmospheric Administration's (NOAA's) Mussel Watch program is the only comprehensive and long-term data set of metal and organic contaminant concentrations in Puget Sound invertebrates, and little is known about the ecological effects at the individual, population or ecosystem level of measured contaminant tissue burdens in benthic infauna and shellfish. Therefore, continued monitoring of contaminant levels in a variety of species, as well as research regarding potential effects is necessary. Additional recommended research topics include: the use of extrapolation factors between edible and non-edible tissues, and the speciation of arsenic and its bioavailability to mammalian consumers of benthic and infaunal invertebrates.

Fish

Fish tissue contaminant burdens and the toxic effects of metals and organic contaminants have been studied at numerous locations throughout Puget Sound. Findings of research conducted to date indicate that fish living in or migrating through the urban/industrial embayments of Central and South Puget Sound accumulate metals and organic contaminants to a greater degree than fish from non-urban sites, and are at higher risk for developing diseases (e.g., liver lesions in English sole), lowered reproductive success and impaired immune system function. Further research is necessary to determine sources of unusual observations of elevated contaminant concentrations (i.e., lead in Sinclair Inlet English sole, mercury in Foulweather Bluff rockfish); the ecological significance of greater PCB burdens in chinook salmon compared to coho; potential stock/population level effects of observed immune system dysfunction and disease; the significance of elevated PCB tissue concentrations to piscivorous wildlife; and early life stage effects of maternally-transferred contaminants.

Mammals

Limited data indicate that top carnivorous marine mammals such as harbor seals and killer whales accumulated organic contaminants such as PCBs in particular. While relatively little research has been conducted in Puget Sound specifically, PCBs have been associated with immune system impairment in marine mammals. Research is required to further elucidate the effects of measured tissue contaminants, as well as the sources of observed contaminants, including the relative importance of local versus international sources of PBTs.

Birds

Relatively few studies have been conducted on the birds of Puget Sound, consequently, there are insufficient data to determine temporal and spatial trends of contaminant tissue burdens, or to assess the potential effects of measured tissue concentrations. Specific questions raised by the available information included: the source of PCBs measured in the eagles of Hood Canal; the cause of eggshell thinning in great blue herons and glaucous-winged gulls; and, the potential sublethal effects of contaminant accumulation in migratory birds overwintering in urban estuaries.

Emerging Issues

During the last several years, some issues in the study of environmental contaminants have been moving to the forefront and may have implications for the direction of research in Puget Sound's marine environment. These issues include: the appropriateness of extrapolating laboratory toxicity studies to field conditions; the ecological relevance of the phototoxicity of polycyclic aromatic hydrocarbons (PAHs); the level of "recently" introduced organic compounds (e.g., polybrominated diphenyl ethers; pharmaceuticals and personal care products); and the speciation and potential bioavailability of cadmium in marine organisms consumed by mammals.

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1. INTRODUCTION

1.1 BACKGROUND AND HISTORY

In 1992, the British Columbia Premier Mike Harcourt and Governor Booth Gardner of Washington State signed an Environmental Cooperation Agreement that committed the province and state to promote and coordinate mutual efforts to ensure the protection, preservation and enhancement of our shared environment for the benefit of current and future generations. Shortly after the agreement was signed, the British Columbia/Washington Environmental Cooperative Council (ECC) was created to address the numerous issues transcending the boundary between British Columbia and Washington. The ECC formed the Puget Sound/Georgia Basin International Task Force to focus on environmental issues in the Strait of Georgia and Puget Sound. The Puget Sound/Georgia Basin International Task Force membership includes representatives from federal, provincial and state agencies, tribes, First Nations, and regional organizations from both sides of the international boundary (PSGBITF 2001).

In 1993, the British Columbia/Washington Environmental Cooperative Council appointed a Marine Science Panel (the Panel) comprised of six university and government marine scientists from British Columbia and Washington. The Panel was charged with making recommendations for management of the shared marine waters. After a year of analysis, the Panel presented twelve recommendations to the ECC in August 1994 which it believed the governments and citizens of the region should undertake as remedies for the highest priority environmental concerns. The EEC directed the Puget Sound/Georgia Basin International Task Force to develop actions to implement the Marine Science Panel's recommendations (PSGBITF 2001).

The International Task Force divided the Marine Science Panel's recommendations into high, medium and low priorities. Controlling toxic waste discharges was assigned a medium priority rating. The Panel noted that while some sources of toxic chemicals are being reduced, non-point sources of toxic chemicals remained a major obstacle to controlling sediment and microbial contamination in the shared waters. The Panel recommended that efforts to bring all point sources of toxic chemicals continue and additional emphasis be placed on controlling non-point sources of pollution including surface water runoff from urban and industrial areas (BCWMSP 1994).

The Task Force established Toxic Chemical Work Groups in British Columbia and Washington in 1998. The goals of these groups are to identify the toxic chemicals in shared waters, evaluate their risk, and propose to the British Columbia/Washington Environmental Cooperative Council and regulatory agencies a strategy to minimize this risk to the environment and economic well-being of our communities (PSGBITF 2001).

1.2 GEORGIA BASIN CLEAN WATER WORK GROUP

The Georgia Basin Clean Water Work Group (GBCWWG), co-chaired by Narender Nagpal of BC Ministry of Air, Land and Water and Ed Wituchek of Environment Canada (Pacific/Yukon Region), developed a Terms of Reference in 1998 that charged the group to identify and prioritize potential risks to the environment and human health from anthropogenic toxic substances, including input and loadings of toxic chemicals, areas of significant contamination, impacts of population growth, and the transport of toxic substances across the international border. The GBCWWG is to notify the Puget Sound/Georgia Basin International Task Force of any urgent environmental or health issues, pertaining to toxic substances, requiring immediate action and the actions required. The Terms of Reference also includes the identification of gaps in existing knowledge including research and monitoring, and a requirement to prioritize the filling of these gaps. A report addressing these issues will be provided to the Puget Sound/Georgia Basin International Task Force. The development of this report will include public consultation and will be coordinated with the United States counterparts. The report will develop options for mitigating the risks to the environment and human health from anthropogenic toxic substances, including strategies for implementation of these mitigation measures. These measures will be developed for toxic substances originating in Canada affecting only Canadian waters and, in cooperation with the United States work group, for toxic substances affecting the shared waters. The implementation plan will identify lead agencies and their potential roles (PSGBTWG 1998).

1.3 PUGET SOUND TOXICS WORK GROUP

The Puget Sound Toxics Work Group (PSTWG) is co-chaired by Mike Gallagher of the Washington Department of Ecology, and Mike Letourneau of the Region 10 office of the United States Environmental Protection Agency. Representatives on the PSTWG consist of state, federal, local governments, and representatives from tribes, businesses and non-government organizations residing in the Puget Sound region. A complete listing of members and their affiliations can be found in Table 1-1. The PSTWG met four times between 1999 and 2002:

- October 27, 1999 – Tacoma;
- May 18, 2000 – Olympia;
- January 31, 2001 – Seattle; and
- October 26, 2001 – Seattle.

In addition, a joint meeting of the Puget Sound Toxics Work Group and the Georgia Basin Clean Water Work Group was held on June 21, 2000 in Mount Vernon.

Table 1-1: Members of the Puget Sound Toxics Work Group

NAME	AFFILIATION
Co-Chairs	
Mike Gallagher	Department of Ecology
Mike Letourneau	US EPA Region 10
Environmental Interest Organizations	
Laurie Valeriano	Washington Toxics Coalition
Soundkeeper	Puget SoundKeepers Alliance
Kathy Fletcher	People for Puget Sound
Business/Industry Organizations	
Grant Nelson	Association of Washington Business
Bill Dewey	Taylor Shellfish Farms
Lincoln Loehr	Heller-Ehrman-White-McAuliffe
Tribal Nations	
Grant Kirby	Northwest Indian Fisheries Commission
Denise Dailey	Makah Tribe
Don Llopfer	Stillaguamish Tribe
Michael Cochrane	Northwest Indian College
Washington State Agencies	
Ann Wick	Washington Department of Agriculture
Gary Bailey	Washington Department of Ecology
Cheryl Niemi	Washington Department of Ecology
Sandi O'Neill	Washington Department of Fish and Wildlife
James E. West	Washington Department of Fish and Wildlife
Steve Jeffries	Washington Department of Fish and Wildlife
Joan Hardy	Washington Department of Health
Allison Ray	Washington Department of Transportation
Tim Goodman	Washington Department of Natural Resources
John Dohrmann	Puget Sound Action Team
Scott Redman	Puget Sound Action Team
Federal Agencies	
Dave Kendall	US Army Corps of Engineers
Mary Mahaffy	US Fish and Wildlife Service
Tracy Collier	NOAA
Christine Psyk	US EPA
Roseanne Lorenzana	US EPA
Dana Davoli	US EPA
Bruce Duncan	US EPA
Lon Kissinger	US EPA
Public Ports	
Eric Johnson	Washington Public Ports Association
Other	
Andrea Copping	Washington Sea Grant Program
Dan Riley	Western State Petroleum Association
Peter Hildebrandt	Environmental Consultant
John Calambokidis	Cascadia Research

Note: This list comprises members on the PSTWG mailing list; an average of 12 people attend workgroup meetings. The statements made in this report do not necessarily reflect the views of the members or their affiliations.

1.4 OVERVIEW OF REPORT

The Puget Sound Toxics Work Group was established to determine the status, trends, and gaps regarding toxic chemicals in the waters, sediments, and biota of Puget Sound. The Work Group works cooperatively with the Georgia Basin Clean Water Work Group to identify areas of mutual concern within shared waters of Puget Sound and Georgia Basin. It is the intent of the work group to report to the British Columbia/Washington Environmental Cooperation Council on their findings and make recommendations on furthering the control of toxic discharges into Puget Sound (PSTWG 2000).

At their May 18, 2000 meeting, the Puget Sound Toxics Work Group agreed, for discussion and reporting purposes, to adopt the physical and political boundaries established by the Marine Science Panel for Puget Sound. Figure 1-1 depicts the boundaries of Puget Sound and Georgia Basin as recognized by the Marine Science Panel. These boundaries extend to the northwestern point (Neah Bay) of Washington State, the southern marine water boundaries near Olympia, Washington, the Cascade mountains to the east and the international border to the north (BCWMSP 1994).

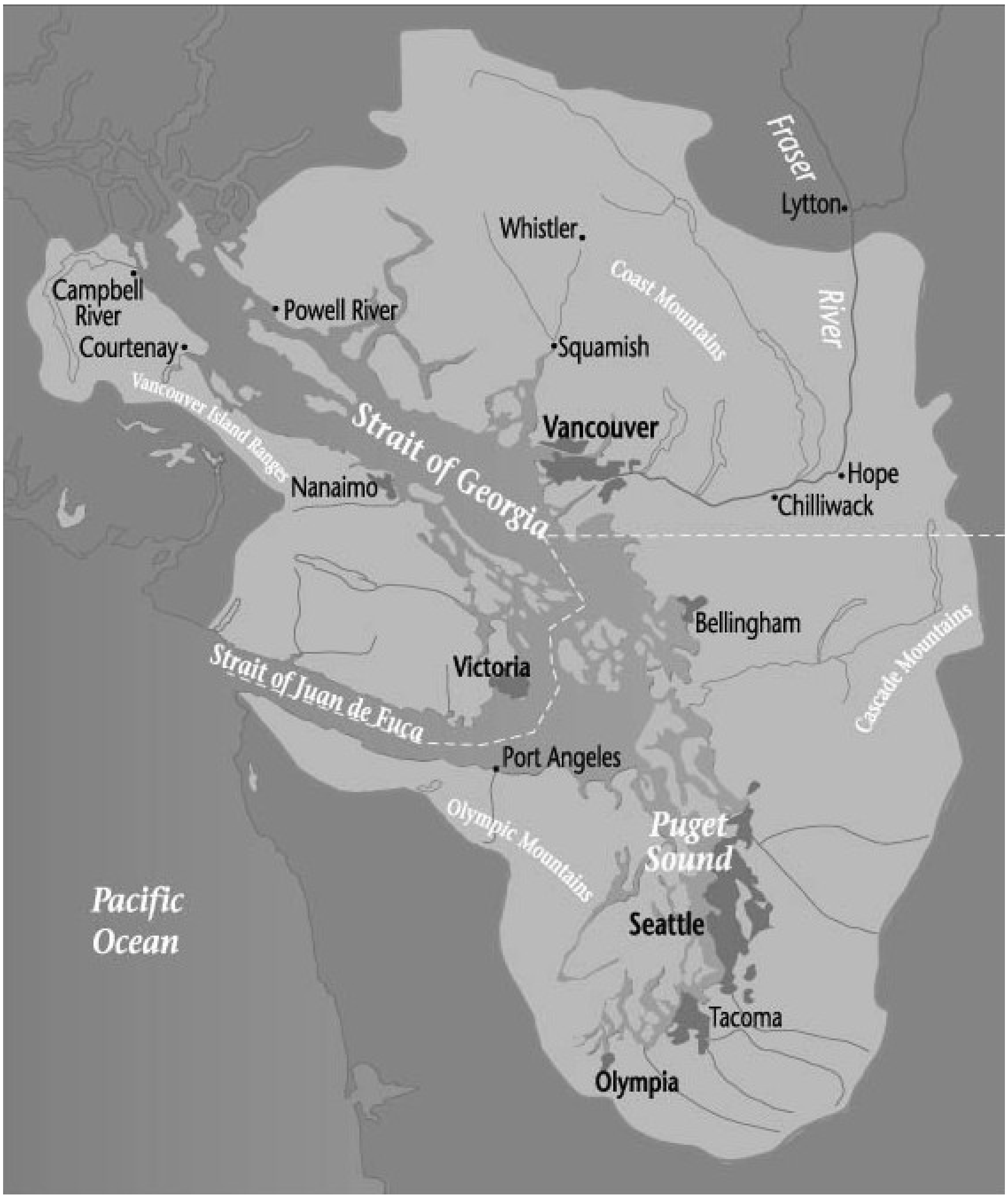
For the purpose of discussions and the generation of this report, the Puget Sound Toxics Work Group also agreed to adopt the Marine Science Panel's definition of a toxic which is any chemical that results in acute or chronic impairment of a biological organism. The Marine Science Panel defines impair as:

> to diminish strength, value, quantity or quality synonym: injure, biological as: of, pertaining to, caused by, or affection life or living organisms and organism as: any living individual; any plant or animal (BCWMSP 1994).

The Puget Sound Toxics Work Group, was provided funding by the Puget Sound Action Team, (pass-through funds from Region 10 EPA) to hire a contractor for research and generation of parts [the body] of this report. In addition, the PSTWG requested that the contractor propose recommendations for additional research and monitoring of toxics in Puget Sound. This report was developed utilizing published and unpublished reports, and interviews with PSTWG members and other experts working on toxics issues in Puget Sound. This report has been reviewed and approved by the PSTWG and the recommendations provided in this report include recommendations made by the contractor (EVS Environment Consultants) and the PSTWG. While this report is intended to meet the charge made to the PSTWG by the Puget Sound/Georgia Basin International Task Force, it is not intended to be a definitive report on all the toxics issues in Puget Sound.

This report is organized in a manner to give the reader a general overview of the toxic chemicals of concern in the Puget Sound Ecosystem, the pathways by which they enter and move through the various media and biota, and the effects of these chemicals on the biota. Where sufficient data exists, this report provides information on concentration trends of the various chemicals and compares concentrations to existing regulatory criteria. In addition, this report identifies those agencies responsible for regulating and monitoring toxics in Puget Sound, and describes research efforts conducted by non-regulatory organizations.

Figure 1-1: Boundaries of Puget Sound and Georgia Basin



1.5 PUGET SOUND TOXICS WORK GROUP CO-CHAIRS

Questions and comments regarding this report can be made directly to the co-chairs of the Puget Sound Toxics Work Group.

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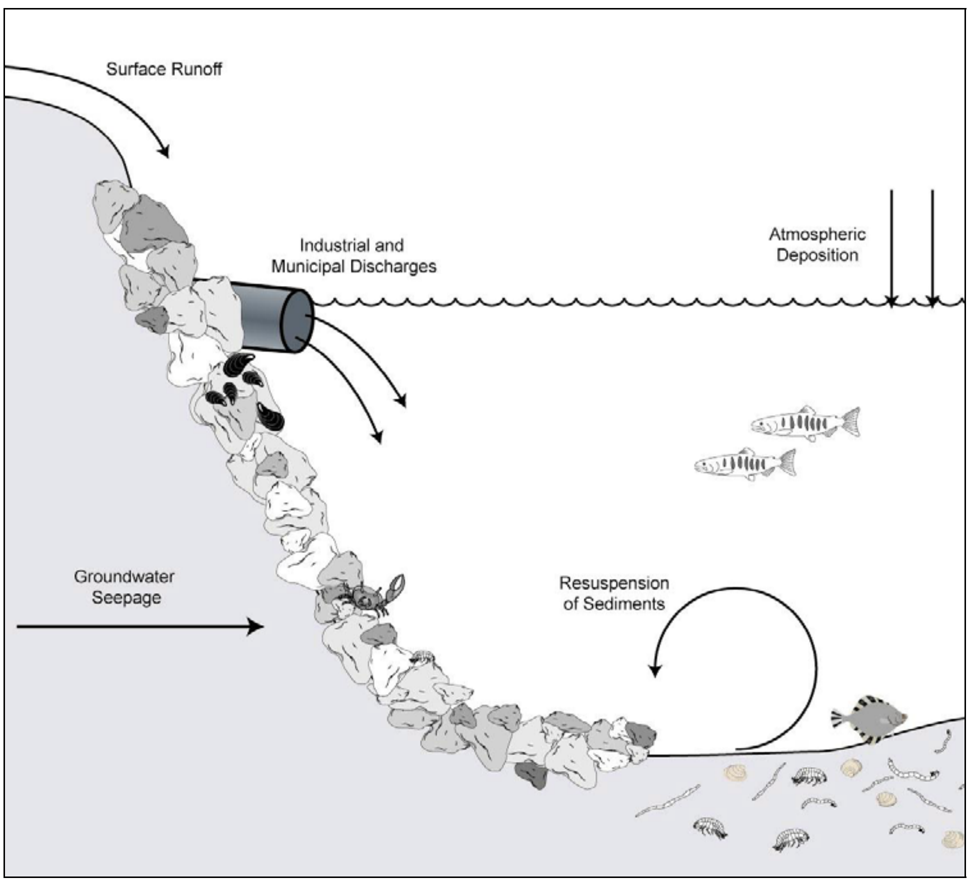
2. SOURCES AND PATHWAYS OF TOXIC CONTAMINANTS IN THE PUGET SOUND ENVIRONMENT

2.1 BACKGROUND

Toxic contaminants reach the aquatic environment through a variety of sources and human activities. In the Puget Sound area, industrial and municipal discharges (permitted and non-permitted), groundwater seepage, atmospheric deposition, and resuspension of sediments can result in the exposure of marine organisms in the receiving environment (Figure 2-1). The contaminants from some sources (i.e., operationally-contaminated industrial sites) may reach the aquatic environment by one or more of these pathways, depending on the nature of the contaminant.

Figure 2-1: Simplified conceptual model of contaminant pathways to the Puget Sound aquatic environment.



2.1.1 Toxic Metals

All elements have a known natural abundance in the environment, as geochemical components of sediments, soils and rocks. Natural weathering processes mobilize these compounds and transport them into streams, rivers and eventually, ocean. However, greater quantities or metals generally enter the aquatic environment through anthropogenic sources such as fossil fuel combustion, industrial emissions, the discharge of municipal wastewaters and via surface runoff (Table 2-1).

Table 2-1: Summary of anthropogenic sources of selected metals to the aquatic environment.

Metal	Sources	
Arsenic	• Industrial emissions, • Insecticides, • Wood preservatives, • Fossil fuel combustion, • Industrial wastes,	• Past applications of lead-arsenate, • Active and abandoned gold- and base-metals mines, ore processing facilities
Cadmium	• Base-metal smelting and refining; • Metal plating; • Manufacture of pigments, batteries and plastics;	• Fossil fuel combustion; • Solid waste disposal and • Sewage sludge applications
Copper	• Industrial effluents, particularly from smelting, refining, and metal plating industries; and	• Municipal wastewaters
Lead	• Manufacture of gasoline additives, pigments, alloys, and ammunition; • Vehicle maintenance and equipment repair; • Antifouling paint on ship hulls and bridges; • Tanks and piping;	• Petroleum refining; • Batteries; • Heavy metal soaps; • Automobile exhaust; • Municipal waste water discharges
Mercury	• Fossil fuel combustion; • Metal mining and reprocessing; • Removed and improperly disposed dental amalgam material	• Chloralkali plants; • Disposal of fluorescent lamps, thermometers, automobile light switches, and thermostats;
TBT	• Antifouling paint additive on ship and boat hulls, docks, fishnets, and buoys; • Fungicidal wood preservatives;	• Textile disinfectants; • Stabilizers in PVC resin.

Sources: Atkinson 1992; Eisler 1987a; Eisler 1988a; Environment Canada 1993a; Environment Canada 1994a; EXTOXNET 1996; Garrett and Shrimpton 1997; USEPA 1985

The toxicity of metals to aquatic organisms ranges widely from slight reduction in growth rates to mortality and may be manifested acutely (i.e., after a short term exposure) or over a longer term (i.e., chronically). The expression of toxic effects in aquatic organisms is dependent on several factors including:

- Exposure route, duration and concentration;
- The form of the metal at the time of exposure (e.g., inorganic arsenic is more toxic than the organic form, while methylmercury is more toxic than inorganic mercury), which can be affected by site-specific physical and chemical conditions (e.g., pH, redox);
- External and internal synergistic, additive or antagonistic interactions of co-occurring contaminants (e.g., cadmium has been observed to reduce the teratogenic effects of methylmercury on fish);
- Sensitivity of a given organism (e.g. mollusks are generally less sensitive to metals than other aquatic phyla);
- Life stage (e.g., embryonic and larval stages of benthic organisms are generally more sensitive);
- Physiological ability to detoxify and/or excrete the metal (e.g., some vertebrates synthesize a protein, metallothionein, which can sequester metals); and,
- The condition of the exposed organism (e.g., a fish that is stressed by elevated water temperatures is more sensitive to toxicant exposure).

2.1.2 Organic Contaminants

Some organic compounds, such as polycyclic aromatic hydrocarbons (PAHs) and dioxins and furans can be naturally occurring (e.g., produced during forest fires) or are byproducts of industrial processes, and have no known uses. PAHs and dioxins and furans continue to be discharged into the environment from both natural and anthropogenic sources. Other organics such as polychlorinated biphenyls (PCBs) are entirely synthetic were and not found in the environment prior to initial production in the 20^{th} century. Even though the manufacture and use of PCBs and organochlorine pesticides ceased in the 1970's, they can still be found in the aquatic environment today and continue to affect aquatic organisms. The anthropogenic sources of selected organic contaminants are summarized in Table 2-2.

Organic compounds range from the simple methane molecule to long-chained, multi-ringed, halogenated structures that vary in persistence in the environment and effects on aquatic organisms. The fate and transport of organic compounds in environmental systems is controlled by the partitioning of the compound between sediment, suspended particulates, pore water, surface water and biota. The observed partitioning of non-ionic organic chemicals like PCB is due to sorption to organic phases, including dissolved organic matter in pore water and sedimentary organic matter. The extent to which a chemical is associated with organic matter relative to their dissolved aqueous concentrations is related to a number of factors including molecular weight, and number and position of chlorine atoms in the case of chlorinated compounds.

Table 2-2: Summary of anthropogenic sources of selected organic compounds.

Organic Compound	Sources	
PCBs	• cooling and insulating fluids in industrial transformers and capacitors • hydraulic fluids, • heat transfer fluids • plasticizers	• paints, • inks, • dust control agents, • carbonless paper and • pesticides
PAHs	• aluminum smelters, • metallurgical and coke production, • creosote-treated products (e.g., marine pilings), • petroleum spills,	• municipal effluents (including stormwater runoff) and • deposition of atmospheric PAHs
Pesticides	• Runoff from agricultural areas • Runoff from residential areas	• Industrial emissions
Dioxins and furans	• manufacture of chlorophenols and their derivatives (used in wood treatment), • from bleaching processes in pulp and paper mills or • incomplete incineration of other chlorinated organic compounds such as PCBs • ash residues and emissions of municipal waste incinerators, • trace impurities in some commercial herbicides such as 2,4,5-T, 2,4-D and 2,4,6-trichlorophenol	• Fossil fuel power plants, • internal combustion engines, • beach bonfires, • residential burning of garbage, • home fireplaces, and • cigarette smoke
Phthalate esters	• plasticizer in polyvinyl emulsions, • antifoaming agents, • suspension agent for solids in aerosols, • lubricant for aerosol valves,	• perfume solvent and fixative, • skin emollient, and • plasticizer in nail polish and hair spray. • municipal waste sludges.

Sources: Alford-Stevens 1986; Atkinson 1992; Environment Canada 1994b; IEMPOP 1995; Kociba and Schwetz 1982a,b; NOAA 1994; PTI 1991.

Organic compounds have a wide range of effects on aquatic organisms, from reproductive impairment such as reduced fecundity and viability of offspring, developmental impairment such as brain and skeletal deformations and reduced growth, to acute mortality of both adults and juveniles. Of particular concern are the persistent, bioaccumulative and toxic compounds. Because many organics are lipophilic, they tend to accumulate in fatty tissues unless the organism has a mechanism for metabolizing and excreting the compound. The contaminants can then be biomagnified up the food chain, resulting in exponentially higher concentrations in higher trophic level organisms such as carnivorous marine mammals. As with metals, the expression of toxic effects related to organic contaminants is dependent on several factors (Section 2.1.1).

2.2 CONTAMINANT SOURCES AND PATHWAYS IN PUGET SOUND

As Figure 2-1 shows, toxic contaminants can reach the marine environment via a number of pathways, including point-source industrial and municipal discharges, surface water runoff, groundwater seepage, resuspension of sediments, and atmospheric deposition. The largest wastewater contributions to Puget Sound come from various industrial facilities and municipal sewer systems (TetraTech 1988). Typical industries located near Puget Sound include: bleach plants; copper smelters; coal handling sites; chrome and silver plating industries; docks; dry cleaners; metal industries; wood treatment facilities; organic chemical manufacturing plants; oil refineries; pulp mills; petroleum distributors; paint and ink industries; photography industries; plastics; roofing; rubber manufacturers; ship building and repair; and scrap yards (PSEP 1991 and references therein).

The long history of industrial activity in Puget Sound has also left a legacy of contaminated sites along the shore, particularly in the urban centers of Seattle and Tacoma. The groundwater underneath and/or sediments adjacent to such sites may still be a source of contaminants to marine biota today. The primary industries that caused historic contamination in the Sound included aluminum smelters, oil refineries, and pulp and paper mills. A significant volume of sediment contaminants have been assessed and cleaned up in areas such as Elliott Bay and Commencement Bay and its waterways, and sediment assessment and cleanup continue today.

In the late 1980s, a series of reports documenting contaminant sources to individual waterbodies (e.g., Elliott Bay, Sinclair Inlet) were prepared under the auspices of the USEPA's National Estuary Program. Since that time, however, contaminant sources have not been reviewed and catalogued in any detail. As a result, scientists and regulators do not have easy access to information that would help them determine where and how toxic contaminants are getting into the food web.

2.2.1 Recommendations

To assist in tracking the sources and effects of toxic contaminants in the Puget Sound marine ecosystem, it is recommended that contemporary sources such as industrial and municipal wastewater discharges, combined sewer overflows and stormwater discharges be identified and quantified.

SOURCES AND PATHWAYS: RECOMMENDATIONS

1. ***Identify contaminants currently present in stormwater runoff and in wastewater treatment plant effluent.***

   The quality and quantity of contaminants present in stormwater runoff and municipal wastewater effluents has likely changed considerably over time due to the increasing population in municipalities surrounding Puget Sound, and to significant source control efforts being made by some counties. A regular characterization of both types of effluent will provide useful information regarding the potential for effects in the receiving environment and for further source control needs. NPDES permits for both stormwater and sanitary discharges often require effluent monitoring, however, compliance is often based on minimal conventional parameters. Therefore, monitoring data submitted in fulfillment of permit requirements does not provide a full characterization of the effluent.

2. ***Conduct periodic screening toxicity tests on first-flush stormwater discharges.***

   One of the greatest concerns regarding the discharge of stormwater to the aquatic environment is the potential loading of contaminants in the "first flush" of surface runoff after a dry period. Atmospheric deposition and residuals from vehicle use accumulate on roadways and the first rain after a dry period can result in a significant "slug" of toxic metals and organics to the receiving environment from stormwater outfalls. One approach to assessing the constituents in stormwater effluent is to conduct screening toxicity tests on first-flush discharges with subsequent chemical analysis if toxicity is observed.

3. ***Determine loading from stormwater outfalls, WWTPs, CSOs and EOFs to Puget Sound.***

   Once stormwater and wastewater effluents are characterized the loading of toxic metals and organic contaminants can be assessed. Such an exercise can contribute to tracking the effects and transport of contaminants of concern through the Puget Sound environment. It would also provide valuable information regarding the need for source control efforts.

4. ***Determine loading from atmospheric inputs.***

   There are few data addressing the quantity or quality of atmospheric deposition in Puget Sound. Long-range transport of pollutants from the western Pacific Rim to North America has become the subject of significant research. There has been and likely will continue to be increases in coal and other industrial emissions from developing countries in Asia; air from Asia can be transported to the west coast of the U.S. in as few as five days (Jaffe et al. 1999). Industrial emissions from within Puget Sound itself can also be a significant source of atmospherically-derived contaminant deposits in the marine environment (PSEP 1991).

Assessing loadings from atmospheric deposition would be useful in determining potential effects to organisms inhabiting the sea-surface microlayer.

5. ***Develop a mass-balance model for toxic metal and organic contaminants in Puget Sound.***

   To assist in identifying sources of contaminants and the relative importance of major transport pathways, it would be useful to develop a model of contaminant inputs to Puget Sound.

6. ***Continue cleanup of contaminated upland and sediment sites throughout the Puget Sound Basin.***

   Much progress has been achieved in the cleanup of contaminated upland and sediments throughout the Puget Sound Basin. However, many contaminated sites still await assessment and cleanup. This activity needs to continue into the future to further decrease the contribution of toxic contaminants from various point and non-point sources to Puget sound.

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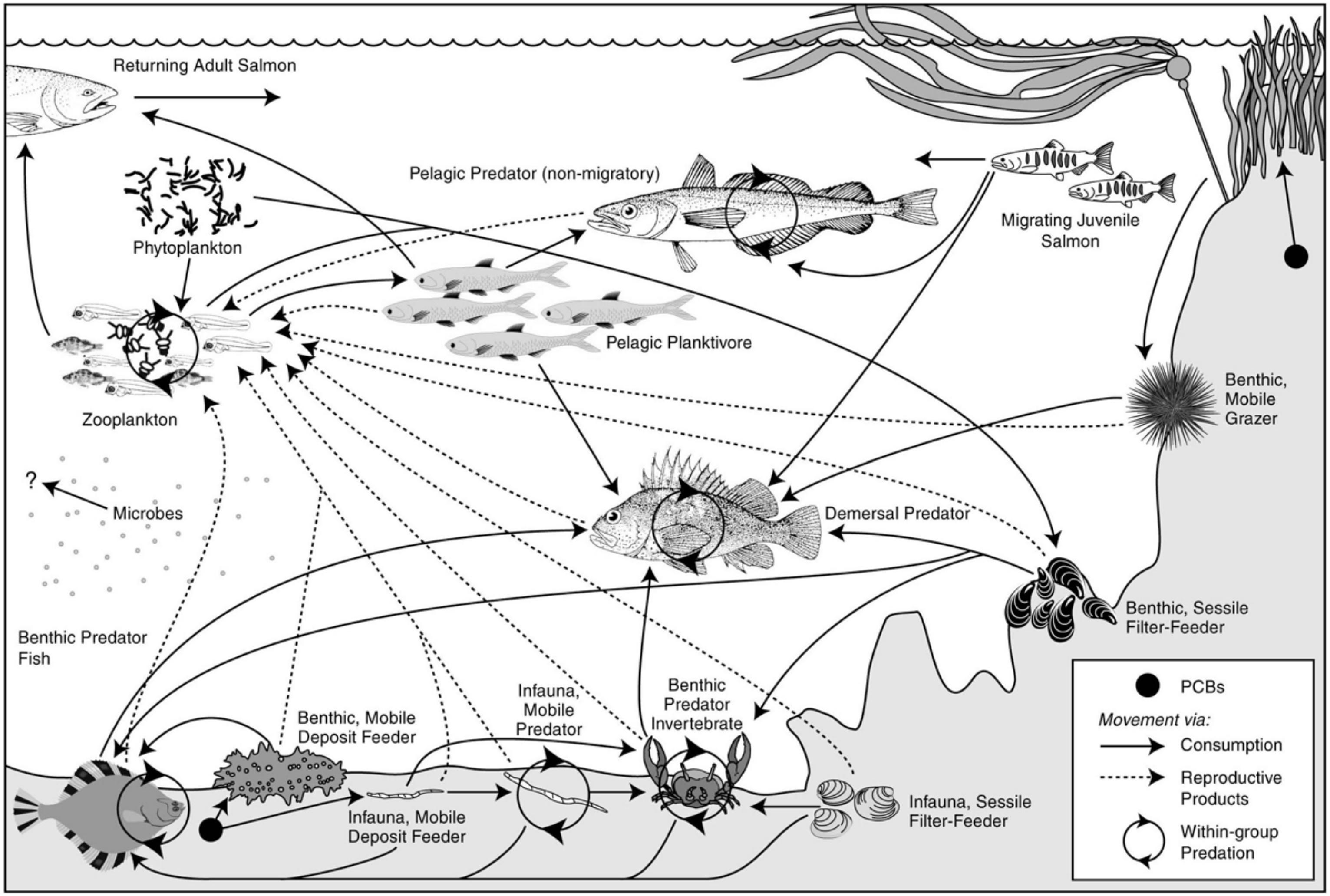
3. FATE AND EFFECTS OF CONTAMINANTS IN PUGET SOUND

Contaminants can enter the Puget Sound aquatic environment via a number of pathways (EVS 2003). Once these contaminants are in the water and sediments of the Sound, portions of the contaminant load can become available to aquatic biota. Both chronic (i.e., sublethal effects such as reduced fecundity or growth, or behavioral modifications that occur after prolonged exposure) or acute (i.e., mortality that occurs after a short exposure to high concentrations) effects can result when aquatic organisms take up and assimilate various contaminants into their body tissues. Numerous properties of the contaminants, as well as of the sediments and of individual marine species, interact in the final expression of toxicity.

In order to better understand these complex interactions, a conceptual model of PCB transfer pathways and aquatic receptor species is included (Figure 3-1). This conceptual model is intended to illustrate the variety of pathways and receptors that might be applicable to Puget Sound as a whole; site-specific conditions, especially changes in land use patterns, will alter the presence (and significance) of the applicable pathways and receptors. The model shows the potential for trophic transfer of contaminants; for example, benthic fish feed on soft-bottom and hard-bottom invertebrates, taking in the contaminant body burdens of their prey, as well as any incidental ingestion from the sediments. These benthic fish then become food items for larger pelagic fish, which are in turn fed upon by predatory marine mammals such as whales and otters.

Figure 3-1: Conceptual model for PCB cycling in the lower food web of the Puget Sound aquatic environment (courtesy of J. West and S. O'Neill of WDFW).



3.1 WATER QUALITY

Puget Sound is a complex collection of embayments, deep water channels and industrialized waterways. Tidal exchange from the Straits of Georgia and Juan de Fuca results in considerable dilution of the water column, while at the same time shallow sills on the ocean floor restrict the movement of deeper waters (Harrison et al. 1994). Due to the diverse physical oceanography of Puget Sound, water quality conditions are varied.

3.1.1 State of Knowledge

Limited data were available for an assessment of toxic metals and organics in the water column of the Puget Sound ecosystem. The data that were available suggest that water column contaminants are highest in urban/industrial embayments, but that metals concentrations in places such as Commencement Bay and its waterways have decreased as a result of contaminated site cleanup and source control efforts (Johnson and Summers 1999; PSWQA 1991).

Furthermore, contemporary data showed that metals and organic contaminant concentrations were below both chronic and acute water quality criteria for the Puget Sound waters of King County and for Commencement Bay. Initial studies of the sea-surface microlayer (SMIC) in the 1980s show that this biologically important ecotone may be at risk for adverse effects from metal and organic contaminant enrichment (Hardy et al. 1987a,b).

3.1.2 Contaminant Effects

- Toxic contaminants in the sea-surface microlayer (i.e., metals, petroleum hydrocarbons, chlorinated organics) in urban/industrial embayments have been reported to reduce hatchability of sand sole eggs during *in situ* toxicity tests (Hardy et al. 1987b).

3.1.3 Monitoring and Data Gaps

Monitoring and data gaps and other issues related to metals and organic contaminants in the water column of Puget Sound include the following:

- Chemical and toxicological analysis of contaminants in the sea-surface microlayer were conducted in the 1980s; there are no data to provide an assessment of current conditions in the SMIC or to determine temporal trends;

- Toxic contaminants other than metals are infrequently measured in the water column, for example, organophosphate pesticides, which are less persistent than other pesticides but can have significant effects on biota;
- The comparison of historical (where available) and current data is difficult due to changes in laboratory analytical techniques and in water quality criteria (i.e., dissolved versus total recoverable);
- There is a lack of monitoring to document changes in environmental health related to source control efforts (Mearns, pers. comm. 2002);
- TBT data for the water column have been collected in Puget Sound but the results are proprietary in nature (Cardwell, pers. comm. 2002) and therefore not publicly available

3.1.4 Recommendations

It is apparent that metals and organic contaminants in surface waters can have considerable effects on the marine organisms of Puget Sound. In order to determine regions of the Sound that may be vulnerable to surface water pollution, sources must be identified and quantified.

SURFACE WATERS: RECOMMENDATIONS

1. ***Conduct marine water monitoring programs for metals and organic contaminants to track changes in environmental health and success of source control programs.***

   Because of the complex behavior of metals and organic contaminants in seawater, and a propensity for these chemicals to partition into sediments and biota, water quality monitoring needs to be focused at locations where the contaminants occur in measurable concentrations and where effects may occur, such as in the vicinity of point source discharges (i.e., industrial effluent discharges, CSOs, stormwater outfalls) and at the sea-surface microlayer. Such monitoring is important for identifying the need for and success of source control programs. Monitoring efforts may include chemical analysis of surface water samples, as well as toxicity testing with one or more representative organisms.

2. ***Reassess the chemistry and toxicity of the sea-surface microlayer.***

   In the mid-1980s chemical analyses and toxicity tests were conducted on the SMIC in Puget Sound in order to determine the sources, fate and effects of toxic contaminants at the atmosphere-hydrosphere interface (Hardy et al. 1987a,b). Sources of the SMIC contaminants were suggested to be direct or indirect atmospheric deposition of metals and fossil fuel combustion byproducts, and the upwelling of domestic sewage from subsurface outfalls (Hardy et al. 1987b). An additional potential source for contaminants in the SMIC is the suspension of benthic sediment during dredging (Word et al. 1987). A recent study of Burrard Inlet, the site of British Columbia's main port facility, indicated metals and PAH enrichment of the SMIC compared to the underlying water column (Moore and Freyman 2001), suggesting that contamination of the SMIC is still a problem in the general geographic area of the Georgia Basin/Puget Sound.

3. ***Investigate the bioavailability of SMIC metals and develop SMIC screening benchmarks specific to Puget Sound.***

   Metals concentrations detected in the sea-surface microlayer of Puget Sound (Hardy et al. 1987a,b) were several orders of magnitude higher than those detected in the subsurface water column and approached or exceeded both the acute and chronic criteria for marine waters (EVS 2003). However, comparison of SMIC contaminants to existing water quality criteria may not be meaningful because metal speciation and therefore toxicity of contaminants may be markedly different than in the subsurface water column (Hardy 1982).

4. ***Investigate the potential for SMIC contaminants to affect intertidal organisms.***

   Sea-surface microlayer contaminants may be deposited on intertidal substrates during ebb tide and affect epibenthic and infaunal species (Gardiner 1992). In conjunction with research regarding the magnitude and bioavailability of SMIC metals and organic compounds, it would be useful to investigate the potential effects of these contaminants on intertidal organisms.

3.2 SEDIMENT QUALITY

Many contaminants have an affinity for the organic or inorganic components of sediment particles. As a result, sediments often act as a contaminant sink with substantially higher concentrations than in the overlying water. During the last decade, chemical contamination of aquatic sediments has been recognized as a serious problem in some U.S. coastal waters. In Puget Sound, for example, "hot spots" of toxic contaminants have been shown to alter and reduce the benthic community (both abundance and species diversity), to interfere with cellular and physiological processes, and cause disease in aquatic organisms (EVS 2003). Contaminants may also affect higher trophic organisms such as mammals through bioaccumulation or biomagnification of the contaminants in the food web. Potential sources of contaminants include historical activities on adjacent upland areas as well as present-day discharges (i.e., industrial and municipal effluents, combined sewer overflows, stormwater, improper disposal of dredgate). Most hot spots are in areas of high vessel traffic, industrial activities, or poor flushing and are often located near urban centers (NOAA 1994).

3.2.1 State of Knowledge

A recent (1997-1999) Puget Sound-wide sediment sampling program that measured bulk sediment chemistry, laboratory toxicity and benthic community structure indicated that a majority of the Sound has healthy sediments (Long et al. 1999, 2000, 2002). The discharge of certain chemicals into the Puget Sound environment has decreased as a result of source control efforts, and significant cleanup efforts have been conducted at contaminated sediment sites in many of the Sound's urban/industrial embayments.

However, sediment contaminants continue to be a problem in some areas and sediment data collected in the last decade indicate that:

- The highest contaminant levels are located in hot spots such as urban/industrial harbors and near municipal and industrial effluent discharges, with a general trend of more contaminants in the central Puget Sound basin;
- Historically contaminated sediments continue to be a source of persistent bioaccumulative toxics, such as PCB, to the marine food chain;
- Laboratory toxicity tests are not always predictive of effects on benthic invertebrate communities related to sediment contaminants;
- The presence/absence of benthic organisms can be an indicator of the magnitude of sediment contamination, although sediments where there is a healthy benthic

community can still contribute to effects in higher trophic level organisms through food-chain transfer of the contaminants;

- There is evidence that source control efforts and *in situ* capping are resulting in decreased PAH sediment concentrations in the biologically active zone (i.e., surficial sediments) at some cleanup sites (e.g., Eagle Harbor);
- Lead sediment concentrations have decreased significantly Sound-wide as a result of source control efforts.

3.2.2 Contaminant Effects

- Sediment PAHs have been implicated in the elevated incidence of liver disease in the English sole of contaminated areas such as the urban/industrial waterways of Elliott Bay and Commencement Bay;

3.2.3 Monitoring and Data Gaps

Monitoring and data gaps related to metals and organic contaminants in the sediments of Puget Sound include the following:

- It is likely that not all historically contaminated sediments have been identified;
- There are no recent sediment core data (Yake 2001; Mearns 2001). As well, cores have only been collected from the central basin of Puget Sound, thus it is difficult to gauge temporal trends in sediment contaminant concentrations;
- Sediment data are not consistently entered into a single database; rather, they may be entered into SEDQUAL or a national database maintained by NOAA, or may not be entered at all;
- Background concentrations of some contaminants such as PCB have not been characterized sufficiently;
- Current laboratory methods in use for some compounds may have higher method detection limits than environmental concentrations of concern;
- There are insufficient data regarding the presence/composition of individual PCB or dioxin congeners in sediments to support human health risk assessments.

3.2.4 Recommendations

Metals and organic contaminants in sediments can have considerable effects on the marine organisms of Puget Sound, either via direct contact, or through food-chain transfer. In order to determine areas with suspected sediment contamination and the potential for effects in the environment, sources must be identified and quantified.

Sediments: Recommendations

1. ***Maintain sediment monitoring programs to track changes in the environmental health of Puget Sound.***

   The Puget Sound Ambient Monitoring Program's (PSAMP) Marine Sediment Monitoring Program (MSMP) has provided a significant volume of chemistry, laboratory toxicity, and benthic community data related to Puget Sound sediments. These data have been collected through two programs:

   - The regular monitoring of core and rotational sampling locations at five year intervals to determine ambient sediment conditions in Puget Sound (PSWQAT 2002); and,
   - A three-year program (1997-1999) conducted jointly with NOAA to characterize Puget Sound sediments at 300 randomly chosen stations (Long et al. 1999, 2000, 2002).

   The data collected through the two sampling programs have provided valuable information regarding the distribution of selected metals and organic contaminants throughout Puget Sound and the potential for effects in associated marine fauna. Continued monitoring at regular intervals will add to the body of information available and will provide a means of tracking the environmental health of Puget Sound.

2. ***Additional sediment core samples, including from areas of Puget Sound that have not yet been sampled, should be collected to further track temporal trends in sediment contaminant concentrations.***

   Temporal trends in sediment chemistry have been illustrated through deep sediment cores collected in 1991 from the central Puget Sound basin (Lefkovitz et al. 1997). The sediment cores indicated that both metals and organic contaminants concentrations peaked in the middle of the last century and appeared to have declined through to 1991 when the cores were taken. Given the fact that the concentrations of contaminants such as PCBs appear to have stabilized in marine organisms such as harbor seals (EVS 2003), it would be valuable to have current core data to see if sediment contaminants have also stabilized.

3. ***Enter sediment data consistently into one, central database for Puget Sound.***

   A number of sediment databases exist, in which data from Puget Sound may be entered (i.e., SEDQUAL; NOAA database), and some studies may not be entered into an electronic database at all. To facilitate the tracking of contaminant trends and cleanup efforts, sediment data (including chemistry, toxicity and benthic community data) should be consistently entered into one central database. This database could potentially be used in conjunction with a tissue burden and effects database, which would be useful in determining spatial and temporal trends and trophic transfer of these contaminants.

4. ***Compare the locations of highly contaminated sediments identified by Long et al. (1999, 2000, 2002) with identified clean-up sites to help direct future clean-up assessment efforts.***

   Long et al. (1999, 2000, 2002) estimated that 22 km^2 of Puget Sound sediments had high contaminant concentrations, exhibited significant laboratory toxicity and suffered from an altered benthic invertebrate community. These areas should be compared to identified clean-up sites to help direct future clean-up assessment work.

5. ***Sediment cleanup efforts should be given a higher priority to reduce the availability of persistent toxic chemicals to the aquatic organisms of Puget Sound.***

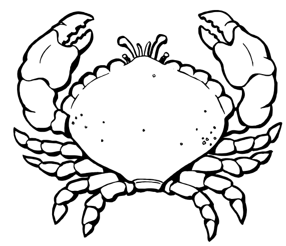
   Much progress has been achieved in the cleanup of contaminated sediment sites throughout the Puget Sound Basin. However, many contaminated sites await assessment and cleanup. Contaminated sediments continue to function as a source of persistent toxic chemicals (e.g., PCB, mercury) to Puget Sound. As a result, higher trophic level consumers such as marine mammals and humans continue to be at risk of exposure to harmful levels of these compounds as they bioaccumulate from the sediments through the food web.

3.3 BIOTA

Puget Sound is a physically complex ecosystem with a wide range of habitat types supporting diverse and abundant aquatic life. Contaminants observed in the water column and sediments may exert acute and/or chronic effects on the organisms that come into direct contact with them, either via dermal exposure or dietary intake. The mechanisms of bioaccumulation and biomagnification result in the further trophic transfer of contaminants through the food web. As a result, localized contamination has been observed to have a far-reaching effect on some species, such as killer whales and other marine top carnivores.

3.3.1 Invertebrates

Invertebrate species in Puget Sound occupy a wide range of habitats and employ a variety of feeding strategies. They may be exposed to contaminants by dermal contact and diet (e.g., burrowing mollusks and polychaetes, benthic crustaceans), while other species such as mussels inhabit areas less proximal to contaminated sediments but may bioaccumulate contaminants from particulate matter in the water column.



3.3.1.1 State of Knowledge

NOAA's Mussel Watch program is the only comprehensive and long-term data set of metal and organic contaminant concentrations in Puget Sound mollusks. Additional studies have provided further information on mollusks as well as other marine invertebrates species. These studies have shown that:

- Because mussels are filter feeders, they tend to have lower tissue contaminant burdens than invertebrates more closely associated with sediments (Ylitalo et al. 1999). Any assessment regarding contaminant trends will tend to be an underestimate of what is happening with benthic organisms such as clams and crabs;
- Arsenic concentrations in marine invertebrates regularly exceeded prescribed screening benchmarks for the protection of piscivorous wildlife and human health. However, the arsenic is predominantly in a form that is not toxic to the organism or consumers;
- There is no clear geographic trend in tissue metals residues that can be related to human activities. For example, cadmium concentrations were found to be highest in mussels from the outer Washington coast;

- Shellfish from both 303(d) listed and reference locations exceeded the inorganic arsenic listing criterion (0.006 $\mu g \cdot g^{-1}$), however, the observed concentrations were likely due to naturally occurring conditions in Puget Sound (Roose and Johnson 2002);
- PCBs and DDT have been detected in almost all of the tissue samples analyzed, while dieldrin has been detected in approximately two thirds of the samples and other organochlorine pesticides have not been detected at all;
- The highest organochlorine residues have been found in organisms from Commencement Bay and Elliott Bay;
- PCB concentrations in mussel and crab edible tissues generally exceeded the 1 in 100,000 cancer risk benchmark, particularly for samples from urban embayments in Central Puget Sound;
- PCB concentrations in mussel and crab edible tissue did not exceed the noncarcinogenic effects concentrations for either human health or piscivorous wildlife (which are higher than the cancer-risk benchmarks);
- Benthic organisms consumed by juvenile salmonids in the Duwamish Waterway and Commencement Bay have higher concentrations of organic contaminants (i.e., PAH, PCB, DDT) than do food organisms from uncontaminated areas (Stein et al. 1995).

3.3.1.2 Contaminant Effects

- Mussels in urban embayments have been observed to have lower growth and higher rates of pathological changes in digestive cells than mussels from remote areas (Krishnakumar et al. 1994);
- Little is known about the ecological effects at the individual, population or ecosystem level of measured contaminant tissue burdens in benthic infauna and shellfish.

3.3.1.3 Monitoring and Data Gaps

Monitoring and data gaps and issues related to metals and organic contaminants in the invertebrates of Puget Sound include the following:

- Contaminant levels and effects in benthic infauna, other than large mollusks harvested for human consumption, have not been studied;
- Contaminant levels and effects in crabs and other shellfish are not well studied;
- Studies of contaminants in crabs are often measured in the hepatopancreas tissue for ecological studies, while assessment programs with the objective of

determining human health effects related to shellfish consumption usually use muscle tissue, or the "edible" portion of the animal. Therefore, data collected for one purpose may not be useful for the other;

- The speciation of some metals, such as arsenic, in shellfish and therefore the bioavailability to mammalian consumers is not well understood;
- Other than the federal National Status and Trends Mussel Watch program, there are no comprehensive, long-term data sets for marine invertebrates in Puget Sound, therefore, it is difficult to assess temporal contaminant trends;
- There are insufficient data regarding the presence/composition of individual PCB or dioxin congeners in invertebrate tissues to support human health risk assessments;
- The relationship between sediment and tissue concentrations is poorly understood, including the preferential uptake of different contaminant forms (e.g., PCB or dioxin congeners);
- There are no Washington State or Puget Sound-specific tissue residue screening benchmarks for marine invertebrates.

3.3.1.4 Recommendations

Invertebrates, particularly benthic-dwelling species, provide one of the first links in the food chain for trophic transfer of contaminants from sediments and there is evidence that invertebrate organisms in Puget Sound accumulate metals and organic compounds. Further research is required, however, to assess the effects of the various toxics on benthic infauna and shellfish, both for individuals and for populations, and to determine temporal and spatial trends in tissue burdens.

INVERTEBRATES: RECOMMENDATIONS

1. ***Continue collecting tissue data to help determine temporal trends and assess effects of toxic contaminants in invertebrate species.***

   The only long-term, comprehensive data set that can be used for assessing the temporal trends of metals and organic contaminants in invertebrates is that of NOAA's Mussel Watch program, which uses *Mytilus* sp. in Puget Sound. Because mussels are filter feeders, they tend to have lower tissue contaminant burdens than invertebrates more closely associated with sediments (Ylitalo et al. 1999). Any assessment regarding contaminant trends will tend to be an underestimate of what is happening with benthic organisms such as clams and crabs. Therefore, it would be useful to develop a long-term data set for other invertebrates including benthic-dwelling mollusks and crustaceans.

Measuring contaminant concentrations in sediment-dwelling benthic invertebrates would also provide a data set for comparison to literature studies regarding the effects of contaminants of concern, and would contribute to an assessment of sources and trophic transfer of persistent, bioaccumulative toxics (PBTs).

2. ***Compile concentrations of contaminants in benthic organisms into a central database to assist with tracking potential sources of toxic contaminants including persistent, bioaccumulative, toxics (PBTs) in the Puget Sound food web.***

There is a large body of both published and gray-literature regarding the tissue burdens of metals and organic contaminants in Puget Sound marine organisms. To assist in determining spatial and temporal trends and trophic transfer of these contaminants, it would be useful if the data for benthic invertebrates were compiled into a GIS-compatible relational database. The database would contribute to efforts to track the sources and trophic transfer of PBTs in Puget Sound.

3. ***Conduct research to determine potential ecological effects of measured contaminant tissue burdens in benthic infauna and shellfish at the individual, population or ecosystem level.***

A majority of the research that has been conducted regarding contaminant concentrations in Puget Sound invertebrates has focused on the potential for effects in human consumers of marine shellfish and the use of invertebrate tissue contaminant concentrations for tracking the environmental distribution of spilled materials. The potential for effects in the organisms themselves is not well studied.

Examples of research that can be done to elucidate effects include:

- Literature-derived tissue effects thresholds, which can be used to assess acute risks to individual organisms;
- Site-specific toxicity testing, wherein chronic endpoints such as reproductive success or behavioral traits are evaluated, which can be valuable in assessing risks to populations.

4. ***Conduct a literature review to help develop Puget Sound-specific screening benchmarks for the protection of invertebrate organisms themselves, and wildlife and human consumers of the organisms.***

   Washington State has not developed tissue residue benchmarks for the protection of benthic invertebrates, or wildlife or human consumers of invertebrate species. As well, site-specific benchmarks that may have been developed for individual contaminated sites in Puget Sound are not readily accessible.

   Literature-derived benchmarks, coupled with site-specific toxicity testing, can be used to calculate protective benchmarks specific to the Puget Sound environment.

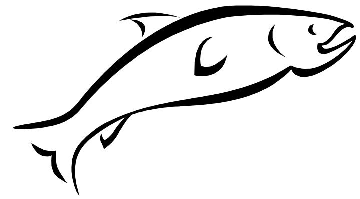
5. ***Conduct research into the use of extrapolation factors and tissue reconstitution models between the edible and non-edible tissues of invertebrates.***

   Studies of contaminants in crabs are often measured in the hepatopancreas tissue for ecological studies, while assessment programs with the objective of determining human health effects related to shellfish consumption usually use muscle tissue, or the "edible" portion of the animal. Therefore, data collected for one purpose may not be useful for the other. Research into the use of extrapolation factors and appropriate tissue reconstitution models would be valuable.

6. ***Conduct research into the speciation of arsenic and its bioavailability to mammalian consumers of benthic and infaunal invertebrates.***

   Arsenic is ubiquitous in living tissue, particularly that of marine organisms, because they readily take up arsenate from seawater (Eisler 1988a). Arsenic concentrations in Puget Sound marine organisms regularly exceeded screening benchmarks for the protection of human consumers (EVS 2003). However, there is some uncertainty regarding the potential for human health effects from the levels of arsenic observed in Puget Sound fish and shellfish due to the fact that the toxicity of arsenic is dependent of the form it is in, with inorganic arsenic being most toxic. The arsenic in fish and shellfish tissue which may be consumed by humans is likely in an organic form that is not toxic, however, there is growing concern with methylated arsenic species (Davoli, pers. comm. 2002).

3.3.2 Fish



To date, the most comprehensive survey of contaminants in fish tissue has been conducted by PSAMP (West et al. 2001a). Ten different fish species representing different life histories and feeding strategies were collected between 1989 and 1999 from stations throughout Puget Sound representing urban, near-urban and non-urban conditions. Fish tissues were analyzed for contaminants including chlorinated pesticides, PCBs, aromatic hydrocarbons, chlorinated aromatic hydrocarbons, phthalate esters and selected toxic metals. Further studies have also been conducted on individual species and in site-specific areas.

3.3.2.1 State of Knowledge

Fish tissue contaminant burdens and the toxic effects of metals and organic contaminants have been studied for numerous locations throughout Puget Sound. The PSAMP program is responsible for a large part of what is known about contaminants in fish. Other studies have addressed fish tissue contaminants on a nation-wide scale or limited to one or two embayments, Commencement and Elliott Bays in particular. These studies have shown that:

- Contaminant burdens are species-specific and may be affected by trophic level, gender, age, and lipid content of the fish;
- Spatial trends in the tissue burden of fish are more apparent for species that are “sedentary” or which occupy a lower trophic status;
- Fish from urban and near-urban areas had the highest tissue burdens of metals and organic contaminants. One exception was for rockfish from Foulweather Bluff, a non-urban station where samples had age-specific mercury concentrations comparable to the urban embayments Elliott Bay and Sinclair Inlet (West and O’Neill 1998);
- The tissue benchmark for the protection of human health from mercury was exceeded in a few samples of quillback rockfish;
- Tissue benchmarks for the protection of human health from arsenic were commonly exceeded in the fish sampled from Puget Sound (EVS 2003), however, the applicability of these benchmarks to marine organisms is not certain;
- The tissue benchmark for the protection of human health from PCB cancer risks was exceeded in almost all of the fish tissue sampled by West at al. (2001a), while only Pacific herring samples exceeded the noncarcinogenic effects level for PCB;

- The highest overall PCB concentrations have been measured in Pacific herring (it should be noted that herring tissue burdens were assessed on a whole-body basis rather than muscle tissue only; West et al. 2001a);
- Tissue benchmarks for the protection of wildlife from both carcinogenic and noncarcinogenic effects of PCB were exceeded in some fish of all the species for which data were available (West et al. 2001a);
- There is a signature of organic contaminants in Central Puget Sound herring (O'Neill and West 2001);
- English sole in Sinclair Inlet have higher age-specific lead concentrations than do sole from other Puget Sound stations (PSWQAT 2000);
- PCB concentrations have been detected in 100% of rockfish from urban embayments, 97% from near-urban areas, and 7% from non-urban sites (West et al. 2001b);
- Female rockfish may transfer PCB to their offspring, whereas they do not transfer mercury (West and O'Neill 1998);
- Outmigrating juvenile salmon have been observed to accumulate PCBs and DDT in contaminated estuaries such as the Duwamish Waterway and Commencement Bay (Stein et al. 1995);
- PCBs are one of the few contaminants observed to accumulate in adult salmon, and adult chinook salmon have higher concentrations than do coho salmon (O'Neill et al. 1998);
- Adult salmon returning to natal streams in South Puget Sound were found to have higher PCB concentrations than fish returning to Central Puget Sound streams (O'Neill and West 2001);
- Organochlorine contaminants measured in adult salmon returning to natal streams in the Puget Sound area may be due to exposure to the toxic compounds in the North Pacific Ocean or from Puget Sound sources. The relative contribution of contaminants accumulated by salmon as they outmigrate through contaminated estuaries during their juvenile life stage is considered negligible (O'Neill et al. 1998);
- PCB tissue benchmarks for the protection of piscivorous wildlife from cancer were exceeded in some fish samples.

3.3.2.2 Contaminant Effects

- English sole are at higher risk for developing liver lesions in areas with PAH contamination (Collier et al. 1998), while other closely related species such as starry flounder do not appear to be similarly affected (Collier, pers. comm., 2002);
- Exposure to PAH and chlorinated hydrocarbons are risk factors for several adverse reproductive effects in English sole including precocious sexual maturation, inhibition of gonadal development and decreased egg weight (Collier et al. 1998);
- The reproductive success of English sole is lower in moderately to highly contaminated sites (Johnson et al. 1994);
- Vitellogenesis (the production of vitellogenin by females in preparation for reproduction) has been observed in male rockfish from Elliott Bay, indicating exposure to an as of yet unidentified endocrine disrupting compound (West et al. 2001b);
- Exposure to toxic contaminants during their estuarine residence time can cause impaired immune function in juvenile salmonids (Varanasi et al. 1993);
- Chum salmon juveniles showed higher indicators of exposure (e.g., damaged DNA; CYP1A activity) to contaminants than chinook salmon, suggesting that chum may be more susceptible to biological injury from the contaminants (Stehr et al. 1998)

3.3.2.3 Monitoring and Data Gaps

Monitoring and data gaps related to metals and organic contaminants in the fish of Puget Sound include the following:

- The reproductive effects of many contaminants of concern are not known;
- PCBs appear to be transferred from female fish to their eggs, however, the effect of contaminant exposure via maternal transfer is unknown at this time. PSAMP is conducting a pilot study of contaminants in herring eggs (O'Neill and West 2001);
- There are not enough data to assess temporal trends in the contaminant burdens and effects in many fish species;
- The ecological significance of measured biliary-FAC concentrations in rockfish is unknown;
- The potential population effects from sublethal exposures to contaminants are not known. This may be difficult to quantify because many other factors (i.e., harvest rates, natural or human-related changes in the physical environment) contribute to population dynamics;

- There is evidence of endocrine disruption (i.e., vitellogenesis) in the male rockfish collected from Elliott Bay, however, the cause was not clear;
- The relative contribution of global versus local sources of PCB to Puget Sound salmon is unknown;
- The speciation of arsenic in fish, and therefore the bioavailability to mammalian consumers, is not well understood;
- There are no regulatory tissue residue screening benchmarks for Puget Sound, either for the protection of the fish themselves or for the protection of wildlife and human consumers of fish;
- There are insufficient data regarding the presence/composition of individual PCB or dioxin congeners in fish tissue to support human health risk assessments;
- The relationship between sediment and tissue concentrations is poorly understood, including the preferential uptake of different contaminant forms (e.g., PCB and dioxin congeners.

3.3.2.4 Recommendations

Fish, English sole in particular, are the most studied aquatic organisms in Puget Sound. Research during the past two decades has shown that fish occupying a range of habitat types and trophic levels are accumulating metals and organic contaminants and that they are manifesting a variety of harmful effects. Despite the considerable data available, however, there are still questions about contaminant sources and potential effects, particularly sublethal effects that may occur as a result of endocrine-disrupting compounds.

FISH: RECOMMENDATIONS

1. ***Continue collecting tissue data to help determine temporal trends and assess effects of toxic contaminants in fish species.***

   Assessing temporal trends in contaminant accumulation by Puget Sound fish is difficult for a number of reasons, including:

   - A lack of sufficient data points through time;
   - High within-year variability in data sets that have been collected over a sufficient period of time; and
   - A strong correlation between age and/or lipid content and contaminant accumulation by some fish.

In order to minimize the effect of the above factors on a temporal trend analysis, a sufficient number of data for a variety of fish species and age classes is required.

Further collection of fish tissue contaminant data will also provide useful information to assess the effects of toxic contaminants and will contribute to the tracking of potential sources and trophic transfer of contaminants.

2. ***Compile concentrations of contaminants in Puget Sound fish into a central database to assist with tracking potential sources of toxic contaminants including PBTs in the Puget Sound food web.***

There is a large body of both published and gray-literature regarding the tissue burdens of metals and organic contaminants in Puget Sound marine organisms. To assist in determining spatial and temporal trends and trophic transfer of these contaminants, it would be useful if the tissue data for fish were compiled into a GIS-compatible relational database. The database would contribute to efforts to track the sources and trophic transfer of PBTs in Puget Sound.

3. ***Investigate the source and potential ecological effects of elevated lead concentrations observed in Sinclair Inlet fish.***

While none of the fish tissue samples collected through PSAMP (West et al. 2001a) exceeded the screening benchmarks for the protection of human health in a recent assessment conducted by EVS (2003), English sole appeared to accumulate lead to a greater degree than rockfish, and there is a spatial trend in lead concentrations that points to a potential problem for English sole in Sinclair Inlet in particular. The highest single sample concentrations of lead in English sole were from Discovery Bay (lead detected in 2 of 6 samples), Port Townsend (lead detected in 2 of 15 samples), and the Strait of Georgia (lead detected in 2 of 21 samples). However, lead was more consistently measured in English sole from Sinclair Inlet (detected in 23 of 26 samples) and age-specific concentrations in these fish were higher than in other locations. These data reflect the fact that lead concentrations in Central Puget Sound sediments were consistently higher in Sinclair Inlet (PSAMP 2002). The significance of these lead concentrations is presently unknown, however, lead at sublethal concentrations is reported to cause developmental, reproductive and neurological problems in fish (Eisler 1988b).

4. ***Investigate the relative importance of global versus local sources of PCB to adult Puget Sound salmon.***

O'Neill et al. (1998) suggested that the contribution of contaminants accumulated by juveniles migrating through contaminated estuaries to the PCB burden of adult salmon was negligible, and that other sources in Puget Sound (i.e., related to contaminated sites) and/or the North Pacific Ocean (i.e., related to atmospheric deposition) were more important.

6. ***Investigate the differences in PCB content between adult chinook and coho salmon returning to Puget Sound and the ecological significance of observed tissue burdens.***

   Adult chinook salmon returning to Puget Sound have been observed to have higher PCB and DDT concentrations than adult coho salmon (O'Neill et al. 1998). This difference is potentially explained by the fact that chinook salmon tend to be older when they return to spawn, they have a higher lipid content, and they tend to consume a greater percentage of fish than do coho. Further investigation would help elucidate whether or not there are differences in uptake between the two fish species and differences in susceptibility to effects from their respective tissue contaminant burdens.

7. ***Investigate the potential stock/population level effect of reduced disease resistance in juvenile salmon migrating through contaminated estuaries in Puget Sound.***

   Juvenile salmon outmigrating through contaminated estuaries such as the Duwamish Waterway and Commencement Bay have been observed to accumulate contaminants from their prey (Stein et al. 1995). Juveniles from these same estuaries exhibited decreased disease resistance (Varanasi et al. 1993, Arkoosh et al. 1998), an effect which persisted in some fish even two months after being removed from the contaminant source (Arkoosh et al. 1998). Immune dysfunction in fish can result in death either directly from a pathogen, or indirectly due to the inability to feed or avoid predators.

8. ***Investigate the effects of measured organic contaminant concentrations in Puget Sound herring.***

   The highest PCB concentrations in Puget Sound fish were found in Pacific herring, particularly the Port Orchard stock. O'Neill and West (2001) suggested that the observed concentrations were due to elevated levels of organic contaminants in the food web of Central Puget Sound, and that they may put the fish at risk for adverse biological effects.

9. ***Investigate the significance of PCB concentrations in excess of the 1 in 100 cancer risk and noncarcinogenic effects tissue benchmarks for the protection of piscivorous wildlife observed in some Puget Sound fish.***

   Some samples of all the fish species tested through PSAMP had PCB tissue concentrations exceeding the benchmark for both the noncarcinogenic effects and the 1 in 100 cancer risk level for the protection of wildlife (EVS 2003). The screening benchmark used was derived for aquatic species found in the Niagara River, however (Newell et al. 1987). Therefore, research regarding the potential for accumulation of PCB by Puget Sound wildlife and associated effects would be valuable.

10. ***Investigate the spawning success of English sole in Puget Sound.***

PAHs and chlorinated hydrocarbons have been linked to reproductive impairment in English sole (Collier et al. 1998) and limited studies indicated that the English sole in contaminated areas such as Sinclair Inlet, the Duwamish Waterway and Eagle Harbor had lower overall reproductive success than did English sole from a clean reference location (Port Susan; Johnson et al. 1994). This information will contribute to an understanding of the potential population level effects of contaminant exposure.

11. ***Investigate the source of mercury to Foulweather Bluff rockfish and the potential effects related to the observed mercury tissue concentrations.***

West and O'Neill (1998) assessed the mercury concentrations in rockfish from six of the 24 PSAMP sampling locations and found that mercury increased with age in the rockfish from all sampling locations. Fish from Sinclair Inlet, Elliott Bay, and Foulweather Bluff had higher age-specific mercury concentrations than did fish from the other sites. Sinclair Inlet and Elliott Bay are in urbanized areas and have a long history of industrial activity, therefore, it is not unexpected that rockfish in these embayments would have relatively higher mercury concentrations than fish from other areas. Foulweather Bluff, however, is located in a non-urban area. Sources of mercury to rockfish at this site should be investigated.

12. ***Research is needed on the endocrine disrupting properties of various organic and metal contaminants.***

Endocrine disrupting compounds such as PCB, TBT and mercury have the potential to affect reproductive and other functions in aquatic organisms. However, the significance of endocrine disruption is not always known. For example, West et al. (2001a) observed vitellogenesis in male rockfish from Elliott Bay, indicating exposure of the fish to exogenous estrogens or estrogen mimics. Vitellogenesis refers to the production of vitellogenin, a protein typically synthesized in the livers of female fish in preparation for reproduction. The potential reproductive effects of vitellogenesis in male organisms is unknown.

13. ***Research is needed on the early life stage effects of maternally-transferred contaminants such as PCBs, dioxins and furans, and mercury.***

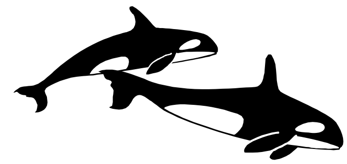
    The potential effects of contaminant exposure via maternal transfer is unknown at this time. Research is needed to determine whether maternally-transferred contaminants affect the survival and development of offspring, or whether the process enables some organisms to reach an effects threshold tissue concentration more quickly than via environmental exposure.

14. ***Conduct a literature review to develop Puget Sound-specific screening benchmarks for the protection of fish themselves, and wildlife and human consumers of fish.***

    Washington State has not developed tissue residue benchmarks for the protection of fish, or wildlife or human consumers of Puget Sound fish. As well, site-specific benchmarks that may have been developed for individual contaminated sites in Puget Sound are not readily accessible.

    Literature-derived benchmarks, coupled with site-specific toxicity testing, can be used to calculate protective benchmarks specific to the Puget Sound environment.

3.3.3 Marine Mammals



Carnivorous mammals such as harbor seals and killer whales occupy the top of the marine food chain and are therefore good indicators of the continued presence of persistent, bioaccumulative toxics such as PCBs and organochlorine pesticides throughout the marine environment, even decades after the chemicals were banned from use in the United States.

3.3.3.1 State of Knowledge

Metals and organic contaminant concentrations have been measured in the tissues (i.e., liver, blubber) of river otters and harbor seals at a number of locations throughout Puget Sound, while southern resident killer whales have been sampled from the Straits of Juan de Fuca and Georgia. The number of studies regarding toxic contaminants in marine mammals is small compared to other biota. These studies have indicated that:

- Metals concentrations in harbor seals were found to be comparable to pinnipeds in other parts of the world (Calambokidis et al. 1984, cited in Calambokidis et al. 1991);
- The concentration of PCBs in killer whales inhabiting Puget Sound and the Washington coast is higher than in the whales from any other industrialized area in North America and northern Europe (Ross et al. 2000);
- Dioxins and furans are low in killer whales (Ross et al. 2000);
- PCB concentrations in harbor seals have decreased since the 1970s but now appear to have stabilized (Calambokidis et al. 2001);
- Gray whales, which filter sediments for benthic invertebrates, were found to have lower contaminant concentrations relative to carnivorous marine mammals;
- Gray whales have detectable levels of chlorinated hydrocarbons, however, no regional differences were found due to the migratory patterns of the species (Varanasi et al 1994).

3.3.3.2 Contaminant Effects

- Harbor seals in Puget Sound are at risk for impaired immune function due to PCBs (Ross et al. 1996);
- The concentration of PCBs in the blubber of killer whales frequenting Puget Sound waters exceeds the threshold above which immunosuppression may be expected (Ross et al. 1996).

3.3.3.3 Monitoring and Data Gaps

Monitoring and data gaps related to metals and organic contaminants in the marine mammals of Puget Sound include the following:

- There are insufficient data to determine temporal trends of PBTs like PCBs and other organochlorine compounds in killer whales;
- Further investigation is required to determine the relative importance of local (i.e., contaminated sites in Puget Sound) versus international (i.e., global atmospheric transport) sources of PBTs like PCBs to higher trophic consumers such as killer whales;
- The mechanisms by which PBTs affect marine mammals and the risks associated with current contaminant burdens are not fully understood (Ross, pers. comm. 2002);
- Congener-specific data for sediment, air and biota, which would behave as a "fingerprint" and help delineate sources and transportation of PBTs in Puget Sound, are not available (Ross, pers. comm. 2002);
- There is a lack of information regarding the sources, transport and fate of unregulated PBTs (such as polybrominated diphenyl ethers; Section 3.4), particularly related to higher trophic level species such as seals, whales and human consumer groups (Ross, pers. comm. 2002).

3.3.3.4 Recommendations

Marine mammals have been likened to canaries in a coal mine – preliminary indicators of the state of ocean ecosystems. In case of Puget Sound, the degree to which mammals such as harbor seals and killer whales have accumulated PCBs put these animals at risk of immune system dysfunction. However, the pathway through which Puget Sound marine mammals are accumulating PCBs, and the mechanisms by which PBTs affect them, are unknown at this time.

MARINE MAMMALS: RECOMMENDATIONS

1. ***Continue collecting tissue data to help determine temporal trends and assess effects of toxic contaminants in resident and migratory marine mammals.***

   An assessment of the temporal trends of toxic organic contaminants in Puget Sound marine mammals is limited to a series of PCB and dioxin measurements made in harbor seal blubber (Calambokidis et al. 2001).

The data indicate that the concentrations of both organochlorine compounds have declined since the early 1970s, and appear now to have stabilized. Continued monitoring of contaminants in harbor seals and killer whales will provide further information regarding the temporal trends of PCB in Puget Sound top carnivores, and the continued potential for effects.

2. ***Compile concentrations of contaminants in Puget Sound marine mammals into a central database to assist with tracking potential sources of toxic contaminants including PBTs in the Puget Sound food web.***

   There is a large body of both published and gray-literature regarding the burdens of metals and organic contaminants in Puget Sound marine organisms. To assist in determining spatial and temporal trends and trophic transfer of these contaminants, it would be useful if the data were compiled into a GIS-compatible relational database. The database would contribute to efforts to track the sources and trophic transfer of PBTs in Puget Sound.

3. ***Research is needed on the early life stage effects of maternally-transferred contaminants such as PCBs, dioxins and furans, and mercury.***

   The potential effects of contaminant exposure via maternal transfer is unknown at this time. Research is needed to determine whether maternally-transferred contaminants affect the survival and development of offspring, or whether the process enables some organisms to reach an effects threshold tissue concentration more quickly than via environmental exposure.

4. ***Investigate the potential ecological effects associated with observed tissue contaminants in Puget Sound river otters.***

   The liver concentrations of several metals and organochlorine contaminants have been measured in Puget Sound river otters (Grove et al. 2001). The ecological significance of these tissue burdens, however, are unknown at this time. It would be useful to continue collecting data regarding tissue burdens and to investigate the potential for effects both at the individual and population level.

5. ***Investigate the source and movement of PBTs (especially PCB) through the Puget Sound food web.***

   Indications are that Central Puget Sound has generally elevated concentrations of PCBs (i.e., greater number of SQV exceedances in Central Puget Sound, higher trophic level organisms like otters and herring in Central Puget Sound have relatively higher levels of PCBs). The source of these contaminants and the potential for further transport to other areas of Puget Sound are not well understood.

6. ***Investigate the use of congener-specific data for sediment, air and biota as a "fingerprint" to help delineate sources and transportation of PBTs in Puget Sound.***

   The potential for developing a "fingerprinting" technique to trace the sources and pathways of PBTS should be investigated. For example, PCBs are a group of 209 individual chemicals and commercial mixtures of PCBs contain known ratios of different congeners. Therefore, it may be possible to identity contaminant transfer by comparing the ratio of congeners present in the originating matrix (i.e., sediment) to the receiving matrix (i.e., benthic fish tissue). Differential uptake (i.e., some congeners are more readily accumulated than others) and the ability of various organisms to dechlorinate will have to be addressed.

7. ***Investigate the relative importance of local versus international sources of PBTs to Puget Sound marine mammals.***

   The ultimate pathway by which PCBs accumulate in killer whales is not clear. Chinook salmon comprise a significant portion of the diet of southern residents (Ford et al. 1998), and chinook salmon captured in Puget Sound had higher PCB concentrations than other fish species (West et al. 2001a). However, chinook salmon spend a majority of their adult life in the Pacific Ocean, and Ross et al. (2000) suggested they are exposed via atmospheric deposition and trophic transfer of PCBs in the North Pacific.

8. ***Research the mechanisms by which PBTs affect marine mammals and the risks associated with current contaminant burdens.***

   Some studies have suggested that harbor seals and killer whales are at risk for immunosuppression due to PCB burdens (Ross et al. 1996). However, the mechanism(s) by which immune dysfunction may occur are unknown. As well, there may be other, as yet unidentified, risks associated with the contaminant burdens currently reported in the mammals of Puget Sound.

9. ***Conduct a literature review to develop Puget Sound-specific screening benchmarks for the protection of marine mammals and wildlife and human consumers of mammals.***

   Washington State has not developed tissue residue benchmarks for the protection of marine mammals, or wildlife consumers of mammals. As well, site-specific benchmarks that may have been developed for individual contaminated sites in Puget Sound are not readily accessible.

Literature-derived benchmarks, coupled with site-specific toxicity testing, can be used to calculate protective benchmarks specific to the Puget Sound environment.

3.3.4 Birds

Few studies have been conducted on contaminants in the marine birds of Puget Sound, in part because finding an appropriate sentinel species (i.e., non-migratory; spends a substantial portion of its life cycle in Puget Sound; forages on marine prey species; is abundant throughout Puget Sound) is difficult (Mahaffy, pers. comm. 2002). As part of PSAMP, the U.S. Fish and Wildlife Service (USFWS) and Washington Department of Fish and Wildlife (WDFW) evaluated pigeon guillemots, great blue heron and surf scoters against these criteria and found the scoters to be the only suitable sentinel species (Mahaffy et al. 1997). Surf scoters are migratory birds that breed in the northern boreal forests of North America and overwinter along both Pacific and Atlantic coasts. The Puget Sound population of this species feeds exclusively in the marine environment, primarily on benthic organisms.

3.3.4.1 State of Knowledge

Tissue concentrations of metals and organic contaminants have been measured in birds from several locations in Hood Canal and South Puget Sound, with several of the studies focusing on contaminant accumulation during overwintering in Commencement Bay. These studies have shown that:

- Surf scoters have been determined to be a useful sentinel species because they are non-migratory; they spend a substantial portion of their life cycle in Puget Sound; they forage on marine prey species; and they are abundant throughout Puget Sound (Mahaffy, pers. comm. 2002);
- Surf scoters overwintering in Commencement Bay accumulated mercury, but without apparent effects (Mahaffy et al. 1997);
- Eagle populations have been increasing throughout Washington State except in the Hood Canal area (Mahaffy et al. 2001);
- Birds from a heronry near a Tacoma smelter did not appear to accumulate metals (Blus et al. 1985);
- PCB concentrations in heron eggs were highest at a heronry near Seattle (Speich et al. 1992);
- The greatest adverse effects were observed in herons from agricultural areas in North Puget Sound (Speich et al. 1992).

3.3.4.2 Contaminant Effects

- Despite the fact that birds overwintering in Commencement Bay (i.e., surf scoters, western grebes) accumulated metals and organic contaminants, they appear to be in good health;
- PCB concentrations in eagle eggs collected from Hood Canal exceeded the threshold level above which adverse reproductive effects have been observed to occur;
- Great blue herons and glaucous-winged gulls have experienced egg-shell thinning, however, the measured PCB and DDT concentrations were not correlated with egg-shell thickness.

3.3.4.3 Monitoring and Data Gaps

Gaps in data regarding metals and organic contaminants in the birds of Puget sound include the following:

- The source of PCBs in the eagles of Hood Canal is not known as sediment and fish tissue concentrations were found to be too low to account for the elevated egg concentrations;
- The potential ecological significance of contaminant accumulation in migratory birds overwintering in urban estuaries is unknown, as the birds appear to be in good health;
- There are not enough data to assess the spatial variability in contaminant uptake by birds utilizing urban/industrial estuaries versus more isolated estuaries;
- The sublethal effects of measured contaminants measured in birds is unknown;
- There are not enough data to assess the relationship between contaminant burdens and eggshell thinning in Puget Sound waterfowl;
- There are no Washington State or Puget Sound-specific tissue residue screening benchmarks for birds.

3.3.4.4 Recommendations

The birds of Puget Sound have not been well-studied and there are limited data regarding the contaminant burdens and potential individual or population level effects of metals and organic compounds. In cases where effects such as egg-shell thinning have been observed, the contaminant sources have not been identified. As with other aquatic receptors, further research is required to determine sources of exposure, and mechanisms by which toxic metals and organic contaminants affect Puget Sound birds.

BIRDS: RECOMMENDATIONS

1. ***Continue collecting tissue data to help determine temporal and spatial trends and assess effects of toxic contaminants in resident and migratory birds.***

   There are no long-term data sets upon which temporal and spatial trends in the contaminant burdens of resident Puget Sound birds may be assessed, rather, most research has focused on the accumulation of metals and organics by migratory birds overwintering in hot spots such as Commencement Bay (e.g., Mahaffy et al. 1997; Henny et al. 1990). Surf scoters have been determined to be a useful sentinel species (Mahaffy, pers. comm. 2002). These birds, or other species as may also be identified as appropriate, should be sampled Puget Sound-wide at regular intervals to develop a long-term data set.

2. ***Compile concentrations of contaminants in birds into a central database to assist with tracking potential sources of toxic contaminants including PBTs in the Puget Sound food web.***

   There is a large body of both published and gray-literature regarding the tissue burdens of metals and organic contaminants in Puget Sound marine birds. To assist in determining spatial and temporal trends and trophic transfer of these contaminants, it would be useful if the data were compiled into a GIS-compatible relational database. The database would contribute to efforts to track the sources and trophic transfer of PBTs in Puget Sound.

3. ***Conduct a literature review to develop Puget Sound-specific screening benchmarks for the protection of birds themselves, and wildlife and human consumers of birds.***

   Washington State has not developed tissue residue benchmarks for the protection of birds, or wildlife or human consumers of Puget Sound birds. As well, site-specific benchmarks that may have been developed for individual contaminated sites in Puget Sound are not readily accessible.

   Literature-derived benchmarks, coupled with site-specific toxicity testing, can be used to calculate protective benchmarks specific to the Puget Sound environment.

4. ***Investigate the source of PCBs in the eagles of Hood Canal.***

   The concentrations of PCBs measured in Hood Canal eagle eggs exceeded reported threshold concentrations above which effects may be observed (Mahaffy et al. 2001). However, the researchers determined that sediment contaminant and fish tissue concentrations were not high enough in Hood Canal to account for the elevated PCBs measured in the eggs and recommended that in future studies, other prey items such as marine mammals and fish-eating birds with broader territories be assessed as potential sources.

5. ***Investigate the relationship between contaminant burdens and eggshell thinning in Puget Sound waterfowl.***

   The eggshells of great blue herons and glaucous-winged gulls have decreased significantly in thickness since 1947, when DDT was introduced (Speich et al. 1992). However, measured PCB and DDT concentrations in present-day tissues were not correlated with eggshell thickness. Other factors that may be contributing to eggshell thinning in great blue heron and glaucous-winged gulls should be investigated.

6. ***Investigate the potential sublethal effects of contaminant accumulation in migratory birds overwintering in urban estuaries.***

   Several birds have been found to accumulate mercury, arsenic, potentially cadmium, DDE, PCBs, and chlordanes while overwintering in Commencement Bay (Henny et al. 1990). The toxicological significance of the increased body burdens of these contaminants was unknown as the birds appeared to be in good health. Little is known about critical body residues or sublethal effects of the metal

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4. EMERGING ISSUES

During the last several years, some issues in the study of environmental contaminants have been moving to the forefront and may have implications for the direction of research in Puget Sound's marine environment. In addition to the recommendations made above regarding the water, sediment and biota of Puget Sound, the following areas of research may be useful in determining the potential for ecological effects of contaminants in the marine environment of Puget Sound.

EMERGING ISSUES: RECOMMENDATIONS

1. ***Investigate the appropriateness of extrapolating laboratory toxicity studies to field conditions.***

   The sediment quality triad approach (Long and Chapman 1985) to assessing the overall health of sediments, options for dredgate disposal and remediation requirements has become a commonly used tool during the last decade. There are questions, however, about the relationship between laboratory toxicity tests and the abundance and diversity of benthic fauna in the natural environment, and the ability of laboratory tests to predict effects in the environment.

2. ***Investigate the ecological relevance of the phototoxicity of PAHs to the marine environment of Puget Sound.***

   Several researchers have determined via laboratory studies that exposure to UV light can affect the toxicity of PAHs and in some jurisdictions, criteria to protect aquatic organisms from photo-induced toxicity have been established based on laboratory toxicity data. However, the ecological (*in situ*) relevance of this phenomenon is not well understood (McDonald and Chapman 2002).

3. ***Characterize the level of polybrominated diphenyl ethers (PBDE) in the sediments and organisms of Puget Sound.***

   PBDEs are constituents in fire retardant and have come under scrutiny in Europe and on the eastern coast of the U.S. PBDEs are structurally similar to PCBs and have been found in increasing quantities in the marine environment.

4. ***Conduct research into the speciation of cadmium and its bioavailability to mammalian consumers of benthic and infaunal invertebrates.***

   Fisheries and Oceans Canada scientists have been studying cadmium in oysters not proximal to anthropogenic sources in response to concerns that farmed oysters would not meet existing or proposed lower FAO guidelines for the protection of human consumers (Kruzynski, pers. comm. 2002). The scientists concluded that the elevated tissue burdens of cadmium were naturally occurring, however, the bioavailability of the cadmium has not been studied yet.

5. ***Investigate the potential ecological effects of the discharge of pharmaceuticals and personal care products (PPCPs) to Puget Sound.***

   PPCPs comprise a broad, diverse collection of thousands of chemical substances including prescription and over-the-counter therapeutic drugs, birth-control products, fragrances, cosmetics, sun-screen agents, diagnostic agents, nutraceuticals, biopharmaceuticals, and many other substances. These chemicals, whether applied externally, or ingested, have the potential to be excreted or washed into sewage systems and from there discharged to the aquatic and terrestrial environments. The potential ecological effects of these substances are not well understood.

6. ***Investigate the potential impacts of long-range transport of global pollutants on the Puget sound marine environment.***

   Several persistent, toxic chemicals that bioaccumulate (e.g., mercury, dioxin, DDT, PCB) are released into the environment in other regions of the world and become part of the global atmospheric transport system. Further investigation is required to evaluate the local impacts of the long-range transport of global pollutants.

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