Human Health Evaluation of Contaminants in Puget Sound Fish

Washington State Department of Health

Division of Environmental Health
Office of Environmental Health
Assessments P.O. Box 47825
Olympia, Washington 98504-7825
1-877-485-7316
http://www.doh.wa.gov/fish

DOH 334-104 October 2006

For people with disabilities, this document is available on request in other formats.
To submit a request, please call 1-800-525-0127 (TDD/TTY call 711).

Mary C. Selecky
Secretary of Health

Joan Hardy, Ph.D.
Toxicologist

Gary Palcisko, M.S.
Health Assessor

Acknowledgements

We would like to thank participants in the Puget Sound Assessment and Monitoring Program (PSAMP) and the Puget Sound Action Team (PSAT) for funding efforts to monitor Puget Sound marine fish. Sandie O'Neill, Jim West, Greg Lippert and Steve Quinnell of the Washington State Department of Fish and Wildlife (WDFW) collected and analyzed fish tissue from Puget Sound and provided comments on the report. We thank them all for providing data to Washington State Department of Health (DOH). We thank Lon Kissinger (Environmental Protection Agency), Dale Norton (Ecology), Deb Lester (King County Department of Natural Resources and Parks), Scott Redman (Puget Sound Action Team) and others who participated in a technical review of this report and provided numerous useful comments and suggestions.

Members of the Northwest Indian Fisheries Commission (NWIFC) were engaged throughout the DOH risk assessment process and we thank them for their many contributions to this report. In particular, we would like to acknowledge Steve Robinson and Fran Wilshusen of the NWIFC for coordinating interactions with DOH; Dave Herrera, Skokomish Tribe, the current chair of the Environmental Policy Committee; and members of the EPC. Rich Brooks and Jeff Dickinson offered helpful ideas during project development while J. Burns, Brian Cladoosby, Jamie Donatuto, Alison O'Sullivan, Denice Taylor, Jeff Thomas, and Christine Woodward reviewed the document and provided valuable recommendations.

We want to thank Rob Duff, Director, Office of Environmental Health Assessments, for his efforts in editing this report and making final policy decisions. We thank Nancy West for providing GIS support. Madeline Beery, Liz Carr, Dave McBride, Milo Straus and Jim W. White also provided input and we thank them.

Table of Contents

Tables

Figures

ACRONYMS AND ABBREVIATIONS

AHA	American Heart Association
API	Asian & Pacific Islanders
ATSDR	Agency for Toxic Substances and Disease Registry
COC	Contaminant of Concern
DDT	Dichlorodiphenyltrichloroethane
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food & Drug Administration
HQ / HI	Hazard Quotient / Hazard Index
LOAEL	Lowest Observed Adverse Effect Level
MRL	Minimum Risk Level
MTCA	Model Toxics Control Act
NOAEL	No Observed Adverse Effect Level
NMFS	National Marine Fisheries Service
OEHA	Office of Environmental Health Assessment
PBDE	Polybrominated Diphenyl Ether
PBT	Persistent Bioaccumulative Toxins
PCB	Polychlorinated Biphenyl
PSAMP	Puget Sound Assessment and Monitoring Program
PSAT	Puget Sound Action Team
PSEP	Puget Sound Estuary Program
RfD	Reference Dose
RMA	Sportfish Recreational Marine Area
TEQ / TEF	Toxic Equivalent / Toxic Equivalency Factor
WDFW	Washington State Department of Fish and Wildlife

UNITS OF MEASURE

g	gram
g/day	grams per day
kg	kilogram
mg	milligram
mg/l	milligrams per liter = parts per million in liquid
mg/kg	milligrams per kilogram = parts per million in solid
mg/kg/day	milligrams per kilogram of body weight per day
ppb	parts per billion
ppm	parts per million
µg	microgram
µg/kg	micrograms per kilogram = parts per billion in solid

Glossary

Acute	Occurring over a short time (compare with chronic).
Agency for Toxic Substances and Disease Registry (ATSDR)	The principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of the U.S. Department of Health and Human Services.
Cancer Slope Factor	EPA's measure of the ability of a substance to cause cancer based on the dose of the substance received.
Carcinogen	Any substance that causes cancer.
Chronic	Occurring over a long time (more than 1 year) (compare with acute).
Comparison Value	Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their CVs might be selected for further evaluation in the public health assessment process.
Contaminant	A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.
Dose (for chemicals that are not radioactive)	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligrams (amount) per kilogram (a measure of body weight) per day (a measure of time) when people come into contact with media containing the substance (e.g., drinking water, breathing air, consuming food, skin contact with soil, etc.). In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually gets into the body through the eyes, skin, stomach, intestines, or lungs.
Environmental Protection Agency (EPA)	The federal agency that develops and enforces environmental laws to protect the environment and the public's health.
Epidemiology	The study of the occurrence and causes of health effects in human populations. An epidemiological study often compares two groups of people who are alike except for one factor, such as exposure to a chemical or the presence of a health effect. The investigators try to determine if any factor (i.e., age, sex, occupation, economic status) is associated with the health effect.
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term (acute exposure), of intermediate duration, or long-term (chronic exposure). Exposure to a substance occurs when an individual encounters environmental media containing that substance (e.g., inhaling air, drinking water, skin/soil contact, etc.).

Hazardous substance	Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.
Ingestion	The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way (see route of exposure).
Ingestion Rate (IR)	The amount of an environmental medium that could be ingested, typically on a daily basis. Units for IR are usually liter/day for water and mg/day for soil.
Inorganic	Compounds composed of mineral materials, including elemental salts and metals such as iron, aluminum, mercury, and zinc.
Lowest Observed Adverse Effect Level (LOAEL)	The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.
Media	Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.
Minimal Risk Level (MRL)	An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), non-cancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). MRLs should not be used as predictors of harmful (adverse) health effects (see oral reference dose).
No Observed Adverse Effect Level (NOAEL)	The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.
Oral Reference Dose (RfD)	An amount of chemical, which if ingested on a daily basis over the course of a lifetime, would not be expected to cause adverse effects. These estimates (with uncertainty spanning perhaps an order of magnitude) are published by EPA.
Organic	Compounds that contain carbon, including materials such as solvents, oils, and pesticides.
Parts per billion (ppb)/Parts per million (ppm)	Units commonly used to express dilute concentrations of contaminants. For example, 1 ounce of trichloroethylene (TCE) in 1 million ounces of water is 1 ppm. 1 ounce of TCE in 1 billion ounces of water is 1 ppb. If one drop of TCE is mixed in a railroad tank car (13,200 gallons), the water will contain about 1 ppb of TCE.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing (inhalation), eating or drinking (ingestion), or contact with the skin (dermal contact).

Executive Summary

Background

Over the past decade, the Washington State Department of Fish and Wildlife (WDFW) collected fish tissue data to determine long-term trends in contaminant levels in Puget Sound fish. Concentrations of many contaminants were measured in muscle tissue (without the skin) from English sole, four species of rockfish and two salmon species as part of the Puget Sound Assessment and Monitoring Program (PSAMP - formerly Puget Sound Ambient Monitoring Program).

Findings

Based on tissue concentrations, frequency of detection, and toxicity, DOH concluded that two of the contaminants are of potential public health concern: polychlorinated biphenyls (PCBs) and mercury. DOH assessed these data to address potential health impacts to humans who eat marine fish from Puget Sound. Findings include:

- Mercury contamination of rockfish species in Puget Sound was primarily related to where they live and to fish age.
    - Mercury concentrations were highest in yelloweye rockfish. Age-adjusted mercury levels were higher in rockfish from urban areas of central Puget Sound than in those from non-urban areas of Puget Sound.
- PCBs were elevated in rockfish from urban bays than in near- and non-urban areas.
- English sole from urban areas had higher contaminant levels (i.e., PCBs and mercury) than those from near-urban and non-urban areas. Older fish also tended to have higher mercury levels.
- Puget Sound coho salmon tended to have lower PCB and mercury levels than Chinook salmon.
- Resident Chinook salmon (also known as blackmouth) from Puget Sound tended to have higher PCB levels than migratory Chinook salmon. Blackmouth do not migrate to the open ocean.

Based on contaminant concentrations in fish and on estimates of consumption by recreational anglers, tribal members, and consumers of fish from the Asian Pacific Islander (API) community, DOH determined that frequent consumers of certain fish may be exposed to contaminants above a level of concern.

Recommendations

DOH encourages all Washingtonians to eat at least two fish meals per week as part of a heart healthy diet in accordance with American Heart Association (AHA) recommendations. A variety of fish is an important part of a balanced diet because:

- Fish is an excellent source of protein, vitamins, and minerals.
- The oils in fish are important for unborn and breast-fed babies.
- Eating a variety of fish helps to reduce the chances of cardiovascular disease.
- Eating a variety of fish helps to reduce exposure to contaminants of concern.

Most foods, regardless of source, contain some contaminants. Switching from fish to other types of food may not eliminate contaminant exposure. One can safely continue to eat the American Heart Association's recommended two fish meals per week by avoiding fish that are high in contaminants. The following meal limits are meant to guide people toward making informed decisions when selecting fish to eat. If people eat Puget Sound fish that have recommended meal limits (e.g., rockfish), they should choose other fish that are lower in contaminants in order to get to their heart healthy two meals per week. Good examples of fish that are lower in contaminants include coho, sockeye and chum salmon, flatfish from non-urban areas of Puget Sound and many other store-bought fish known to be low in contaminants. DOH has compiled a list of the many fish low in contaminants based on our own data and previously published data. This list is available at http://www.doh.wa.gov/fish.

DOH provides the following meal advice for anglers and other consumers of Puget Sound fish. This advice is emphasized for women of childbearing age and children because young children may be more susceptible than adults to adverse impacts of contaminant exposure. These recommendations are based on a 60 kg (132 lb) adult and on an assumption that a fish meal is eight-ounces of pre-cooked fish. Children should eat proportionally smaller meal sizes. These recommendations considered exposure to multiple chemicals (i.e., mercury and PCBs) in each fish meal.

Rockfish from Puget Sound

DOH recommends the following for all consumers with respect to rockfish from Puget Sound:

- No consumption of yelloweye rockfish caught anywhere in Puget Sound. This advice, although derived from a small sample size, is based on public health concerns due to high mercury concentrations in these fish. Furthermore, WDFW currently restricts non-tribal harvest of Puget Sound yelloweye and canary rockfish.

- For all other species of Puget Sound rockfish, follow the guidance given below.

Table ES-1. Meal recommendations for rockfish from Puget Sound listed by Washington State Department of Fish and Wildlife recreational marine areas.

Recreational Marine Area (see Figure ES-1)		Consumption Guidance for rockfish from Puget Sound	Exceptions (see Figure ES-2)
6	East Juan de Fuca Strait	No more than 1 meal/week	**None**
7	San Juan Islands	No more than 1 meal/week	**None**
8.1	Deception Pass, Hope Island, and Skagit Bay	No more than 1 meal/week	**None**
8.2	Port Susan and Port Gardner	No more than 1 meal/week - with noted exceptions	**No more than 2 meals per month:** Mukilteo-Everett and Port Gardner.
9	Admiralty Inlet	No more than 1 meal/week	**None**
10	Seattle-Bremerton Area	No more than 1 meal/week - with noted exceptions	**No consumption**: Elliott Bay (east of imaginary boundary from Duwamish Head to Pier 91, including the Duwamish River) and Sinclair Inlet (west of Dyes Inlet and Mitchell Point).
11	Tacoma-Vashon Area	No more than 1 meal/week - with noted exceptions	**No more than 2 meals per month:** Commencement Bay (SE of imaginary boundary between Sperry Ocean dock and Cliff House Restaurant).
12	Hood Canal	No more than 1 meal/week	**None**
13	South Puget Sound	No more than 1 meal/week	**None**

NOTE: Meal size equals eight ounces of uncooked fish for an average-sized adult.

English Sole and Other Flatfish

English sole was the only flatfish sampled and analyzed by PSAMP. While differences in life history may result in varied contaminant concentrations between species, DOH used chemical results from English sole tissue analyses to develop consumption recommendations for all Puget Sound flatfish. WDFW sport fish regulations use the term “bottomfish” to define numerous species. Meal limits specified for flatfish may not be applicable to other bottomfish such as lingcod.

The following table is a summary of consumption guidance for all consumers of Puget Sound English sole and other flatfish. Note that consumption of English sole and other flatfish from urban bays should be limited (Everett, Eagle Harbor, Commencement Bay) or avoided (Duwamish Waterway). Before fishing, anglers should consult WDFW fishing guidance for catch limits.

Table ES-2. Meal recommendations for English sole and other flatfish from Puget Sound listed by recreational marine areas (see Figure ES-3).

Recreational Marine Area (see Figure ES-1)		Consumption Guidance for English Sole and other Flatfish from Puget Sound	Exceptions (see Figure ES-3)
6	East Juan de Fuca Strait	**No meal limit**	**None**
7	San Juan Islands	**No meal limit**	**None**
8.1	Deception Pass, Hope Island, and Skagit Bay	**No meal limit**	**None**
8.2	Port Susan and Port Gardner	**No meal limit** – with noted exceptions	**No more than 2 meals per month:** Everett-waterfront from Mukilteo ferry dock to City of Everett. Based on extrapolation from sediment concentrations.
9	Admiralty Inlet	**No meal limit**	**None**
10	Seattle-Bremerton Area	**No meal limit** – with noted exceptions	**No consumption:** Duwamish Waterway (includes Harbor Island East and West Waterways) **No more than 1 meal per month**: Sinclair Inlet (west of Dyes Inlet and Mitchell Point). **No more than 2 meals per month:** Elliott Bay (east of imaginary boundary from Duwamish Head to Pier 91). **No more than 1 meal per wk**: Eagle Harbor and Port Orchard (waterway separating Bainbridge Island and Kitsap Peninsula).
11	Tacoma-Vashon Area	**No meal limit** – with noted exceptions	**No more than 2 meals per month**: Inner Commencement Bay (SE of imaginary boundary between Sperry Ocean dock and Cliff House Restaurant). **No more than 1 meal per wk**: Outer Commencement Bay (SE of imaginary boundary between Boathouse Marina and Brown's Point).
12	Hood Canal	**No meal limit**	**None**
13	South Puget Sound	**No meal limit**	**None**

NOTE: Meal size equals eight ounces of uncooked fish for an average sized-adult.

Puget Sound Salmon

DOH recommends the following with respect to Chinook and coho salmon in Puget Sound:

- Chinook salmon from Puget Sound may be consumed once (eight ounces) per week (or four times per month).
  - Anglers who catch resident Chinook salmon (also known as blackmouth) in the Puget Sound winter blackmouth fishery should limit their consumption to two eight-ounce meals per month. A Chinook caught in the Puget Sound wintertime fishery weighing

greater than four pounds is likely to be a blackmouth. Blackmouth reside in Puget Sound and appear to accumulate more PCBs than Chinook that migrate to the ocean.

- There are no restrictions on coho caught from marine or in-river fisheries from all areas of Puget Sound. Although DOH acknowledges that coho are not free of contaminants, they are relatively low in contaminants compared to many Puget Sound and store-bought fish. High-end consumers should follow general advice presented below on eating fish as part of a healthy diet.

Other Salmon Species

- Sockeye, pink and chum salmon were not sampled as part of the PSAMP effort. Data from other sources show that sockeye, chum and pink salmon tend to have very low PCB levels, most likely related to life history and diet. Therefore, DOH has no restriction on consumption of these species of Puget Sound salmon.

Preparing Fish to Reduce Exposure to PCBs

Many contaminants (e.g., PCBs) are concentrated in fat. The following preparation methods can further allow consumers to reduce their exposure to some contaminants:

- When cleaning fish, remove the skin, fat, and internal organs before cooking.

- Grill, bake, or broil fish so that fat drips off while cooking.

Figure ES-1. Recreational marine areas in Puget Sound, Washington, as defined in WDFW sport fish regulations.

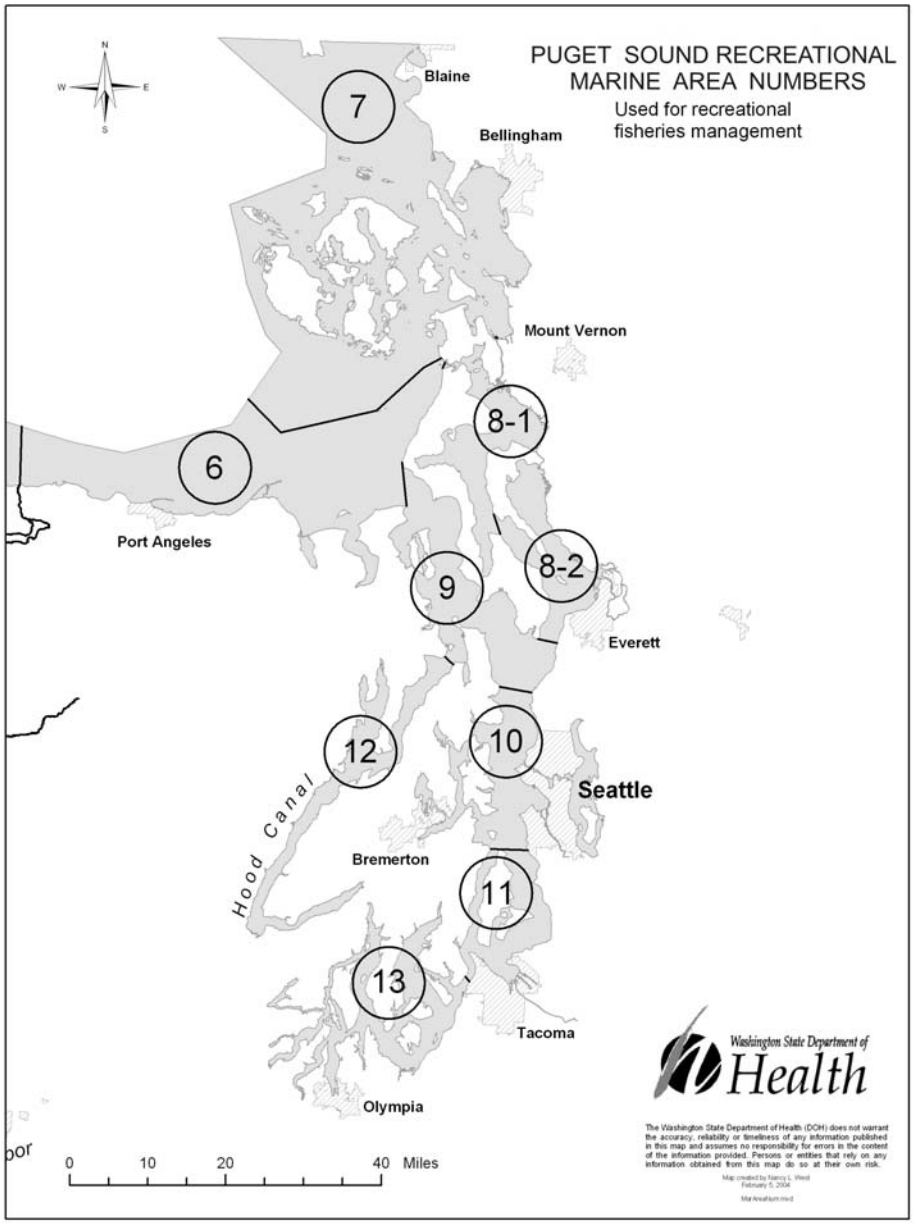


Figure ES-2. Meal limit recommendations for rockfish from urban areas of Puget Sound. Area designations are consistent with WDFW recreational marine areas. The general meal limit recommendation for rockfish throughout Puget Sound is 1 meal per week.

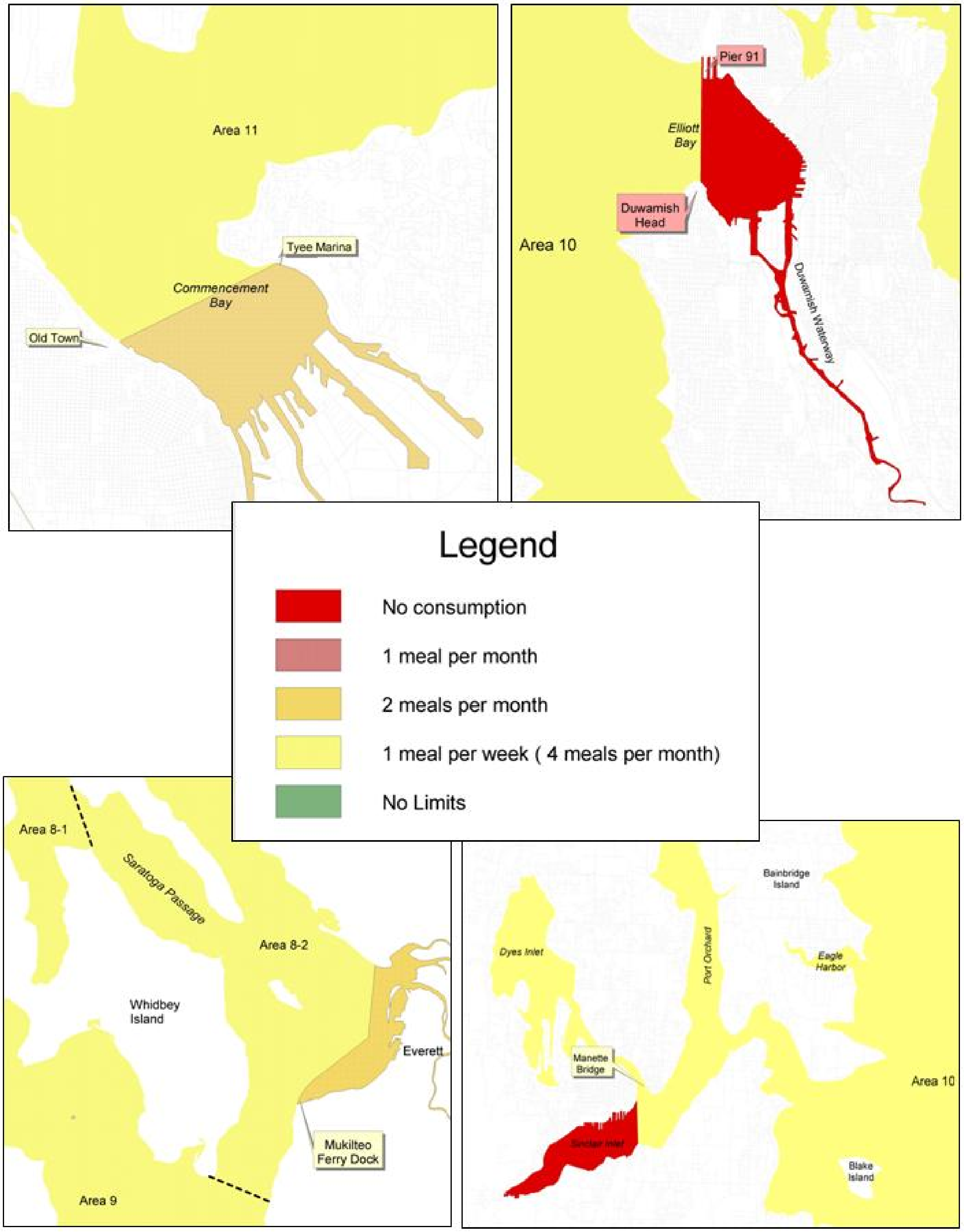
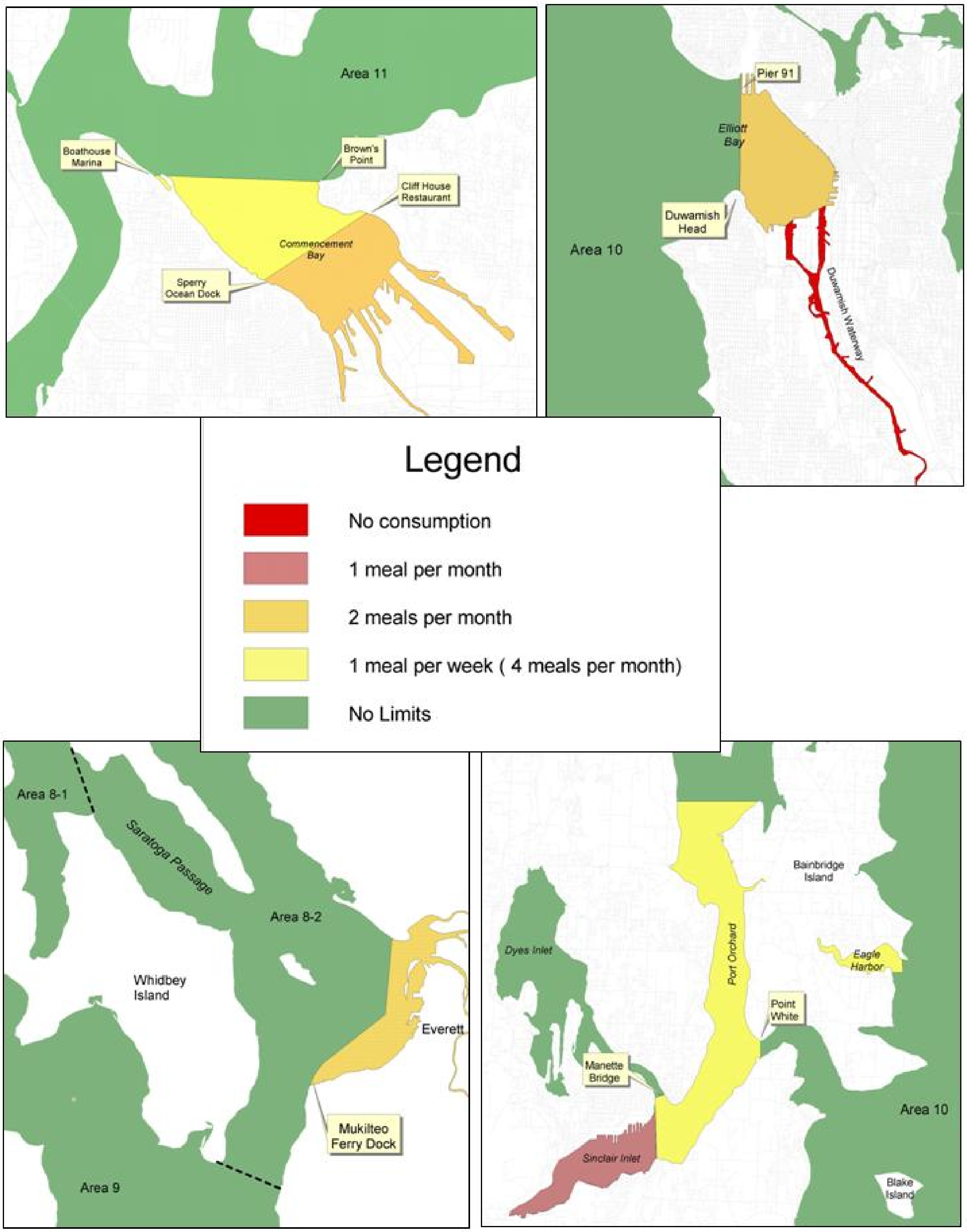


Figure ES-3. Meal limit recommendations for English sole and flatfish from urban areas of Puget Sound. Area designations are consistent with WDFW recreational marine areas.



Introduction

The Washington State Department of Health (DOH) works to protect and improve the health of people in Washington State. Part of this mission is to reduce or eliminate exposures to health hazards in the environment. DOH's Office of Environmental Health Assessments (OEHA) evaluates chemical hazards in the environment, develops strategies to reduce exposure to environmental contaminants, and provides education and outreach to communities to help minimize health impacts to the public. One focus of OEHA is on human health impacts from consuming contaminated fish.

The Washington State Department of Fish and Wildlife (WDFW) has collected fish tissue data from Puget Sound since 1989 in an effort to determine long-term trends in contaminant levels. DOH was asked to assess these data to address potential health impacts to humans who eat marine fish from Puget Sound. The scope of this assessment is limited to Puget Sound and primarily focused on marine fish data collected by WDFW for the Puget Sound Assessment and Monitoring Program (PSAMP). PSAMP is a long-term, multi-agency effort designed to monitor the environmental health of Puget Sound. While analyses included many contaminants (West et al. 2001), DOH identified only two chemicals at levels of potential concern to human health, polychlorinated biphenyls (PCBs) and mercury, based on frequency of detection, contaminant concentrations, and contaminant toxicity (Appendix E).

The purpose of this report is to review and evaluate potential health risks that may result from exposure to bioaccumulative contaminants through the consumption of Puget Sound fish based on data collected by WDFW. PCBs are assessed for cancer and non-cancer endpoints while mercury is assessed for non-cancer effects only. Consideration is given to fish life history, chemical toxicity, potential exposure to contaminants by fish consumers (based on estimated consumption), consumer body weight, comparison of contaminant levels with fish from other regions, and the overall health benefits of eating fish. The above factors are weighed by DOH to provide guidance for consuming Puget Sound fish.

Background

Puget Sound is a fjord, an inlet created by a glacier. The Sound is also an estuary, an arm of the sea that extends inland to meet the mouth of a river (or rivers) where fresh water meets salt water. Historically, glaciers scoured Puget Sound to a depth of 275 meters and created shallow plugs called sills at several locations: at Admiralty Inlet, between the San Juan Islands, at Deception Pass, at the mouth of Hood Canal, and at The Narrows (near Tacoma). Puget Sound's physical characteristics affect the relationship between sediments and organisms, including transfer of contaminants. Many pollutants, which are generally the result of direct and indirect discharges into aquatic systems, end up in the bottom sediments. The major types of pollutants discharged into Puget Sound include sewage, pulp and paper industry wastes, petroleum, heavy metals, and synthetic organic chemicals (Strickland 1983).

Contaminants in the sediment and water column may accumulate in organisms through processes called bioaccumulation and bioconcentration. Some contaminants may biomagnify, thereby concentrating in organisms higher on the food web. Bioaccumulative chemicals are generally hydrophobic and have an affinity for carbon, either in sediments or the lipids of aquatic organisms. Many bioaccumulative contaminants end up in sediments because the organic carbon content of sediments is higher than that of the water column. PCBs are an example of bioaccumulative chemicals that adhere to the surfaces of organic particles in the water column, resulting in their eventual deposition and accumulation in sediments. Since most particles end up within the sediment in aquatic systems, these sediment-associated contaminants may affect the health of bottom fish such as English sole and/or other species that eat bottom-dwelling prey. Highest PCB concentrations are typically found in fine-grained, organically rich sediments (NRC 2001).

Mercury and PCBs have been detected in fish and other organisms in Puget Sound as well as in other aquatic systems in the U.S. (Dellinger et al. 1996, Giesy et al. 1997, Gerstenberger et al. 1997, Jaffe et al. 1985, Kuehl et al. 1994, Landolt et al. 1985, Landolt et al. 1987, Loganathan et al. 1995, Maruya and Lee 1998, Miller et al. 1993, Ryan et al. 1984, Stow et al.1995, West et al. 2001, Zabik et al. 1995). Mercury, a heavy metal, can biomagnify in fish species to levels that can be harmful to humans who consume fish (ATSDR 1999). Most mercury that bioaccumulates is in the form of methylmercury. Mercury exposure is of particular concern to the developing fetus and to young children. PCBs, banned from use and production in the U.S. since 1977, are known as organochlorine compounds. PCBs are of concern to the developing fetus and are classified as probable human carcinogens. PCBs are persistent and continue to enter the environment indirectly from such products as electrical transformers, lubricants, plastic, and paint and indirectly through atmospheric deposition. In Puget Sound, PCBs are generally concentrated in industrialized urban embayments or waterways such as Sinclair Inlet, Commencement Bay, or the Duwamish Waterway. The number of U.S. fish advisories based on PCBs is second only to those based on mercury (EPA 1999a, EPA 2001a).

Fish Species

Rockfish (brown, copper, quillback, and yelloweye), English sole, and Chinook and coho salmon were collected from Puget Sound as part of PSAMP. Descriptions of each species including information on their distribution, feeding patterns, and life histories can be found in Appendix A. “Age” is often an important factor when evaluating contaminant levels in fish because levels of certain chemicals tend to increase as fish get older. Of the species collected for PSAMP, rockfish can live the longest (up to 90 years), followed by English sole (between 2 and 21 years), Chinook salmon (typically up to a few months in freshwater and 2 to 4 years in the marine environment), and then coho salmon (typically one winter in freshwater and 16 – 18 months in the marine environment) (Hart 1973; S. O’Neill, personal communication, 2004; G. Ruggerone, personal communication, 2005).

Chinook and coho salmon are anadromous, which means they are hatched and reared (depending on species) in fresh water, rear for some of their life in the ocean, and then return to fresh water to spawn. Some Chinook remain in Puget Sound during the period when most migrate to the ocean. Chinook that have this life-history type are referred to as “blackmouth.” Chinook and coho usually feed higher in the food web than other salmon species and therefore have greater potential for contaminant bioaccumulation than other salmon species. Salmon accumulate most of their body weight and associated burden of contaminants while foraging in marine waters (O’Neill et al. 1998).

English sole are bottom feeders with a limited home range while rockfish tend to be even more sedentary. Contaminant levels in English sole and other bottom fish may show greater spatial variation than other species due to the localized nature of sediment contamination in Puget Sound. Contaminants such as PCBs and mercury may be present at higher levels in older (i.e., rockfish) and larger fish because these metabolically-resistant contaminants can bioaccumulate over time (i.e., exposure time is greater in older fish). Further, contaminants biomagnify (chemical concentrations increase in species toward the top of the food chain) as fish grow and consequently feed on higher trophic level prey (Rand 1995).

Contaminants of Concern

PSAMP analyzed fish muscle tissue for over 100 chemicals found on the USEPA Priority Pollutant List or Hazardous Substance List (Appendix E). Chemicals included chlorinated pesticides, polychlorinated biphenyls (PCBs), other organic compounds (phenols and substituted phenols, aromatic hydrocarbons, chlorinated aromatic hydrocarbons, phthalates, and others), and metals such as mercury, lead, copper and arsenic. Based on analytical results, DOH concluded that only PCBs and mercury were detected with sufficient frequency and of high enough levels to warrant an assessment of human health risk. These chemicals are frequently observed in aquatic organisms due to their persistence, toxicity, and ability to bioaccumulate and/or biomagnify. A description of these chemicals, including aspects of exposure and toxicity, can be found in Appendix B.

Additional compounds detected in fish collected for the PSAMP program included DDT, copper, and arsenic. Other compounds were seldom detected. DDT and its breakdown products (DDD and DDE) were detected frequently, but mostly at very low levels. Copper was often detected but always at low levels since fish can regulate copper in their systems. Thus, copper was not an issue for human health because of the low levels observed and its low toxicity to humans. Highest arsenic levels were reported in bottomfish (West et al. 2001); however, concentrations were not related to any known sources of arsenic pollution. Human health impacts due to arsenic levels in fish tissue were not assessed. The majority of arsenic found in finfish is thought to be in the form of relatively non-toxic organic compounds. Inorganic arsenic accounted for 0.01-1.3% in Puget Sound fish and crab analyzed by Washington State Department of Ecology in 2002 (Ecology 2002).

Polybrominated diphenyl ethers (PBDEs), an emerging group of contaminants, were not analyzed as part of this PSAMP dataset but have been detected in fish tissue from Puget Sound. Information on PBDEs is presented in the discussion section of this report. WDFW has begun to sample and analyze PBDEs in Puget Sound fish. Toxicological reference values for PBDEs are forthcoming from EPA.

Methods

Fish Sampling

Rockfish

Quillback, copper, yelloweye, and brown rockfish were collected from Puget Sound by SCUBA divers with spears, by hook-and-line from a boat, or by bottom trawling (West et al. 2001). Rockfish were also received as donations from sport or tribal fisheries. Various species of rockfish were collected at several stations beginning in 1989 (quillback and copper rockfish), 1995 (brown rockfish), and 1996 (yelloweye rockfish) (Table 1, Figure 1). Certain stations were sampled more frequently than others (West et al. 2001).

Although quillback, brown and copper rockfish were analyzed for a number of contaminants, only results for PCBs and mercury are presented in this report. Brown, copper and quillback rockfish are widely distributed throughout Puget Sound (Matthews 1990). Since all species of rockfish are predominantly non-migratory, contaminants in muscle tissue are likely to reflect local conditions (West et al. 2001). Samples were either from an individual fish or a composite where muscle tissue from several fish were mixed together. After 1995, all rockfish were analyzed as individuals.

English Sole

From 1989 to 2001 WDFW collected English sole annually with an otter trawl in the months of April and May, at numerous locations throughout Puget Sound (Table 1 and Figure 2).[1] Sites were classified by WDFW as urban, near-urban, and non-urban. These subjective classifications were developed for data interpretation and risk communication purposes and not intended for use in remedial decisions. Eight sites were sampled regularly throughout this period: Commencement Bay, Elliott Bay, Port Gardner, Sinclair Inlet, Nisqually, North Hood Canal, the Strait of Georgia, and Vendovi Island. Most English sole samples were composites comprising 20 individuals per composite. Equal amounts of skinned muscle tissue were collected from individual fish. Sampling methods for fish tissue are described in West et al. (2001).

---

[1] Monitoring is on-going. Data from 2003 are available but were not included in analyses due to different extraction solvents used in sample preparation (S. O'Neill, personal communication, 2006).

Table 1. Puget Sound English sole (ES) and rockfish (R) sampling stations classified by urban, near-urban, or non-urban setting.*

Urban stations		Near urban stations		Non urban stations	
Commencement Bay (Thea Foss)	ES, R	Budd Inlet	ES	Apple Cove Point	ES
Commencement Bay 2	ES, R	Bellingham Bay (outer)	ES	Birch Point	ES
Duwamish	ES	Blakely Rock	R	Carr Inlet 1	ES
Eagle Harbor	ES	Brown's Point	R	Case Inlet 1 (South Case Inlet)	ES
Elliott Bay (Seattle Waterfront)	ES, R	Cherry Point	ES	Case Inlet 3 (North Case Inlet)	ES
Elliott Bay 2 (Harbor Island)	ES, R	Commencement Bay 3 (Ruston)	ES	Day Island	R
Elliott Bay 4 (Myrtle Edwards)	ES, R	Commencement Bay 4 (Old Tacoma)	ES, R	Discovery Bay	ES
Fuller Shipwreck (Elliott Bay)	R	Commencement Bay 5 (Brown's Point)	ES, R	Double Bluff	R
Mukilteo-Everett	ES, R	Dalco Passage	R	Fern Cove	ES
Outer Commencement Bay	ES	Dash Point	ES	Foulweather	R
Port Gardner	ES, R	Dyes Inlet	ES	Hood Canal	ES, R
Sinclair Inlet	ES, R	Elliott Bay 5 (Alki)	ES	Hood Canal M	ES
Sinclair Inlet (Tribal)	R	Gig Harbor	R	Hood Canal S	ES
		Lakota	R	McAurther Bank	ES
		Liberty Bay	ES	Nisqually	ES
		Port Orchard	ES	Orcas Island	ES, R
		Port Townsend	ES	Outer Birch Point	ES
		Sinclair Inlet 2 (Outer Sinclair)	ES, R	Pickering Passage	ES
		Sinclair Inlet 3	ES	Possession Point	ES
		Sinclair Inlet 4 (Battle Point)	ES	Port Ludlow	ES
		Sinclair Inlet 5 (Blake Island)	ES	Port Madison	ES
				Point Roberts	ES
				Port Susan	ES
				San Juan Islands	R
				Saratoga Passage	ES
				Shilshole	ES
				Strait of Juan de Fuca	ES
				Strait of Georgia	ES
				Vendovi Island	ES
				Wollochet	ES

* Urban, near-urban, and non-urban stations were determined by WDFW (West et al. 2001) and updated for this report.

Figure 1. Puget Sound sites where rockfish were sampled by WDFW for the Puget Sound Assessment and Monitoring Program.

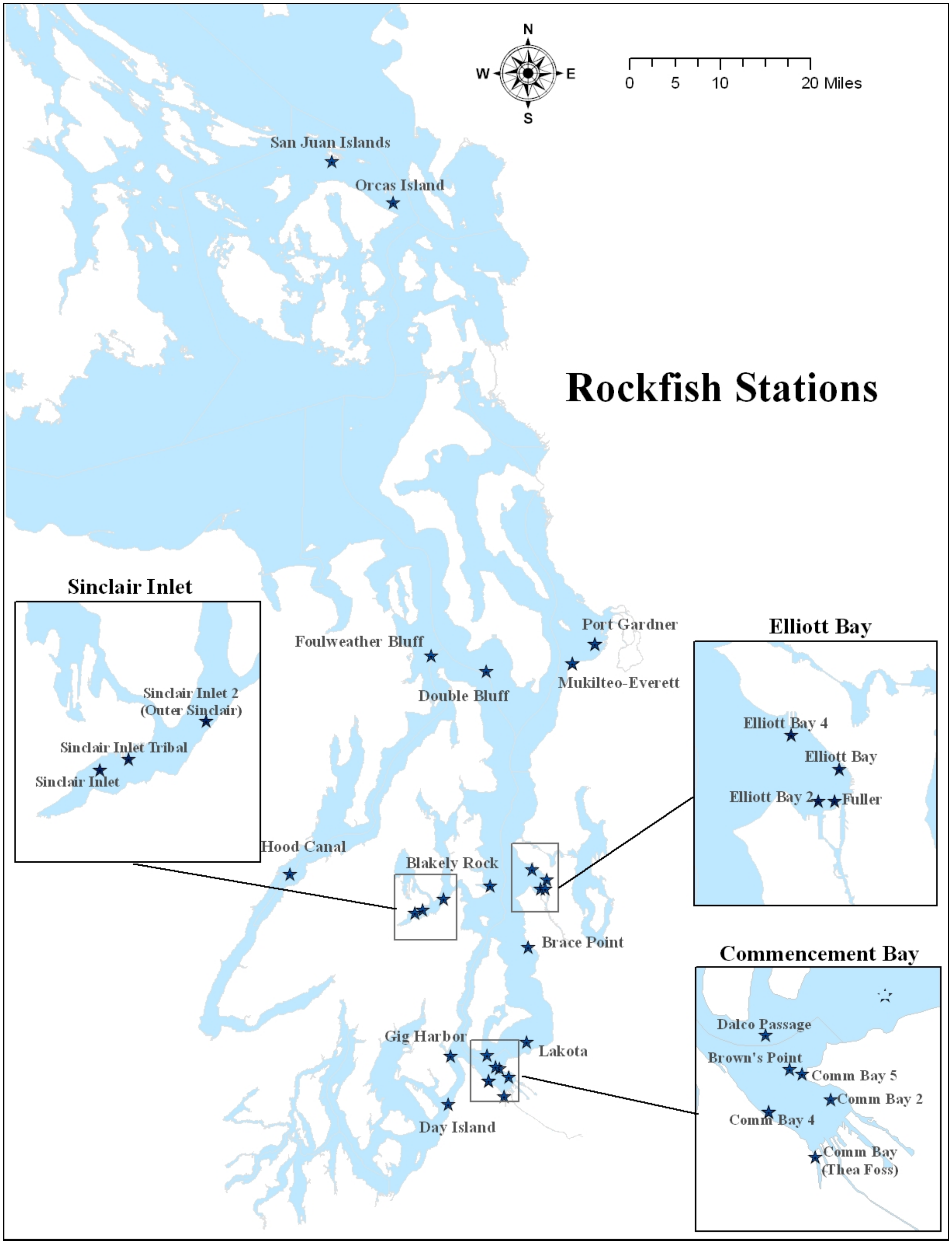


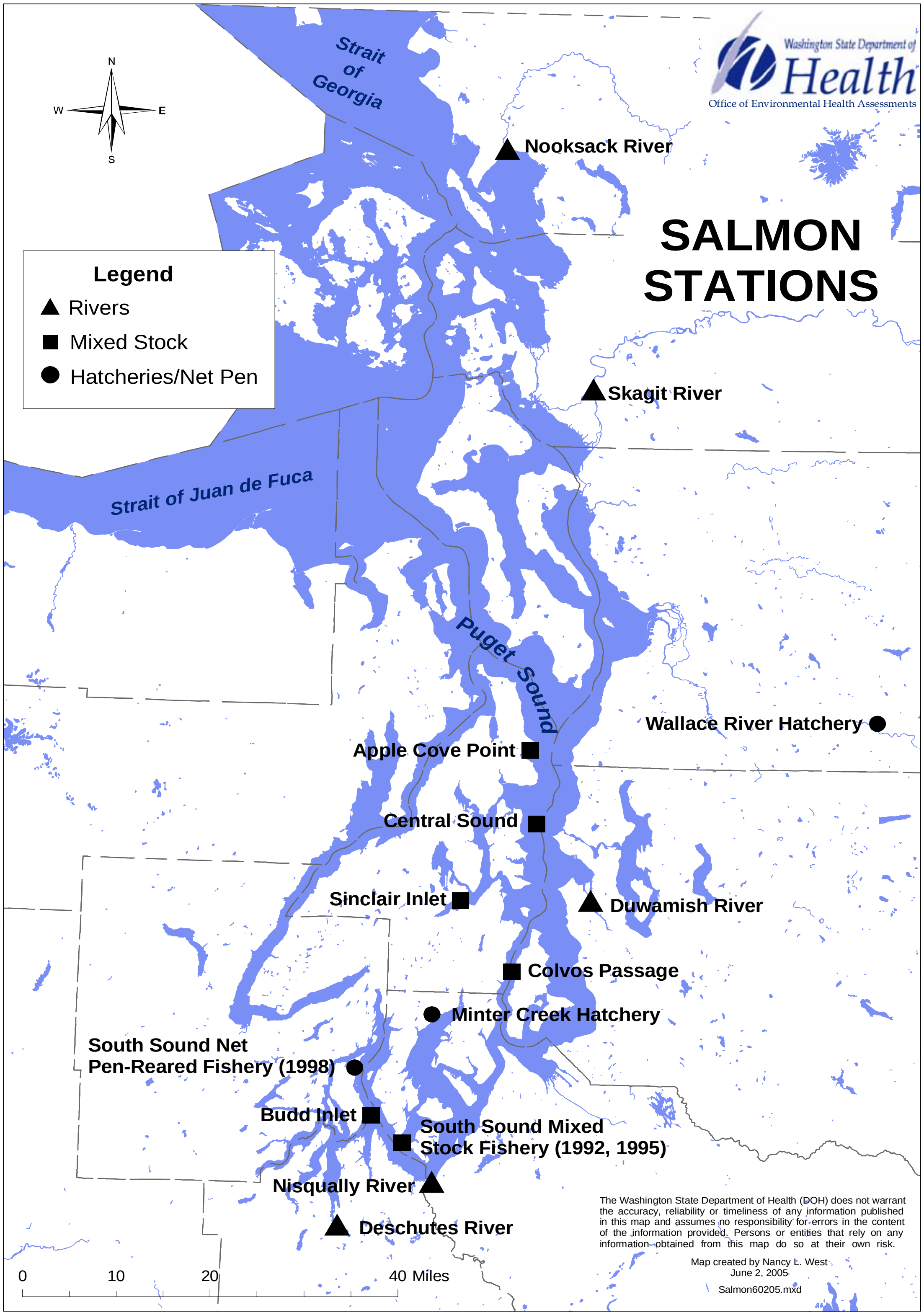
Figure 2. Puget Sound sites where English sole were sampled by WDFW for the Puget Sound Assessment and Monitoring Program.

Coho and Chinook salmon

Chinook and coho salmon were selected for monitoring because of their importance in tribal, recreational and commercial fisheries. As such, they represent a pathway through which contaminants move from Puget Sound to humans (Landolt et al. 1987, West et al. 2001). Sampling locations for coho and Chinook included rivers and river mouths from which fish were presumed to originate ("in-river" areas) and offshore marine areas where the origins of the fish were unknown (West et al. 2001) (Figure 3). Blackmouth, or resident Chinook, were not collected separately from other Chinook in this study.

Coho and Chinook salmon were collected with a commercial purse seine or purchased from licensed fish buyers and treaty tribal fishermen in late summer and early fall, beginning in 1990. Whole salmon were transported to the laboratory on ice where they were measured and weighed, and scales removed for later age determination. Fish were wrapped individually in aluminum foil, placed in plastic bags and stored on ice until tissues were removed for contaminant analyses (West et al. 2001). As with other fish species, salmon analyses were conducted on both individual and composite samples of skinned muscle tissue.

Figure 3. Stations where salmon were sampled in Puget Sound by WDFW for the Puget Sound Assessment and Monitoring Program.



Tissue Analysis

A detailed description of analytical methods used to measure contaminants in Puget Sound fish sampled and analyzed by PSAMP is available (West et al. 2001). The following provides a summary of information described in the WDFW report. Chemical analyses for organic and inorganic compounds followed procedures from the Puget Sound Estuary Program (PSEP 1989a, 1989b). These protocols reference USEPA Contract Laboratory Program Procedures (EPA 1986a, 1986b) and incorporate additional Quality Assurance/Quality Control (QA/QC) requirements.

All metals, including mercury, were analyzed as total elemental concentrations and reported as parts per million wet weight (ppm). Separate digestates were prepared for mercury using the nitric acid/sulfuric digestion method then analyzed by the cold vapor atomic absorption method. DOH assumed that total mercury concentrations were available as methylmercury because 90 - 100% of total mercury is typically in the form of methylmercury in adult fish (EPA 2001a).

Organic compounds were extracted from tissue samples by soxhlet extraction (for 1989 and 1990 samples) or sonication with a methylene chloride and acetone mix (for 1991, 1992, and 1993 samples). Beginning in 1991, all extracts were cleaned by gel permeation chromatography. The extracts were split, one for pesticide and PCB analyses and the other for base/neutral/acid-extractable (BNA) compounds.

Pesticides and PCBs were analyzed using gas chromatography-electron capture detection (GC/ECD), with Aroclor mixtures used as standards for quantifying PCB concentrations and reported as parts per billion (ppb) wet weight. In 1989 and 1990, a dual megabore column was used on the GC/ECD, but in 1991, 1992, and 1993, a dual narrow-bore column better suited to analyzing low concentrations was substituted. Starting with 1992 rockfish samples, new chromatography software was used for quantification of pesticides and PCBs, allowing laboratory chemists to more accurately quantify low concentrations of these chemicals. Because of these method changes, PCB data from 1989 and 1990 were not included in this evaluation. Chromatographic peaks used to quantify individual Aroclors may have contributions from multiple Aroclors, resulting in overestimation of an individual Aroclor level. Total PCBs in tissue can be overestimated when inflated results for individual Aroclors are summed.

A congener-specific screening method and estimation of total PCBs and pesticides (using high performance liquid chromatography with photodiode array - HPLC/PDA) was adopted in 1997 (Krahn et al. 1994). The method provided measures of 15 of 209 PCB congeners (77, 101, 105, 110, 118, 126, 128, 138, 153, 156, 157, 169, 170, 180, and 189). In 1997 and 1998, a number of tissue samples were analyzed using both the Aroclor-PCB (GC/ED) and the congener-PCB (HPLC/PDA) method. Results of both methods are included in this report. The HPLC/PDA method avoids overestimation of PCB concentration inherent in the Aroclor-summation procedure but may underestimate total PCBs because it only analyzes a fraction of PCB congeners.

Total PCBs were estimated in this report using two methods:

- Arithmetic summation of individual Aroclors (1248, 1254, and 1260), and

- Analytical measurement of total PCBs by the HPLC/PDA screening method (measuring the concentration of 15 of 209 PCB congeners). This method provided estimates of "total PCBs" from measurements of total area under the congener curve. These results were later adjusted to derive an Aroclor-equivalent concentration based on observed trends from samples analyzed using both methods.

WDFW staff validated 1989 and 1990 data and, beginning in 1991, an independent QA/QC chemist reviewed tissue chemistry data. Internal QA/QC reports are available from WDFW on request. For this report, one-half of the detection value was used when chemicals were not detected above the analytical detection level. The average detection limit for Aroclors was 2.0 ppb and <1.0 ppb for individual congeners by the HPLC/PDA method.

Risk Assessment

The following is an overview of steps used by DOH to determine whether or not fish consumers are potentially overexposed to contaminants in fish and to develop meal recommendations for consuming these fish (Figure 4).

- The first step is to determine how much fish is consumed by potentially-exposed anglers, tribal members, additional high-consuming populations, and other citizens. DOH typically uses mean and 90th (or 95th) percentile population-specific consumption rates to estimate average and high-end exposures.

- The second step is to obtain contaminant data (in this case from PSAMP) or to analyze fish samples for contaminant concentrations to estimate levels in fish tissue.

- Using this information, DOH can establish what contaminants people are exposed to and estimate the doses a person would receive from consuming fish.

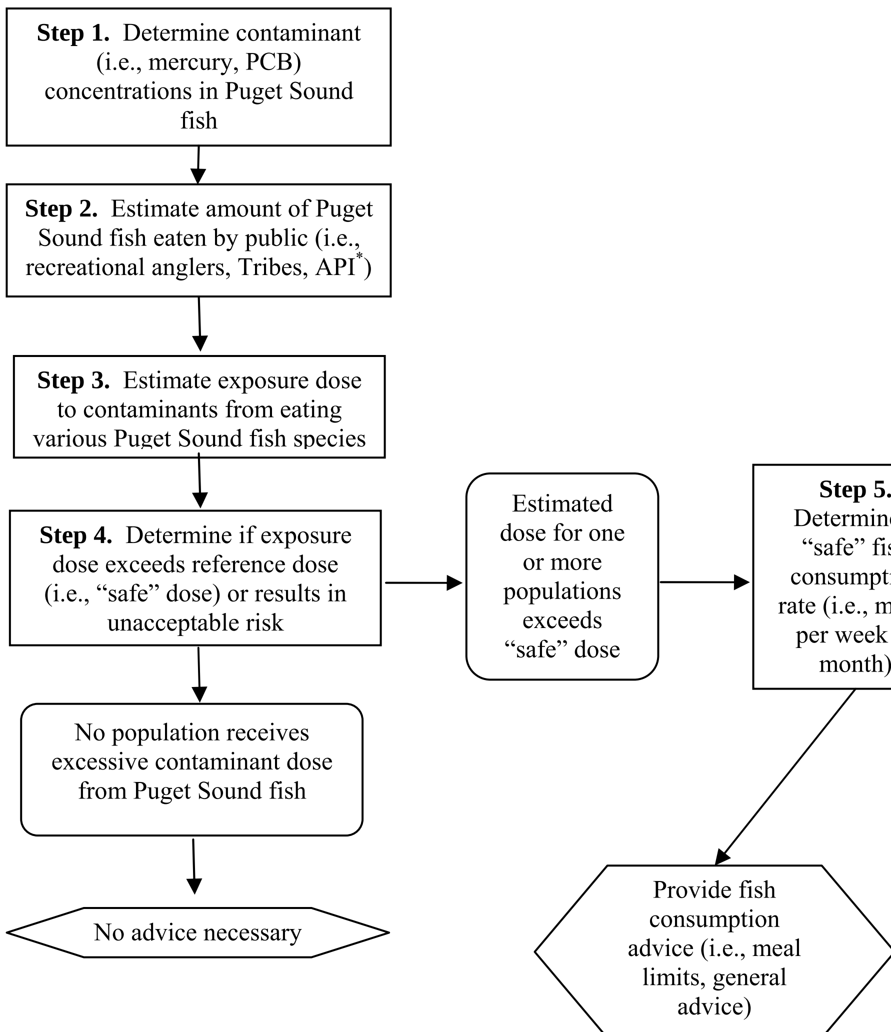
- The next step is to determine if the calculated exposure dose is potentially unsafe. This is done in this report by comparing the calculated exposure dose to an oral reference dose (RfD) specific to each chemical of concern. A reference dose is a level of exposure below which non-cancer adverse health effects are not likely to occur. Further, lifetime increased cancer risk attributable to carcinogenic contaminants (i.e., PCBs) in fish is calculated and presented.

- Finally, if a population is over-exposed (i.e. PCB HQ > 1) based on a representative consumption rate, DOH then calculates acceptable meal limits based on non-cancer endpoints. A reference dose is considered protective of both non-cancer and cancer health effects for contaminants evaluated in this assessment (i.e., PCBs and mercury).

In a further step, DOH calculates acceptable meal limits based on exposure to multiple chemicals (in this case, in Puget Sound fish) to account for combined toxicity of chemicals acting on the same organ systems.

Finally, DOH considers results of the above analyses along with other factors, such as the health benefits of eating fish and the availability of less contaminated fish or food from other sources, to formulate public health messages. Advice will be communicated to people who regularly eat fish from Puget Sound (i.e., Native Americans, anglers, etc.).

Figure 4. Flow chart of steps DOH used to assess human exposure to contaminated fish**.**



* Asian and Pacific Islanders

Approach for assessing non-cancer risk

In order to evaluate the potential for non-cancer adverse health effects that might result from exposure to contaminated fish tissue, a dose is estimated for each contaminant of concern. The estimated dose for each contaminant is then compared to EPA's oral reference dose (RfD). RfDs are doses below which non-cancer adverse health effects are not expected to occur (so called "safe" doses). The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure of a chemical to the human population (including sensitive subpopulations) that is likely to be without risk of harmful non-cancer effects during a lifetime. They are derived from effect levels obtained from human population and laboratory animal studies. These outcome levels can be either the lowest observed adverse effect level (LOAEL) or a no-observed adverse effect level (NOAEL). In human or animal studies, the LOAEL is the lowest dose or threshold at which an adverse health effect is seen, while the NOAEL is the highest dose that does not result in any adverse health effects.

> **Oral Reference Dose (RfD)**
> Oral reference doses (RfDs) are levels of exposure to chemicals below which non-cancer effects are not expected. EPA sets RfDs based on chronic exposure only. An RfD is derived by dividing a toxic effect level determined in animals or humans by "safety factors" to account for uncertainty and provide added health protection.

Because of uncertainty associated with these data, the toxic effect level is typically divided by "safety factors" resulting in the lower and more protective RfD. If a dose exceeds the RfD, this indicates only the potential for adverse health effects. The magnitude of this potential can be inferred from the degree to which this value is exceeded. If the estimated exposure dose is only slightly above the RfD, then that dose will likely fall well below the toxic effect level. The higher the estimated dose is above the RfD, the closer it will be to the toxic effect level.

Comparisons between the exposure dose and the RfD are called hazard quotients (HQ) and are determined by the following equation:

$$\text{Hazard quotient} = \frac{\text{Estimated dose (mg/kg/day)}}{\text{RfD (mg/kg/dy)}}$$

If the hazard quotient is greater than one, then the RfD is exceeded. Exceeding a reference dose does not mean a person will experience an adverse health effect, only that the potential exists. The more a hazard quotient exceeds a value of one, the greater potential for adverse health effects.

The Agency for Toxic Substances and Disease Registry (ATSDR) recommends that interactions between multiple chemicals be assessed for the potential that combined exposures could result in adverse effects that are more (synergistic) or less (antagonistic) severe than would be anticipated from the addition of each chemical dose (ATSDR 2004a). In the absence of any data to suggest synergism or antagonism, ATSDR recommends that an assumption of additivity be made for chemicals acting on the same target organ. Mechanistic data on how PCBs and mercury interact are lacking, so their combined effect is considered additive for the purpose of this assessment (ATSDR 2004b). The two chemicals of concern in this assessment have been linked to several harmful effects including impacts on neurodevelopment and the immune system. Non-cancer effects associated with exposure to multiple chemicals detected in fish tissue were evaluated by adding the hazard quotients (HQs) for specific harmful effects that can be caused by both PCBs and mercury. This total is referred to as a hazard index (HI) that can be used to account for multiple chemical exposures.

If a hazard index approach is used, the RfD for each contaminant should be for the same health effect. The following table shows endpoint-specific RfDs or minimal risk levels (MRLs)[2] for chemicals commonly found in fish.

To calculate hazard indices, the endpoint-specific (e.g., developmental endpoint, immunological endpoint, etc.) hazard quotient for each contaminant must be calculated as shown below:

$$HQ_{\text{(Developmental)}} = \text{Estimated dose} / RfD_{\text{(Developmental)}}.$$

Next, hazard quotients are summed to determine the hazard index for a specific endpoint, as shown below:

$$HI_{\text{(Developmental)}} = HQ_{\text{PCBs (Developmental)}} + HQ_{\text{Mercury (Developmental)}}.$$

The following table shows endpoint-specific RfDs or MRLs for PCBs and mercury.

Table 2. Organ- or endpoint-specific RfDs or MRLs (mg/kg/day) used to calculate an endpoint-specific hazard index.*

Endpoint/Organ	Methylmercury	PCBs
Hepatic	NA	1x10 -4
Endocrine	NA	1x10 -4
Immunological	3x10 -4	2x10 -5
Reproductive	4x10 -4	2x10 -4
Developmental	1x10 -4	3x10 -5
Neurological	3x10 -4	3x10 -5

*All values taken from EPA's Integrated Risk Information System (IRIS) or ATSDR's Interaction Profile for Persistent Chemicals Found in Fish (Chlorinated Dibenzo-P-Dioxins, Hexachlorobenzene, P,P'-DDE, Methylmercury, and Polychlorinated Biphenyls).
NA = Not available.

Approach for assessing cancer risk

Some chemicals have the ability to cause cancer. Cancer risk is estimated by calculating a dose and multiplying it by a cancer potency factor, also known as a cancer slope factor, which is an estimate of the ability of a chemical to cause cancer. Some cancer potency factors are derived from human population data, others are derived from laboratory animal studies involving doses much higher than typically encountered in the environment. Use of animal data requires extrapolation of the cancer potency obtained from these high dose studies down to real-world, environmentally relevant exposures. This process involves much uncertainty. In the face of uncertainty, EPA generally uses health protective estimates of a substance's carcinogenicity (for example, using the upper 95% confidence limit on the dose response curve) and assumes that the cancer dose response relationship is linear at low doses.

[2] Minimal risk levels (MRLs) are derived by the Agency for Toxic Substances and Disease Registry (ATSDR). Methods of derivation are not substantially different from those used by EPA to derive oral reference doses (RfDs).

Currently, many risk analyses assume that there is no "safe dose" of a carcinogen and that a very small dose of a carcinogen is associated with a small increased risk of cancer. However, EPA's new "Guidelines for Carcinogen Risk Assessment" stress the need to determine, if possible, a chemical's mode of action in causing cancer. For chemicals that are carcinogenic via a mutagenic mode of action and for carcinogens for which the mode of action is unknown, EPA assumes public health-protective default positions in reviewing scientific data. For example, animal tumor findings are judged to be relevant to humans, and cancer risks are assumed to have no threshold; (i.e., there is no dose without any effect). For other modes of action, nonlinear approaches may be considered, which is a dose below which no cancer risk is assumed (EPA 2005).

Cancer risk estimates are often not *yes/no* answers as with non-carcinogens but estimates of chance (probability) related to exposure. Such estimates, however uncertain, are useful to determine the magnitude of a cancer threat since, for some carcinogens, any level of exposure may have some associated risk. The validity of the "no safe dose" assumption for cancer-causing chemicals is not clear. Some evidence suggests that certain chemicals considered to be carcinogenic must exceed a threshold of tolerance before initiating cancer.

This document presents estimated lifetime increased cancer risk numerically. For instance, a cancer risk of 1×10^{-5} or 1 in 100,000 can be better understood by considering 100,000 exposed individuals required for an attributed exposure to result in a single cancer case over a lifetime (e.g., 70 years). These estimates are for *excess* cancers that might result in addition to those normally expected in an unexposed population. EPA's acceptable cancer risk range is typically 10^{-4} to 10^{-6} when making cleanup decisions at Superfund sites.

Cancer is a common illness and its occurrence in a population increases with age. Depending on the type of cancer, a population with no known environmental contaminant exposure could be expected to exhibit a substantial number of cancer cases. Many different forms of cancer result from a variety of causes. Some forms of cancer are more serious than others and not all are fatal. Approximately one quarter to one third of people living in the United States will develop cancer at some point in their lives. For this assessment, cancer risks were calculated for fish consumers based on their exposure to PCBs.

Uncertainty

There are many uncertainties associated with the risk assessment process described above. Uncertainty refers to incomplete understanding of factors such as chemical toxicity, human variability, human behavior patterns, and chemical concentrations in the environment. Uncertainties can be significant or inconsequential and can only be reduced through further study.

In risk assessments, uncertainty about chemical toxicity and how it varies among individuals can be significant. For most chemicals, there is little knowledge of the actual health impacts that can occur in humans from environmental exposures. In the absence of epidemiological or clinical evidence, risk assessors rely on toxicological experiments performed on animals. These animals are exposed to chemicals at much higher levels than are found in the environment. Doses associated with no observable adverse effect or the lowest observable adverse effect in animal studies are often extrapolated to “real world” exposures for use in human health risk assessments. In order to be protective of human health, uncertainty factors are used to lower that dose in consideration of variability in sensitivity between animals and humans and the variability within humans. These uncertainty factors can account for a difference of two to three orders of magnitude in the calculation of risk. For this reason, results from the risk assessment process are only one consideration in the establishment of state fish consumption guidance/advisories.

Results

Contaminant Concentrations in Puget Sound Fish Species

The following is a brief summary of PSAMP contaminant data from 1989-2003. Means and ranges of mercury and PCB concentrations in four species of rockfish, English sole, and Chinook and coho salmon are presented (Table 3). Mean contaminant concentrations were also calculated for each fish species by individual sampling location (Appendix D, Tables D1 – D4).

Mercury

The highest mean mercury concentration was observed in rockfish from Puget Sound (mean for all rockfish species = 0.287 ppm) (Table 3). Increased fish age was the primary factor associated with increased mercury concentrations in these species (O’Neill and West 2006). Highest individual mercury concentrations were observed in a 55-year-old yelloweye rockfish from Brace Point in central Puget Sound (1.44 ppm) and a 90-year-old yelloweye collected near San Juan Island (0.928 ppm) (Appendix C, Table C6). The mean age-adjusted mercury level in rockfish from three urban bays of central Puget Sound (Sinclair Inlet, Elliott Bay, Port Gardner/Everett) was significantly greater than levels from rockfish collected from other Puget Sound areas (excluding Foulweather Bluff) (O’Neill and West 2006).

The mean mercury concentration was much lower in English sole (0.060 ppm, n = 577) than in rockfish (0.287 ppm, n = 349). Similar to rockfish, mercury accumulation in English sole was higher in older fish. English sole mercury concentrations were slightly higher in fish from urban locations than in near- and non-urban areas.

The lowest mean mercury concentration was observed in Puget Sound coho (0.039 ppm, n = 225). The mean mercury level in Chinook salmon (mean = 0.093 ppm, n = 106) was over twice as high as levels in coho.

Polychlorinated biphenyls (PCBs)

Location was the primary factor associated with PCB concentrations in rockfish. The highest mean PCB concentration (sum of Aroclors) for a Puget Sound species was observed in brown rockfish (213 ppb, n = 11, Table 3), which is reflective of their sampling location - many brown rockfish were from Sinclair Inlet (326 ppb, n = 6, Appendix C, Table C2). High PCB concentrations were also observed in quillback rockfish from Elliott Bay (293 ppb, n = 5) and Sinclair Inlet (144 ppb, n = 3). Mean PCB concentrations from non-urban rockfish were markedly lower (mean = 5.8 ppb, n = 85). Gender was another important factor with regard to PCB concentration in tissue, with higher PCB levels observed in male rockfish than females.

As with rockfish species, location was the primary factor related to English sole PCB tissue concentrations; PCB levels in samples of English sole from urban areas were higher than in samples collected from near- or non-urban areas. Highest mean PCB levels were observed in English sole from the Duwamish River (168 ppb, n = 6)[3] and Sinclair Inlet (121 ppb, n = 45). The lowest mean PCB level was found in English sole from non-urban areas (9.3 ppb, n = 186).

For salmon, PCB levels were lower in coho than in Chinook. Mixed stock Chinook salmon from marine areas of Puget Sound had higher mean PCB levels than those caught in-river (73 ppb and 50 ppb, respectively). Similarly, mean PCB levels in mixed stock coho salmon were slightly higher than those from in-river areas (34 ppb and 31 ppb, respectively).

Table 3. Summary of mercury (ppm, wet weight) and PCBs (ppb, wet weight) measured in four species of rockfish, English sole, Chinook salmon and coho salmon from Puget Sound.

	Mercury			**Total PCBs (Aroclors)[a]**			**Total PCBs (Aroclor Equivalent)[b]**		
	n	Range (ppm)	Mean (ppm)	n	Range (ppb)	Mean (ppb)	n	Range (ppb)	Mean (ppb)
ROCKFISH (BROWN, COPPER AND QUILLBACK)	349	0.002-1.18	0.287	188	3-614	55.3	160	3-384	75.3
Urban	157	0.032-1.18	0.368	59	16-614	134	129	12-384	87.8
Near-urban	68	0.002-0.620	0.225	44	4-141	45.1	12	14-128	39.6
Non-urban	124	0.040-0.806	0.218	85	3-17	5.8	19	3-32	12.6
Brown Rockfish	41	0.020-1.18	0.407	11	20-614	213	40	12-308	70.5
Urban	34	0.033-1.18	0.471	11	20-614	213	32	12-308	78.8
Near-urban	7	0.020-0.330	0.100	0	NA	NA	8	14-97	37.2
Copper Rockfish	50	0.04-0.69	0.172	18	6-23	11.3	17	14-105	46.8
Urban	21	0.059-0.690	0.244	5	16-23	17.6	16	14-105	48.6
Near-urban	10	0.060-0.508	0.162	1	18.0	18.0	1	16.8	16.8
Non-urban	19	0.04-0.20	0.099	12	6-14	8.2	0	NA	NA
Quillback Rockfish	258	0.002-1.06	0.290	159	3-429	49.3	103	3-384	81.8
Urban	102	0.056-1.06	0.360	43	20-429	127	81	18-384	99.1
Near-urban	51	0.002-0.62	0.255	43	4-141	45.7	3	16-128	53.4
Non-urban	105	0.060-0.806	0.240	73	3-17	5.5	19	3-32	12.6
Yelloweye Rockfish	2	0.928-1.44	1.184	2	17-49	33.3	NA	NA	NA

[3] Recent sampling of English sole from the Duwamish River revealed PCB levels in English sole fillets approximately 4-5 times higher than in fish collected by PSAMP for this location.

Table 3. (cont.) Summary of mercury (ppm, wet weight) and PCBs (ppb, wet weight) measured in four species of rockfish, English sole, Chinook salmon and coho salmon from Puget Sound.

	Mercury			Total PCBs (Aroclors)[a]			Total PCBs (Aroclor Equivalent)[b]		
	n	Range (ppm)	Mean (ppm)	n	Range (ppb)	Mean (ppb)	n	Range (ppb)	Mean (ppb)
ENGLISH SOLE	577	0.017-0.14	0.060	434	2-462	38.6	169	4-214	46.6
Urban	256	0.023-0.140	0.072	191	6-462	73.6	82	12-214	74.1
Near-urban	81	0.020-0.118	0.053	57	3-76	17.2	27	13-96	36.2
Non-urban	240	0.017-0.130	0.051	186	2-52	9.3	60	4-39	13.7
SALMON									
Chinook									
All of Puget Sound	106	0.051-0.160	0.093	210	11-223	54.0	NA	NA	NA
In-river[c]	78	0.058-0.160	0.096	176	11-223	50.2	NA	NA	NA
Marine[d]	28	0.051-0.130	0.082	34	21-212	73.2	NA	NA	NA
Central Sound	22	0.051-0.120	0.074	18	21-170	75.6	NA	NA	NA
South Sound	6	0.092-0.130	0.113	16	24-212	70.6	NA	NA	NA
Coho									
All of Puget Sound	225	0.008-0.110	0.039	221	5-126	31.8	224	16-106	35.5
In-river[c]	183	0.008-0.110	0.038	175	5-98	31.1	139	17-82	34.6
Marine[d]	32	0.028-0.071	0.051	46	8-126	34.4	42	21-106	42.1
Minter Creek and Wallace River Hatchery	10	0.020-0.043	0.029	NA	NA	NA	43	16-106	32.1
Central Sound	26	0.028-0.069	0.049	20	8-61	18.3	10	30-59	46.8
South Sound	6	0.045-0.071	0.057	26	18-126	46.8	32	21-106	40.6

Note: Means reflect equal weighting of individual and composite samples.
[a] Sum of Aroclors 1248, 1254, and 1260.
[b] Approximation of equivalent Aroclor concentration from HPLC data.
[c] "In-river" refers to nearshore areas near rivers and river mouths from which salmon most likely originated.
[d] "Marine" refers to offshore areas where the origins of salmon are unknown.

Estimating Exposure to Contaminants in Puget Sound Fish

Fish Consumption Rates

Numerous Puget Sound human seafood consumption surveys have been conducted. Consumption surveys that ask how much fish is being eaten, how often, and which species are being consumed can be used to estimate exposure rates from eating contaminated fish. DOH considered four regional seafood consumption surveys for Puget Sound. Members of the Suquamish Indian Tribe (Suquamish 2000) and the Tulalip and Squaxin Island Tribes (Toy et al. 1996) were interviewed in two separate studies to estimate Puget Sound Native American consumption rates. A survey of the Asian Pacific Islander (API) community was conducted by EPA (EPA 1999b) to estimate consumption rates. Recreational anglers from four Puget Sound areas were surveyed in two studies by NOAA (Landolt et al. 1985, 1987).

DOH used the mean and 90th percentile fish consumption rates (for consumers only, when available) from these surveys to estimate exposure to contaminants in Puget Sound fish for various populations (Appendix C). People who eat fish at the 90th percentile are considered high-end consumers. Rates were not adjusted to the fraction of seafood harvested from Puget Sound, leading to an overestimation of fish consumption rates for individual species and for Puget Sound exposure but not necessarily for exposure from overall fish consumption.

The following risk estimates use species-specific consumption rates when available. This approach can result in higher risk estimates for species with lower contaminant concentrations if consumption rates for that species are high. For example, risks for salmon consumption by recreational anglers are higher than they are for rockfish despite much lower salmon PCB levels. Exposure to contaminants from sources other than fish consumption is not considered in this assessment.

Calculating exposure dose

Exposure doses were calculated using the average species-specific contaminant concentration for English sole and rockfish from urban, near-urban, and non-urban areas of Puget Sound. For salmon, doses were calculated based on whether the salmon is from an "in-river" or "marine" fishery, with marine salmon further divided into south Sound or central Sound categories. This approach estimates exposure to individuals that consume fish from a wide range of Puget Sound areas. Station-specific exposure doses were also calculated which help identify specific species and areas of Puget Sound where advice to limit consumption may be warranted (Appendix C). Both average and high-end consumption rates were used to estimate hazards, thereby providing additional information for exposed populations.

Comparison of Exposure to Reference Dose

Exposure doses were compared with PCB and mercury reference doses for each station (Appendix C). In all cases, the mean concentration of a contaminant in fish was used as a measure of central tendency. In addition, average concentrations for urban, near-urban, and non-urban areas of Puget Sound were used for rockfish and English sole, and averages for in-river and marine areas were used to determine the hazard quotient for each salmon species.

PCB and mercury hazard quotients for each fish consuming population were calculated (Tables 4 and 5). A hazard quotient greater than one indicates that an exposure dose from fish consumption exceeds the reference dose (RfD).

PCBs in Rockfish

PCB concentrations in non-urban rockfish are sufficiently low so that no average or high-end consumers eat at a rate resulting in an exposure dose exceeding the reference dose. However, PCBs in urban rockfish are elevated to the point where average Suquamish and API consumers of rockfish exceed a hazard quotient of one (i.e., PCB HQ > 1). Thus, PCBs in urban area rockfish may be at levels that result in PCB exposure above known "safe" levels for some populations. Rockfish station-specific PCB hazard quotients for each fish consuming population were also determined (Appendix C, Table C2).

PCBs in English sole

No population (average or high-end) consumes English sole from non-urban or near-urban locations at a rate that results in an exposure dose exceeding the reference dose (i.e., their PCB HQ is less than 1) (Table 4). Only high-end API consumers of urban bottomfish reach a PCB HQ >1. This indicates that fish consumers are not likely to be exposed to PCBs at levels of concern from eating Puget Sound English sole (with the exception of English sole from some urban areas). Species-specific consumption rates were used to estimate exposure doses from consumption of English sole. Consequently, the true dose from consumption of all types of Puget Sound flatfish may be underestimated for some people.

PCBs in Salmon

High-end Native American consumers of in-river and marine Chinook salmon exceed a PCB HQ of 1. This includes estimates based on consumption rates of the Suquamish, Tulalip, and Squaxin Island Tribes. High-end API consumers and average recreational consumers also exceed a PCB HQ of 1.

PCB hazard quotients from consumption of Puget Sound coho salmon are less than one for all consumers except high-end Suquamish consumers of coho from "marine" stocks. Although average PCB levels in Puget Sound coho are below levels of concern, some individual station averages may be slightly above levels of concern, as evidenced by station-specific hazard quotients (Appendix C, Table C5).

Table 4. PCB hazard quotients related to consumption of Puget Sound fish.

Consumer Population	Rockfish (Brown, Copper and Quillback)			English sole			Salmon			
							Chinook		Coho	
	Urban	Near-urban	Non-urban	Urban	Near-Urban	Non-urban	in-river	marine	in-river	marine
Suquamish										
Average	1.1	0.4	0.0	0.2	0.0	0.0	0.5	0.7	0.3	0.3
90th %ile	4.9	1.6	0.2	0.7	0.2	0.1	1.5	2.1	0.9	1.0
Tulalip										
Average	0.1	0.0	0.0	0.2	0.1	0.0	0.3	0.5	0.3	0.3
90th %ile	0.2	0.1	0.0	0.5	0.1	0.1	0.7	1.1	0.8	0.9
Squaxin										
Average	0.4	0.1	0.0	0.2	0.1	0.0	0.7	1.0	0.3	0.3
90th %ile	1.0	0.3	0.0	0.6	0.2	0.1	1.2	1.7	0.8	0.8
API										
Average	2.6	0.9	0.1	0.5	0.1	0.1	0.4	0.6	0.3	0.3
90th %ile	5.5	1.9	0.2	1.0	0.2	0.1	1.1	1.6	0.7	0.7
Recreational										
Average	0.8	0.3	0.0	0.6	0.1	0.1	1.9	2.7	0.5	0.5

SHADED areas indicate a HQ greater than or equal to 1.
Note: Values > 1.0 indicate that the PCB reference dose is exceeded.

Mercury in Rockfish

Regardless of location, mercury levels in rockfish are sufficiently high enough to result in mercury HQs > 1 for high-end rockfish consumers from the Suquamish Tribe and the Asian and Pacific Islander community (Table 5). However, average consumers from all communities except the API are not likely to be exposed to mercury at levels of concern from rockfish consumption.

Mercury in English sole

No consumers of Puget Sound English sole exceed a mercury HQ > 1 (Table 5). All average and high-end fish consumers are not likely to exceed a "safe" mercury dose from consumption of Puget Sound English sole.

Mercury in Salmon

No consumers of Puget Sound salmon exceed a mercury HQ > 1 (Table 5). All average and high-end fish consumers are not likely to exceed a "safe" mercury dose from consumption of Puget Sound salmon.

Table 5. Mercury hazard quotients related to consumption of Puget Sound fish.

Consumer Population	Rockfish (Brown, Copper and Quillback)			English sole			Salmon			
							Chinook		Coho	
	Urban	Near-urban	Non-urban	Urban	Near-Urban	Non-urban	in-river	marine	in-river	marine
Suquamish										
Average	0.6	0.4	0.4	0.0	0.0	0.0	0.2	0.2	0.1	0.1
90^{th} %ile	2.7	1.6	1.6	0.1	0.1	0.1	0.6	0.5	0.2	0.3
Tulalip										
Average	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
90^{th} %ile	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.2	0.3
Squaxin										
Average	0.2	0.1	0.1	0.0	0.0	0.0	0.3	0.2	0.1	0.1
90^{th} %ile	0.5	0.3	0.3	0.1	0.1	0.1	0.5	0.4	0.2	0.3
API										
Average	1.4	0.9	0.8	0.1	0.1	0.1	0.2	0.1	0.1	0.1
90^{th} %ile	3.0	1.9	1.8	0.2	0.1	0.1	0.4	0.4	0.2	0.2
Recreational										
Average	0.4	0.3	0.3	0.1	0.1	0.1	0.7	0.6	0.1	0.2

SHADED areas indicate a HQ greater than or equal to 1.
Note: Values > 1.0 indicate that the mercury reference dose is exceeded.

Assessing exposure to multiple contaminants

The above hazard quotients address a population's exposure to individual chemicals from consumption of individual species. Since both mercury and PCBs have the potential to impact developmental and immune endpoints in humans, endpoint-specific hazard quotients were used to derive hazard indices (ATSDR 2004b). Multiple chemical exposures can be assessed by adding hazard quotients for similar endpoints, in this case for developmental and for immunological effects. Hazard indices for various fish consumer groups at individual stations were also calculated (Appendix C, Tables C10-C17). Hazard indices are slightly higher than hazard quotients for each consumer, reflecting the assumption PCB and mercury toxicity is additive with respect to developmental and immune system endpoints (Tables 6 and 7).

Table 6. Immune system endpoint hazard indices related to consumption of Puget Sound fish.

Consumer Population	Rockfish (Brown, Copper and Quillback)			English sole			Salmon			
							Chinook		Coho	
	Urban	Near-urban	Non-urban	Urban	Near-Urban	Non-urban	in-river	marine	in-river	marine
Suquamish										
Average	1.3	0.5	0.2	0.2	0.1	0.0	0.6	0.8	0.3	0.4
90th %ile	5.8	2.2	0.7	0.8	0.2	0.1	1.6	2.3	1.0	1.1
Tulalip										
Average	0.1	0.1	0.0	0.2	0.1	0.0	0.4	0.5	0.3	0.3
90th %ile	0.3	0.1	0.0	0.6	0.2	0.1	0.8	1.1	0.9	1.0
Squaxin										
Average	0.4	0.2	0.1	0.2	0.1	0.0	0.8	1.1	0.3	0.4
90th %ile	1.2	0.4	0.1	0.7	0.2	0.1	1.3	1.9	0.8	0.9
API										
Average	3.0	1.1	0.4	0.5	0.1	0.1	0.5	0.7	0.3	0.3
90th %ile	6.6	2.5	0.8	1.1	0.3	0.2	1.2	1.7	0.7	0.8
Recreational										
Average	1.0	0.4	0.1	0.6	0.2	0.1	2.1	2.9	0.5	0.6

SHADED areas indicate a HI greater than or equal to 1.
Note: Values > 1.0 indicate exposure of potential concern.

Table 7. Developmental endpoint hazard indices related to consumption of Puget Sound fish.

Consumer Population	Rockfish (Brown, Copper and Quillback)			English sole			Salmon			
							Chinook		Coho	
	Urban	Near-urban	Non-urban	Urban	Near-Urban	Non-urban	in-river	marine	in-river	marine
Suquamish										
Average	1.4	0.6	0.4	0.2	0.1	0.0	0.5	0.7	0.3	0.3
90^{th} %ile	5.9	2.7	1.7	0.6	0.2	0.2	1.5	1.9	0.8	1.0
Tulalip										
Average	0.1	0.1	0.0	0.2	0.1	0.1	0.3	0.4	0.3	0.3
90^{th} %ile	0.3	0.1	0.1	0.5	0.2	0.1	0.8	0.9	0.7	0.9
Squaxin										
Average	0.5	0.2	0.1	0.2	0.1	0.1	0.7	0.9	0.3	0.3
90^{th} %ile	1.2	0.6	0.3	0.6	0.2	0.1	1.3	1.6	0.7	0.8
API										
Average	3.1	1.4	0.9	0.4	0.1	0.1	0.5	0.6	0.2	0.3
90^{th} %ile	6.7	3.1	2.0	0.9	0.3	0.2	1.1	1.4	0.6	0.7
Recreational										
Average	1.0	0.5	0.3	0.5	0.2	0.1	1.9	2.4	0.4	0.5

SHADED areas indicate a HI greater than or equal to 1.
Note: Values > 1.0 indicate exposure of potential concern.

Cancer Risk Calculations

Increased cancer risks attributable to PCB exposure from average consumption of Puget Sound fish by species are generally in the 10^{-5} to 10^{-6} range (Table 8). The highest estimated overall cancer risk is attributed to high-end Suquamish consumers of rockfish from urban areas (2.0 x 10^{-4}). A cancer risk of 1×10^{-4} is the upper end of the range of cancer risks (10^{-4} to 10^{-6}) considered acceptable by EPA when conducting risk assessments at Superfund sites and a risk of 10^{-6} is used as a goal for cleanups in Washington.

Table 8. Lifetime increased cancer risk attributable to consumption of Puget Sound fish.

Consumer Population	Rockfish (Brown, Copper and Quillback)			English Sole			Salmon			
							Chinook		Coho	
	Urban	Near-urban	Non-urban	Urban	Near-Urban	Non-urban	in-river	marine	in-river	marine
Suquamish										
Average	4.5E-05	1.5E-05	2.0E-06	7.7E-06	1.8E-06	9.7E-07	2.0E-05	2.9E-05	1.2E-05	1.3E-05
90th %ile	2.0E-04	6.6E-05	8.4E-06	3.0E-05	6.9E-06	3.7E-06	5.8E-05	8.5E-05	3.6E-05	4.0E-05
Tulalip										
Average	4.8E-06	1.6E-06	2.1E-07	9.0E-06	2.1E-06	1.1E-06	1.3E-05	1.9E-05	1.1E-05	1.2E-05
90th %ile	9.1E-06	3.1E-06	3.9E-07	2.2E-05	5.1E-06	2.8E-06	2.9E-05	4.2E-05	3.2E-05	3.5E-05
Squaxin										
Average	1.5E-05	5.1E-06	6.5E-07	9.1E-06	2.1E-06	1.2E-06	2.7E-05	3.9E-05	1.3E-05	1.4E-05
90th %ile	3.9E-05	1.3E-05	1.7E-06	2.6E-05	6.1E-06	3.3E-06	4.8E-05	7.0E-05	3.1E-05	3.4E-05
API										
Average	4.4E-05	1.5E-05	1.9E-06	7.9E-06	1.8E-06	1.0E-06	7.4E-06	1.1E-05	4.6E-06	5.1E-06
90th %ile	9.5E-05	3.2E-05	4.1E-06	1.7E-05	4.0E-06	2.2E-06	1.9E-05	2.7E-05	1.2E-05	1.3E-05
Recreational										
Average	1.4E-05	4.6E-06	6.0E-07	9.9E-06	2.3E-06	1.3E-06	3.2E-05	4.6E-05	8.2E-06	9.1E-06

SHADED values indicate cancer risk exceeds 10^{-4}.

Discussion

As part of the Puget Sound Assessment and Monitoring Program (PSAMP), over 100 contaminants were analyzed in muscle tissue from English sole, four species of rockfish, and two species of salmon collected in Puget Sound. This report focuses on mercury and PCBs based on frequency of their detection, levels detected in fish, and chemical toxicity. DOH evaluated PCBs and mercury in fish tissue to determine whether populations that consume Puget Sound fish are exposed to contaminants at levels that could cause health problems.

Estimated exposures described previously in this report indicate that some consumers of Puget Sound fish exceed reference doses (or hazard indices) for various contaminants of concern. When estimated exposures for any given population exceed comparison values considered to be protective (i.e., RfDs), meal limits are calculated to help formulate recommendations for consumers. DOH considers all consumers, but meal advice is emphasized for pregnant women, those who might become pregnant, and children because mercury and PCBs have been shown to impact the developing fetus.

Calculating meal limits

DOH developed recommended meal limits of individual Puget Sound fish species based on EPA's RfDs, an individual's body weight, and the known contaminant concentration in fish. In this approach, the RfD is used to calculate the quantity of fish a person of a given body weight can safely consume, given varying contaminant concentrations found in fish tissue.

The equation used to calculate a safe consumption rate is shown below, using defined exposure parameters (Table 9) (EPA 2000):

$$\text{Number of 8-oz. meals per month} = \frac{\text{RfD} \times (\text{Days / Month}) \times \text{BW}}{\text{Meal size} \times \text{C}}$$

Table 9. Exposure parameters for calculating eight-ounce fish meal limits.

Parameter	Value	Units	Source / Notes
Reference Dose (RfD)	$PCB_{(immune)} = 0.00002$ $PCB_{(developmental)} = 0.00003$ $Mercury_{(developmental)} = 0.0001$ $Mercury_{(immune)} = 0.0003$	mg/kg-day	EPA 1993 EPA 2001b ATSDR 2004b
Days / Month	30.4	Days per month	
Body Weight (BW)	60 (adult female)	kg	EPA 1997
Concentration in fish (C)	Mean contaminant concentration Specific to each fish species and/or location	mg/kg	
Meal size	0.227	kg	kg per 8 oz

Meal limits were calculated based on non-cancer endpoints of mercury and PCBs. Meal limits based on the carcinogenic endpoint for PCBs were not calculated because current weight-of-evidence for PCB toxicity is stronger for non-cancer versus cancer endpoints (Schantz et al. 2003, Longnecker et al. 2003, ATSDR 2000). Results from recent epidemiological studies of fish consumers in the U.S. suggest that neurodevelopmental impacts on the developing fetus are associated with PCBs. Immune system sensitivity to PCB exposure has also been shown in lab primates. Although high doses of PCBs are carcinogenic in laboratory animals, studies of human populations exposed to PCBs at environmentally relevant levels have not shown a clear cancer link. Therefore, DOH used the PCB non-cancer endpoint (PCB RfD) in conjunction with the mercury RfD as primary determinants for calculating recommended meal limits in this health assessment.

This assessment considers additive non-cancer effects of PCB and mercury exposure. Because mercury and PCBs have similar toxic endpoints (immune and developmental endpoints), the preceding equation can be adapted to calculate meal limits that account for additive toxic effects. The adapted equation is shown below:

$$\text{Number of 8-oz meals per month} = \frac{\text{RfD}_{\text{(mercury developmental)}} * (\text{Days/ Month}) \times \text{BW}}{\text{Meal size} \times [\text{C}_{\text{PCB}} \times (\text{RfD}_{\text{(mercury developmental)}} / \text{RfD}_{\text{(PCB developmental)}} + \text{C}_{\text{mercury}})]}$$

For many risk assessments addressing the general population, the average adult (including males and females) is assumed to weigh 70 kg (approximately 154 lbs) (EPA 1997). For this assessment, DOH used an assumed body weight of 60 kg (approximately 132 lbs, the average female adult body weight). This weight was chosen to ensure that women of childbearing age are adequately considered and protected when determining a consumption rate protective of neurological and developmental endpoints in the developing fetus.

Determining Allowable Consumption Rates within Recreational Marine Areas (RMAs)

WDFW sampled and analyzed fish in Puget Sound as part of PSAMP. Objectives of the sampling and analyses were to determine if fish were contaminated, identify what contaminants were in the fish, assess spatial and temporal trends of contamination, and examine the ecological risk to fish from bioaccumulation of chemicals. DOH objectives in assessing WDFW's data were to establish if Washingtonians are over-exposed to contaminants from consuming Puget Sound fish, determine potential meal limits if citizens are overexposed, examine the risks/benefits of eating fish, and establish an effective approach for communicating fish guidance information. Since the primary sampling objective of WDFW was for ecological purposes and not for human health assessment, some issues arose regarding data used in this health assessment.

One question about the data used in this assessment was whether the sample size adequately represented different species and locations Data collected by WDFW contained many fish samples analyzed for numerous chemicals, but for a comprehensive health assessment, larger numbers, greater spatial distribution throughout Puget Sound, and data on fish populations and fish size by Recreational Management Area (RMA) would have been more appropriate to evaluate human health effects. The PSAMP sampling effort was designed to estimate spatial and temporal patterns of contaminants in important Puget Sound species while accounting for factors (e.g., fish age, location) that affect accumulation of contaminants. Since this DOH health assessment was based on data collected for PSAMP purposes, certain assumptions were necessary to extrapolate data for use in developing general health guidance. Accordingly, DOH used station-specific meal limit calculations to estimate limits for broader areas of Puget Sound (Appendix D). For rockfish and English sole (flatfish), limits were derived for RMAs as used by the WDFW to manage non-tribal sport fisheries (Figures ES-1 and 11). These areas are easily recognized by sport fishers who must abide by existing catch limits set for each zone. While some areas were sampled at numerous sites, other RMAs were only sampled at a few sites; moreover, concentrations of contaminants could vary significantly among samples within a RMA. In situations where data were not available, DOH used best professional judgment to extrapolate station-specific data over a broader area (e.g., a RMA).

Rockfish

Four species of rockfish were sampled in Puget Sound. The extent to which these data can be extrapolated to other marine species is unclear. Since various rockfish species are not distributed evenly throughout the Sound, meal limit advice for each RMA is based on available but limited number of samples. In general, younger copper rockfish are found south of Tacoma Narrows while older quillback and brown rockfish are usually observed in north Puget Sound. At present, non-tribal rockfish fisheries are open in all sportfish marine areas except Area 12 (Hood Canal); this area is closed because of concerns about low dissolved oxygen. WDFW currently has a non-tribal sportfish catch restriction on all yelloweye (and canary) rockfish in Puget Sound based on conservation issues.

Only two individual yelloweye rockfish were caught for analysis, aged 55 and 90 years. Both fish had very high levels of mercury. While these two samples are not necessarily indicative of contamination in the yelloweye population across Puget Sound, DOH recommends no consumption of this species based on the high levels of mercury found in these fish. Therefore, the following discussion of rockfish by RMA excludes yelloweye rockfish.

Mercury is the key contaminant of concern in rockfish, although PCB concentrations are also elevated in urban area rockfish (Appendix D, Table D1).[4] Age is a primary factor in concentration of mercury in rockfish, with older fish exhibiting higher concentrations of mercury than younger rockfish. However, older rockfish are not necessarily larger than younger rockfish. Since age is the main factor for predicting mercury concentrations in rockfish from non- and near-urban areas, it would be helpful to understand the age distribution of rockfish in different areas of Puget Sound (e.g., recreational marine areas). Unfortunately, substantial age data for rockfish by RMA is not currently available.[5] For the purpose of this discussion, DOH assumes that rockfish age is equally distributed throughout Puget Sound. Therefore, meal limit recommendations for rockfish (excluding yelloweye) for non-urban and near-urban areas are consistent across Puget Sound at one meal per week with a few exceptions. Levels of both mercury and PCBs in rockfish from urban areas are elevated resulting in more stringent meal limits as follows:

- Rockfish in RMA 8.2 were collected at Mukilteo-Everett and at Port Gardner, both urban areas. No more than two rockfish meals per month are recommended at these sites. The rest of RMA 8.2 comprises near- or non-urban waters. Although no fish were sampled in these areas, no more than one meal per week is recommended, based on the assumption that rockfish from non-contaminated areas within RMA 8.2 have similar contaminant levels as rockfish in other non-urban Puget Sound areas.

- Most samples from RMA 10 were from contaminated areas such as Elliott Bay and Sinclair Inlet. Rockfish in these urban bays contained the highest PCB levels observed for these species. Rockfish from Elliott Bay and Sinclair Inlet should not be consumed. For other near-or non-urban areas in RMA 10, no more than one meal per week of rockfish should be consumed.

- Rockfish sampled in Commencement Bay (RMA 11) were relatively young (4.5 years) yet contained more PCBs than similarly-aged fish in non-urban areas. Older quillback rockfish sampled near Old Town (Commencement Bay 4) had relatively high levels of both mercury (0.292 ppm) and PCBs (112 ppb). Therefore, recommended meal limits for Commencement Bay rockfish are two meals per month.

- Although WDFW's sampling in South Puget Sound (RMA 13) was represented by only one location, this area had the lowest levels of contaminants in rockfish, leading to the highest calculated meal limits. South Puget Sound does not have as much good rockfish habitat as other areas of Puget Sound, which contributes to fewer and younger rockfish.

---

[4] WDFW defines urban areas as Puget Sound bays near commercial or industrial centers. Near-urban areas are located near developed areas of Puget Sound, while non-urban areas are areas and bays least influenced by industry and development. In part, these classifications are based on associated sediment contaminant concentrations.

[5] Presently, WDFW is evaluating catch records to determine rockfish size distribution throughout Puget Sound to fill this data gap.

Rockfish in this area are younger than average for Puget Sound (average age of rockfish sampled from RMA 13 was 5.4 years). Further analyses of WDFW catch record data may confirm that rockfish from other locations within RMA 13 are also young, thereby justifying increased meal limits. In the absence of such confirmation, recommended meal limits for rockfish in RMA 13 are consistent with other areas of Puget Sound: no more than 1 meal per week of rockfish.

Table 10. Rockfish meal limit calculations based on area-specific chemical concentrations for brown, copper, and quillback rockfish.

Location	Average Mercury concentration (ppm)	Average PCB concentration (ppb)	Calculated meals per month based on mercury	Calculated meals per month based on PCBs	Calculated meals per month based on additive endpoint
Non-urban locations	0.218	5.8	3.7	28	3.4
Near-urban locations	0.225	45.1	3.6	3.6	2.2
Commencement Bay [a]	0.099	53.6	8.1	3.0	2.7
Elliott Bay [b]	0.340	140	2.4	1.1	1.0
Port Gardner Everett [c]	0.267	46.0	3.0	3.5	1.9
Sinclair Inlet [d]	0.748	198	1.1	1.1	0.6

[a] Comprised of Commencement Bay, Commencement Bay 2, and Commencement Bay 4 stations.
[b] Comprised of Elliott Bay, Elliott Bay 2, Elliott Bay 4, and Fuller Shipwreck stations.
[c] Comprised of Mukilteo-Everett and Port Gardner stations
[d] Comprised of Sinclair Inlet and Sinclair Inlet Tribal stations.

English sole – Based on PSAMP Tissue Data

For English sole, 52 locations were sampled in areas categorized as urban, near-urban and non-urban representing a broad range of sediment contamination conditions. In this report, contaminant information for English sole muscle tissue has been used as a surrogate for other flatfish species. The extensive amount of English sole contaminant data was adequate to determine consumption recommendations for flatfish from many specific locations and was used to extrapolate results, when necessary, from one area of Puget Sound to another.

In most cases, English sole had low contaminant levels in non-urban and near-urban areas of Puget Sound (Tables 3 and 11). Meal limit calculations for English sole from these areas were consistently high enough to preclude the need for meal restrictions (Appendix D, Table D2).

English sole from urban areas tended to have higher levels of both mercury and PCBs and therefore more stringent calculated meal limits. RMAs 10 and 11 represent a large area of Puget Sound with numerous non-urban, near-urban and urban sampling stations. The following bullets highlight lower meal limits for several urban areas within RMA 10 and 11:

- The highest mean PCB level in English sole was found at the Duwamish station (168 ppb). This area is undergoing cleanup under EPA's Superfund process. DOH recently issued a fish advisory that recommends avoiding resident fish species within the Lower Duwamish Waterway (e.g., English sole, flounder and perch).

- Several other stations (e.g., Harbor Island, Sinclair Inlet, Commencement Bay – Thea Foss, and Eagle Harbor) were located where sediment cleanups have occurred or are occurring. The second highest mean PCB level in English sole was observed at Sinclair Inlet (123 ppb) where sediment cleanup is being conducted by the U.S. Navy. The high level of contaminants in English sole from these areas resulted in more restrictive meal limit calculations for these sites (Appendix D, Table D2).

Table 11. Calculated meal limits for English sole at non-urban, near-urban and select urban locations of Puget Sound.

Location	Average Mercury concentration (ppm)	Average PCB concentration (ppb)	Calculated meals per month based on mercury	Calculated meals per month based on PCBs	Calculated meals per month based on additive endpoint
Non-urban locations	0.051	9.3	16	17	9.8
Near-urban locations	0.053	17.2	15	9.3	7.3
Elliott Bay [a]	0.080	69.0	10	2.3	2.2
Sinclair Inlet	0.074	121	11	1.3	1.3
Commencement Bay [b]	0.069	60.9	12	2.6	2.5

[a] Comprised of Elliott Bay, Elliot Bay 2, and Elliott Bay 4 stations.
[b] Comprised of Commencement Bay, Commencement Bay 2, and Outer Commencement Bay stations.

English sole – based on PSAMP sediment PCB concentrations

PCB concentration in sediment appears to be the major factor influencing PCB concentration in English sole muscle tissue for a given location. In order to address the lack of sampling in some Puget Sound urban bays, WDFW determined a relationship based on PSAMP sediment and tissue data to predict English sole PCB concentrations where fish were not sampled (O'Neill and West 2006). In conjunction with mean sediment PCB concentrations from PSAMP, the following equation was used to estimate PCBs in English sole tissue at these sites:

$$[mPCB] = e^{1.64} * [sPCB]^{0.35} * e^{0.13} * Age$$

Where:

mPCB = concentration of PCBs in muscle as sum of 3 Aroclors, ng/g, wet wt.,
sPCB = concentration of PCBs in sediments as sum of 3 Aroclors, ng/g, dry wt.,
Age = fish age in years.

Although the resulting predicted concentration in fish tissue is an estimate, it is useful to calculate meal limits for locations where sediment concentrations are known but where English sole were not sampled. Four urban locations were identified in non-sampled bays of Puget Sound: Bellingham Bay, Budd Inlet, Everett Harbor, and Port Angeles.

Table 12. Estimated concentrations of PCBs in English sole (flatfish), based on matched PCB sediment concentrations.

Location	Sediment N	Sediment PCB concentration (ppb, dry wt.)	Predicted E. sole concentration (ppb, wet wt.)	Meals per month
Bellingham Bay	45	14.8	29.9	5
Budd Inlet	9	13.9	29.3	5
Everett Harbor	33	355	91.0	2
Port Angeles	22	12.7	28.3	6

Estimated flatfish tissue concentrations in non-sampled areas resulted in more stringent meal limit restrictions for Everett Harbor than estimates based on results from non-urban or near-urban sampling stations in the same RMA. No meal restrictions are recommended for the other three sites.

Salmon

Concentrations of contaminants in Puget Sound Chinook and coho salmon were well defined in this study and DOH believes samples were adequate to determine meal limits for these species. PCBs were the key contaminants of concern in both Chinook and coho salmon (Appendix D, Table D3 and Table D4). Only limited data were available to address differences between wild and hatchery or net pen stocks. Future data collection may address questions of variability between wild and hatchery fish, as well as chemical concentrations in farm-raised salmon.

Chinook salmon were caught in marine areas of the Sound and near the mouths of five Puget Sound rivers: Nooksak, Skagit, Duwamish, Nisqually, and Deschutes. Although slight differences were observed in salmon caught in north vs. south Puget Sound, recommended meal limits for Chinook are consistent across Puget Sound. Based on PCB concentrations, DOH recommends a limit of one eight-ounce meal per week of Puget Sound Chinook salmon. Non-resident Chinook salmon are caught in a marine fishery in late summer and fall by sport, commercial, and tribal fisheries in north, central and south Puget Sound.

A concern raised from available PSAMP data is the apparently high PCB concentration in resident Chinook salmon, also known as blackmouth. Blackmouth are caught by recreational anglers primarily in winter. Resident blackmouth in south Puget Sound (Apple Cove Point) have higher concentrations of chemicals than non-resident fish captured in the Puget Sound spring or fall fishery, although blackmouth were not evaluated separately in this report. WDFW has limited data that show average blackmouth PCB levels at 80-90 ppb compared to an average of approximately 50 ppb in migratory Puget Sound Chinook. A recent WDFW analysis of blackmouth tissue revealed that PCB levels in these fish are correlated with length (and therefore age); that is, PCB levels are expected to increase as salmon length increases. The minimum legal length for recreationally-caught Chinook in Puget Sound is 22 inches (~56 cm). The predicted PCB concentration for blackmouth at the minimum legal length is approximately 65 ppb, higher than the average PCB level in non-resident Chinook. Using the correlation established by WDFW, a 70-cm blackmouth would have 100 ppb PCBs (predicted) in muscle tissue. Due to apparent higher PCB levels, blackmouth require separate advice to protect anglers (and their families) who target this population. Anglers who catch resident Chinook (i.e., blackmouth) in Puget Sound should limit themselves to two eight-ounce meals per month.

Coho salmon were sampled near the mouths of the same five Puget Sound rivers as Chinook. Samples were comprised of Puget Sound marine area fish, hatchery fish returning to Minter Creek and Wallace Creek, and Agate Pass and South Sound net pen coho salmon. Puget Sound coho salmon have lower PCB levels than Puget Sound Chinook salmon (Appendix D, Table D4). Some evidence shows that PCB levels are slightly higher in coho from areas of south and central Puget Sound compared to north Puget Sound coho. This is likely due to the longer residence time in Puget Sound of coho from south Sound. The implications of these subtle differences in PCBs among Puget Sound coho for Puget Sound anglers and Tribal members are unclear, but differences are not enough to require separate advice for coho from various Puget Sound areas. Coho salmon is among the least contaminated species of fish that contain a high level of beneficial omega-3 fatty acids. Of nine most commonly eaten commercial fish species tested by DOH in 2005, only three species - cod, catfish, and pollock - have lower overall contaminants than Puget Sound coho (Figure 10). Clearly, coho salmon is one of the best choices of fish to eat. No limit on consumption of Puget Sound coho is proposed at this time.

Other Considerations

The preceding portion of this document describes how DOH uses fish contaminant data to determine whether or not broad health advice is necessary and addresses consumption of Puget Sound fish on a species-specific basis. Calculations used to quantify health risks and site-specific meal limits above do not account for other important factors such as the presence of contaminants in other fish and foods or health benefits of fish consumption. The following discussion considers these issues and how they affect DOH's risk communication messages.

Presence of Contaminants (Mercury and PCBs) in other Fish and Foods

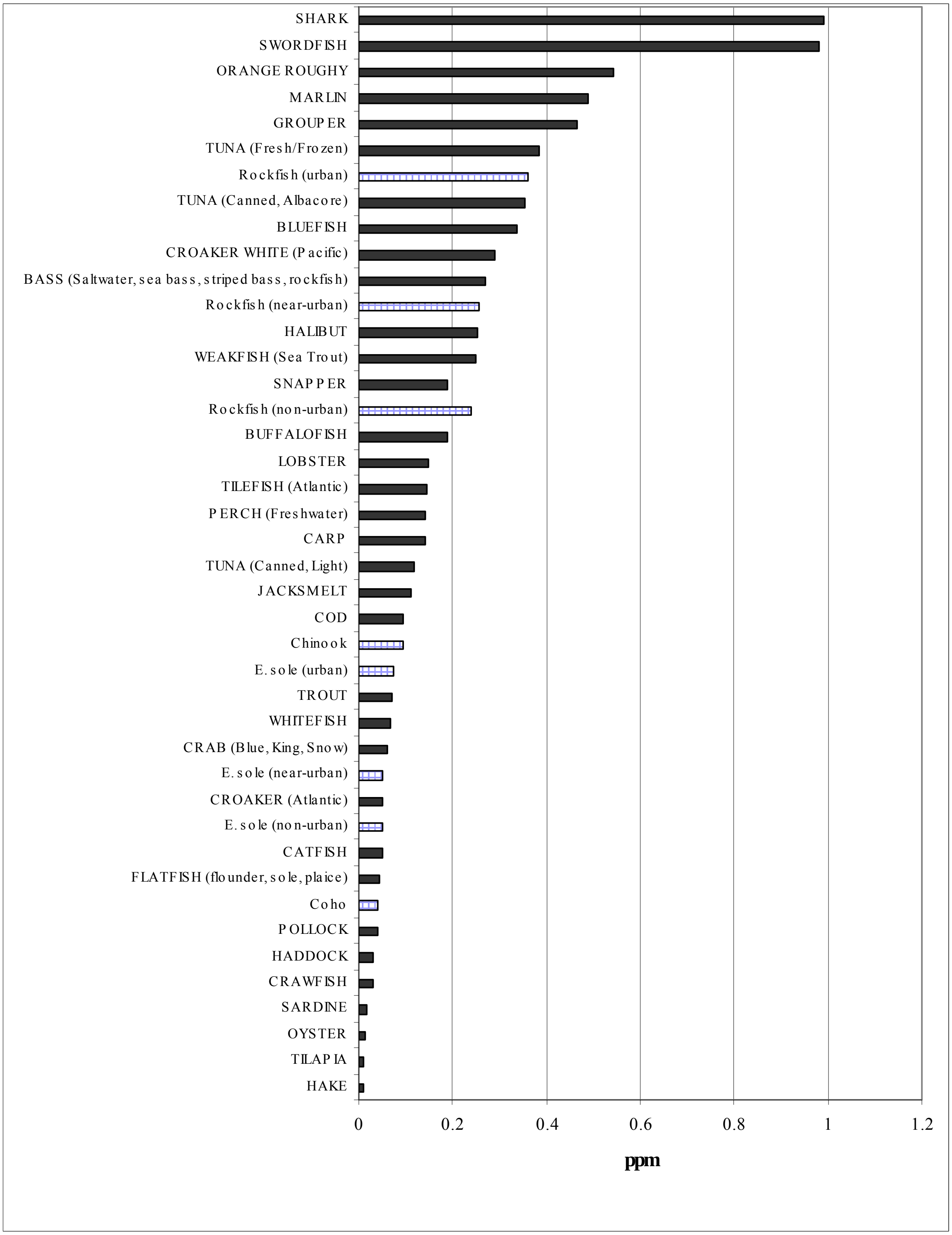
Most people eat a variety of foods that come from many places. The same contaminants of concern found in Puget Sound fish (i.e., mercury and PCBs) are widespread in the environment and, therefore, can be found in fish from other waterbodies and in other foods. Before issuing advice based solely on risk assessment results, DOH compares contaminant levels in other fish and foods to levels in Puget Sound fish. This process serves to assist consumers when considering healthy food options while encouraging fish consumption.

Mercury: Puget Sound Fish vs. Fish Tested by FDA

Mercury is ubiquitous in the environment as a result of natural and anthropogenic releases. Methylmercury, the most common form of organic mercury and the most toxic, can biomagnify as it passes from lower to higher trophic levels through consumption of prey organisms. As a result, fish at the top of the food chain can have mercury concentrations several orders of magnitude higher than concentrations in surrounding waters. For example, species of fish that contain the highest mercury concentrations include shark, swordfish, and king mackerel.

Mercury concentrations in Puget Sound fish were compared to fish from other areas in the United States (FDA 2006) (Figure 5). The mean mercury concentration in Puget Sound rockfish (excluding yelloweye rockfish) from urban areas was similar to that of tuna (fresh/frozen and canned albacore) based on FDA data. Rockfish from near- or non-urban Puget Sound areas had mercury concentrations similar to levels in halibut. Puget Sound English sole and salmon had mercury levels lower than half of the listed commercial species. Lowest mean mercury concentrations were found in commercial sardines, oysters, tilapia, and hake.

Figure 5. Average mercury concentrations in fish from Puget Sound (hash-marked bars) and from the U.S. Food & Drug Administration's survey of U.S. fish species 1990 – 2004 (solid bars)**.**



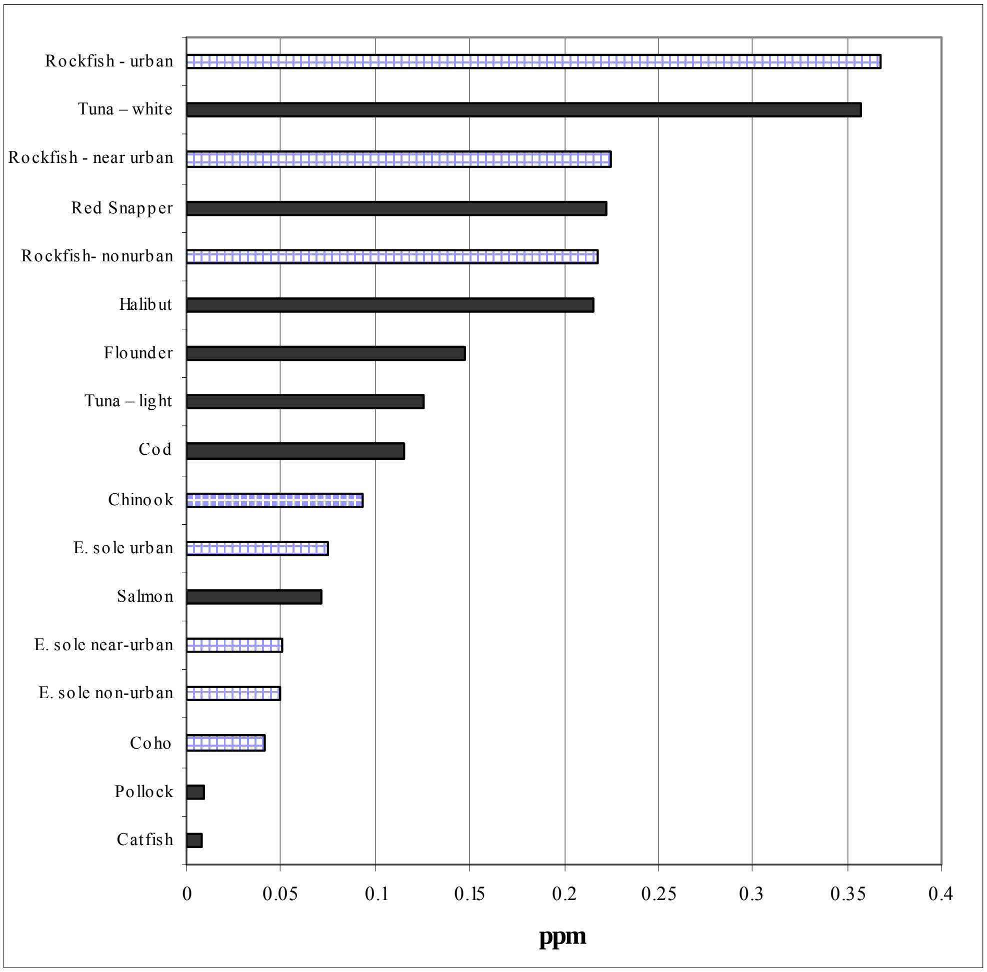
Note: Mercury data is from FDA (2006) combined with current PSAMP mercury data.

Mercury: Puget Sound Fish vs. Fish from Washington State Markets

Recent testing by DOH determined mercury concentrations for nine species purchased from markets and grocery stores in Washington State (unpublished data 2003, 2005) (Figure 6). The nine species tested are the most frequently consumed types of fish in Washington. Mercury concentrations were lowest in commercial catfish and pollock, while Puget Sound English sole and salmon had lower mercury levels than six of nine commercial fish analyzed. Mercury levels in rockfish from near-and non-urban area of Puget Sound were similar to those of red snapper and halibut. Rockfish from urban areas of Puget Sound had highest mercury levels of all species but were similar to concentrations in canned white (albacore) tuna tested by DOH.

Mercury concentrations in albacore tuna (white tuna) were almost three times higher than light tuna. Current advice from DOH recommends that women of childbearing age and young children should eat no more than one canned albacore tuna meal per week. This is approximately one can for an adult woman and proportionately less for a child, based on his or her body weight. Further, DOH encourages women of childbearing age and young children to choose chunk light tuna over albacore to further reduce mercury exposure.

Figure 6. Average mercury concentrations in fish collected from markets and grocery stores in Washington State (solid bars) compared to Puget Sound fish (hash-marked bars) (DOH, unpublished data, 2005).



Mercury: Puget Sound Fish vs. Freshwater Fish in Washington State

In 1987, EPA conducted the National Study of Chemical Residues in Fish (EPA 1992). Highest mercury tissue concentrations were found in smallmouth bass, largemouth bass, and walleye, with mean concentrations of 340, 460, and 520 ppb, respectively. A similar study conducted in the northeastern United States and eastern Canadian provinces investigated mercury concentrations in freshwater sport fish collected in the 1980s and 1990s (NESCAUM 1998). In this study, largemouth bass, smallmouth bass, and walleye mean mercury levels were 510, 530, and 770 ppb, respectively. A national dataset compiled by EPA from 43 states also showed elevated mean mercury concentrations in these same species at 520, 320, and 430 ppb, respectively (EPA 2001a). For comparison, the highest mercury concentration in an individual Puget Sound fish was observed in a yelloweye rockfish (1.44 ppm) while highest mean mercury concentrations were observed in urban rockfish (0.368 ppm, n = 157).

Concern about mercury in Washington State bass was prompted by limited data from Washington and extensive data from other North American freshwater systems indicating elevated mercury levels in these species. In 2002, Ecology sampled and analyzed largemouth and smallmouth bass for mercury from twenty lakes and rivers throughout Washington (Ecology 2003). The mean mercury tissue level for 185 smallmouth and largemouth bass was 217 ppb, with a range of 22 to 1280 ppb (Ecology 2003). DOH used the 90th percentile mercury concentration (450 ppb) of this data set to issue a statewide bass advisory in 2003 recommending a limit of no more than two meals per month for women of childbearing age and young children (DOH 2003). While typically the mean concentration is used in risk assessments to set consumption recommendations, DOH chose the higher value after consultation with numerous local health jurisdictions. Use of the 90th percentile ensures adequate public health protection to consumers of smallmouth and largemouth bass and is based on relatively higher levels observed nationally compared to somewhat lower levels observed in Washington's relatively small sample set.

Polychlorinated biphenyls (PCBs)

PCB levels in environmental media (e.g., sediment, fish) have been declining since production of PCBs was banned in the U.S. in 1977, but PCBs are still found in most fish and many other foods. Throughout the northern hemisphere, PCB concentrations in fish declined rapidly in the 1970s through the mid-1980s then leveled off through the mid-1990s (Matta et al. 1986, Stow et al. 1995, Bignert et al. 1998, Hickey et al. 2006). This trend was demonstrated in salmon as well, although trends for Puget Sound salmon cannot be assessed given method differences in determining PCBs (Stow et al. 1994, Lamon et al. 1999, Malins et al. 1980).

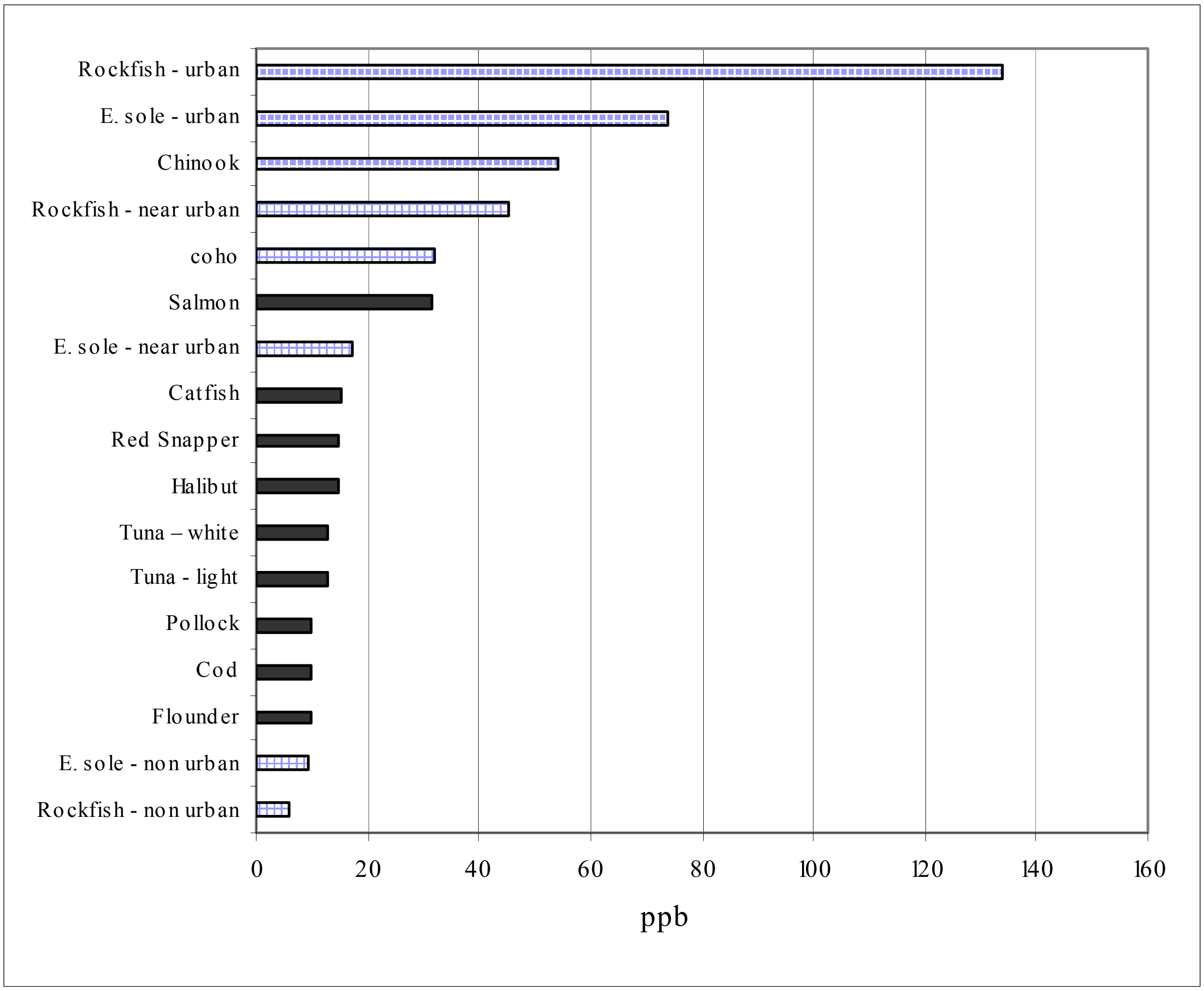
Mean total PCB concentrations have been determined in marine fish and shellfish tissues from various sites across the U.S. In one study, tissue collected from urban sites contained higher mean total PCB concentrations than those from non-urban sites (Ylitalo et al. 1999), similar to findings for English sole in this study. Winter flounder tissue from sites in Northeastern U.S. contained a wide range of total PCBs reflecting localized sediment conditions: New Bedford Harbor (380 ppb) – an urban site; Deer Island (42 ppb), Merrimack River (22 ppb), Raritan Bay East (30 ppb) and Salem Harbor (49 ppb) – near-urban sites; and Johns Bay (15 ppb) and Rocky Point (12 ppb) – non-urban sites. Similarly, English sole PCB levels from non-urban sites, near-urban and urban sites in Puget Sound reflect localized sediment conditions.

PCBs: Puget Sound Fish vs. Commercial Fish in Washington Markets

PCBs were recently analyzed in fish obtained from several grocery stores by DOH (DOH, unpublished data, 2005) (Figure 7). The objective of this study was to characterize PCBs, PBDEs and mercury levels in canned tuna and in frequently consumed fresh fish sold in Washington grocery stores. The following species were chosen based on frequency of consumption: catfish, cod, flounder, halibut, red snapper, pollock, Chinook salmon, and tuna (canned white and light). Forty small and large grocery stores were randomly sampled using total sales as a proxy for sales of fish. Preliminary results for total PCBs (Aroclors) indicate their presence in halibut, red snapper, and salmon (>10% detection frequency). Chinook salmon had the highest average PCB concentration (31.5 ppb PCBs, total Aroclors).

In general, rockfish and English sole from urban areas of Puget Sound and Puget Sound Chinook salmon had higher PCB levels than any of the commercial fish analyzed by DOH (including Chinook salmon from markets) (Figure 7). Rockfish and English sole from non-urban areas had PCB levels similar to commercial flounder, cod, pollock and tuna. Coho from Puget Sound had similar PCB levels as Chinook salmon obtained commercially for the DOH study.

Figure 7. Mean PCB concentrations (total Aroclors) in fish collected from markets and grocery stores in Washington State (solid bars) compared to Puget Sound fish analyzed for this study (hash-marked bars) (DOH, unpublished data, 2005).



PCBs: Puget Sound Salmon vs. West Coast Salmon

PCBs have been analyzed in other coastal Chinook salmon populations. Although comparisons with these fish are complicated by differences in study design, such as analytical methods (Aroclors vs. congeners), detection limits, fish size, and tissue type, they are useful to assess large differences in PCB levels in Chinook from other marine areas. Lowest total PCB concentrations in coastal Chinook salmon were observed in skin-on fillets from Kenai River fish, Alaska (12 ppb) (Figure 8). PCB levels were also low in Chinook from the coasts of

Washington, Oregon, and British Columbia (all under 20 ppb). PCB levels in Puget Sound Chinook were higher than in coastal fish and ranged from 36 ppb (Nooksak River) to 73.2 ppb in central and south Puget Sound marine areas.

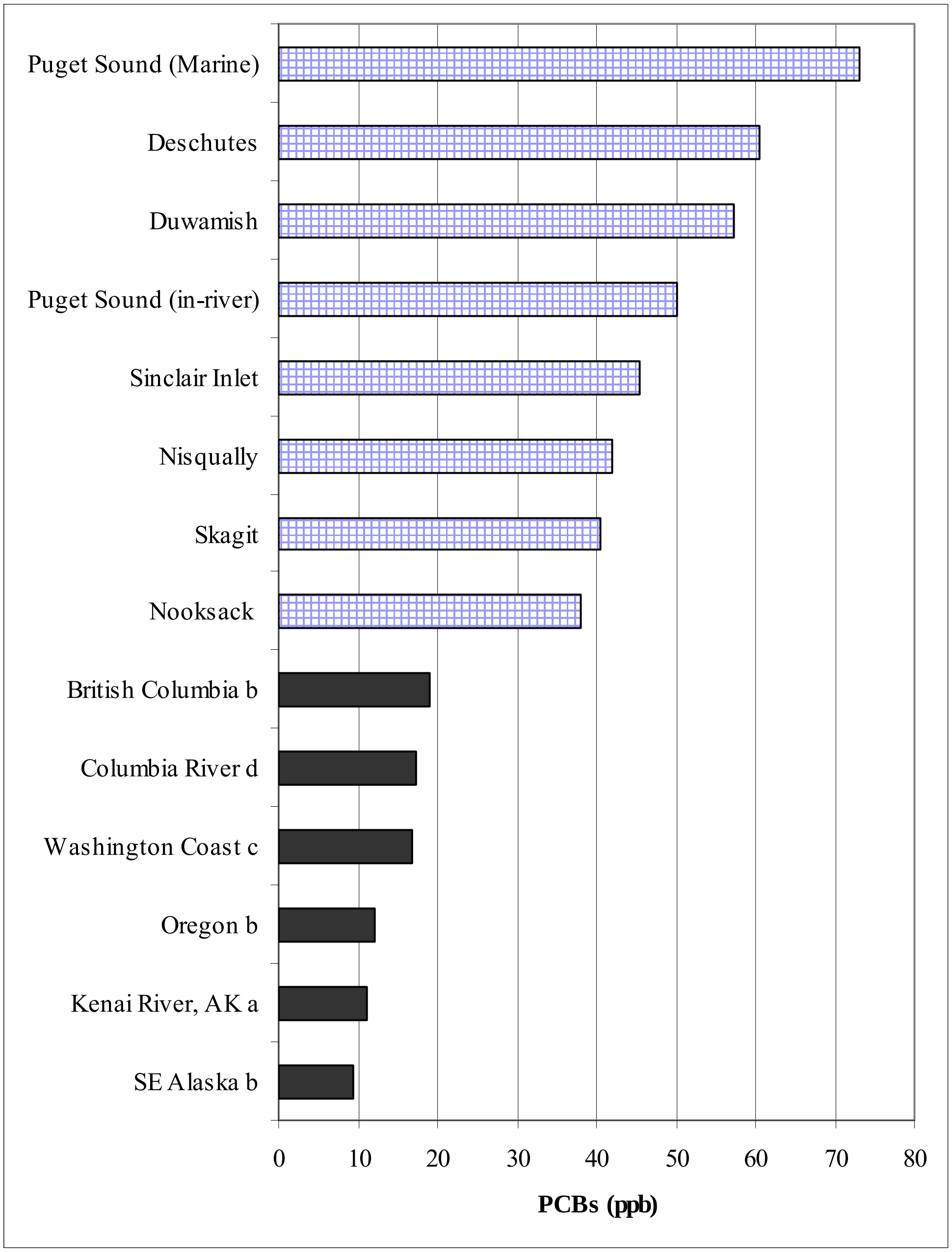
Chinook from coastal Washington contain lower PCB levels than Chinook originating from Puget Sound. Since Chinook salmon typically consume forage fish from Puget Sound for a longer period than other populations, they most likely accumulate a portion of their PCBs during residence in the Sound. In fact, WDFW found elevated PCB levels in salmon prey (Pacific herring) collected from Puget Sound (S. O'Neill, personal communication, 2004).

Some Chinook spend their entire life cycle in Puget Sound. These fish are available to commercial and sport fishers from December to February and are known as blackmouth, or resident Chinook. WDFW has collected some information, and is gathering additional data to show that these fish have PCB levels significantly higher than Chinook that migrate out to sea. If warranted, DOH will propose fish consumption guidance specific to resident Chinook from Puget Sound based on forthcoming information.

Recently, whole body sockeye salmon from Lake Washington were analyzed for total PCBs (DOH 2004). The average total PCB concentration in ten sockeye from the lake was 7.8 ppb. Sockeye differ from other salmon species because they require a lake environment for part of their life cycle and feed largely on zooplankton, especially crustaceans, during their fresh-water life stage. While at sea, sockeye feed mainly on planktonic foods such as crustaceans, especially euphausid shrimp, rather than on forage fish.

Other salmon species from Puget Sound include chum and pink salmon. Evaluation of limited data and using assumptions based on knowledge of fish diets and life histories has led experts to believe that PCB values for Puget Sound chum and pink salmon would also be lower than for coho and Chinook (DOH 2004; Hites et al. 2004; S. O'Neill, personal communication, 2005).

Figure 8. Mean PCB levels in Puget Sound Chinook salmon (hash-marked bars), Washington coast, Alaska, Oregon, and British Columbia (solid bars).

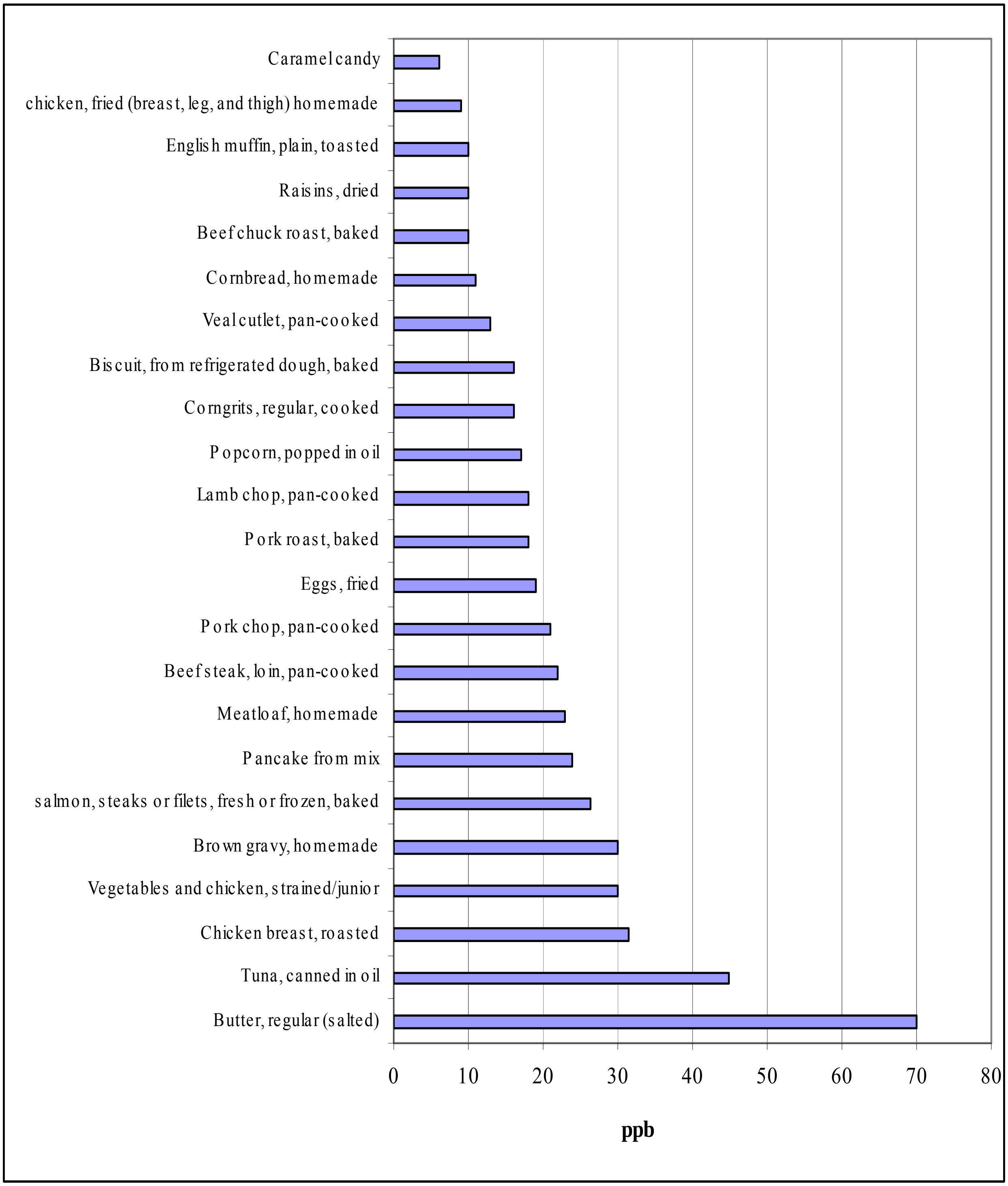


[a] Krahn 2003
[b] Hites et al. 2004
[c] Missildine et al. 2005
[d] EPA 2002b

PCBs in Other Foods

PCBs are found not only in fish but also in meat and dairy products. PCB concentrations in fish, meat, and dairy products vary widely depending on where they are caught or raised and on processing/cooking techniques. FDA conducted market basket surveys from 1991-2003 and measured PCB concentrations in various foods (Figure 9) (FDA 2003). Sample sizes were very low for most foods (n = 1) except tuna (n =14) and popcorn (n = 4). Firm conclusions about PCBs in other foods cannot be made based on these data, but this information demonstrates that avoiding fish will not eliminate dietary exposure to PCBs.

Figure 9. PCB levels in other foods as tested by the U.S. Food & Drug Administration (2003)

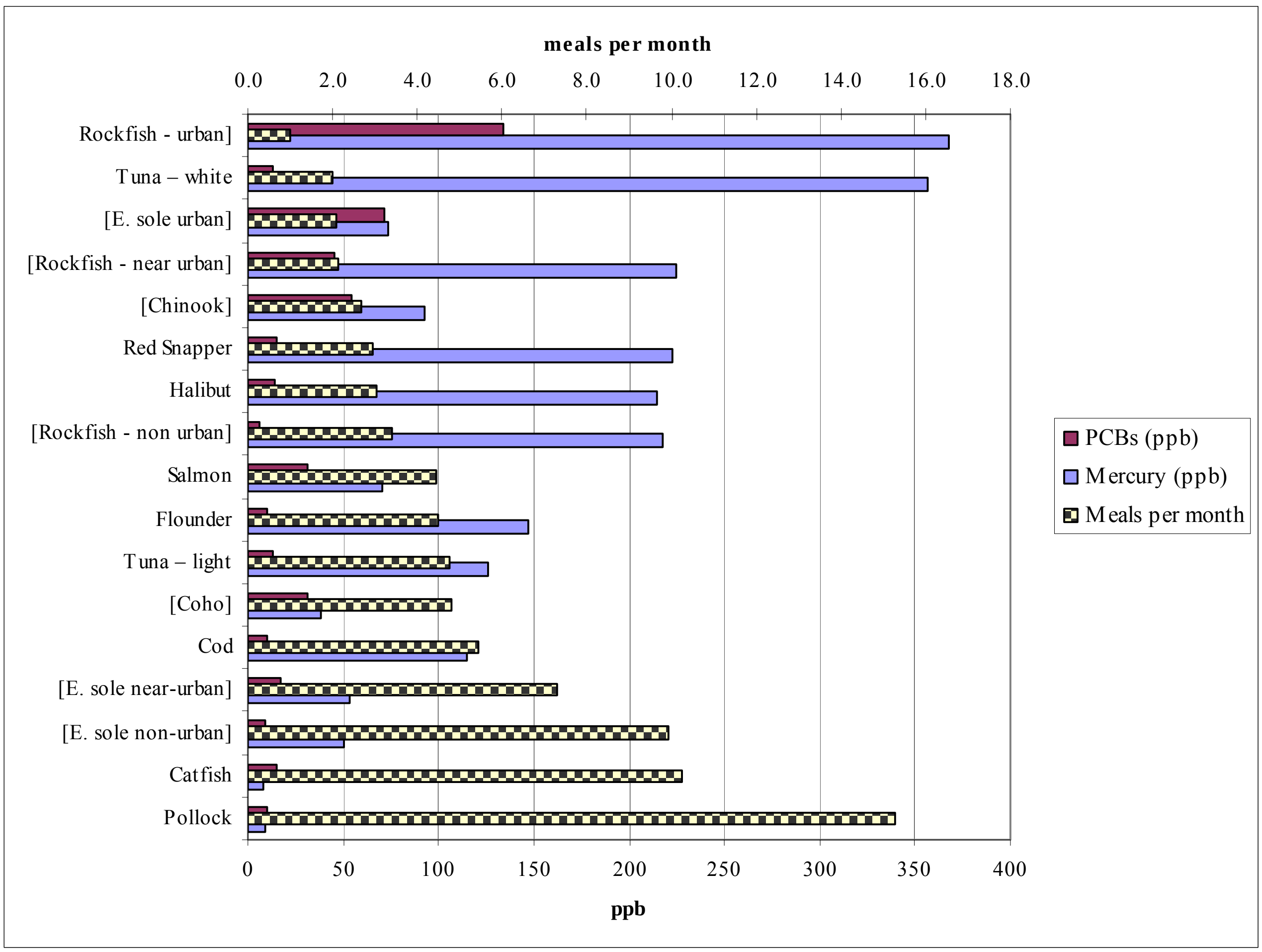


Note: Sample sizes were very low for most foods (n = 1) except tuna (n =14) and popcorn (n = 4).

Comparing PCBs and Mercury

When choosing fish, it is important to consider levels of both mercury and PCBs. Here, PCBs and mercury are shown with the corresponding number of meals per month shown on the secondary (top) axis (Figure 10). Meals per month below consider additive developmental and/or immune effects of PCBs and mercury. It is easier to identify fish low in both mercury and PCBs when viewing concentrations of both chemicals on the same graph. As an example, consider halibut vs. Chinook salmon. Based solely on PCBs, a person would conclude that commercial halibut is a better choice than Puget Sound Chinook salmon. When considering both mercury and PCBs concentrations, halibut and Puget Sound Chinook are equal choices. Considering meals/month (hatched lines), Puget Sound coho and non- and near-urban English sole are among the top five fish listed that can be eaten most frequently.

Figure 10. Average PCB and mercury concentrations (ppb) for commercial and Puget Sound fish plotted with corresponding meals per month (hatched bar).



[ ] - indicates Puget Sound Fish, other fish DOH 2005.

Sources of Contamination

Most contaminants in Puget Sound are thought to originate primarily from anthropogenic sources. PCBs were widely used for industrial applications prior to the 1970s and have become distributed throughout the environment from disposal of equipment. Mercury continues to be deposited into Puget Sound due to airborne emissions from industrial operations and natural events.

Highest average total PCB sediment concentrations in Puget Sound are observed in urban bays like Elliott Bay and Sinclair Inlet (372 ppb dry weight, n = 496 and 148 ppb dry weight, n = 267, respectively) and in known contaminated areas such as the lower Duwamish River (439 ppb dry weight, n = 1,079) (M. Dutch, personal communication, 2004) (Puget Sound summaries were calculated based on detected and undetected values). Contaminant sources in urban bays include industrial sites, urban runoff, municipal waste facilities, shipyard activities, Department of Defense sites, and other current and historic releases. Sediment-associated contaminants have resulted in demonstrable bioaccumulation in Puget Sound fish.

Benefits of Fish Consumption

Recent studies have attempted to quantify risks of eating contaminated fish with benefits associated with their ingestion (Rembold 2004, Tuomisto et al. 2004, Lund et al. 2004, Sakamoto 2004, SACN 2004, Bouszan et al. 2005, Cohen et al 2005, Konig et al. 2005) Further work is expected on this subject as more reports on fish contaminant levels and human health become available. At present, fish are known to be an excellent protein source that is low in saturated fats, rich in vitamin D and omega-3 fatty acids and other vitamins and minerals.

The primary health benefits of eating fish are well documented and relate to the reduction of cardiovascular disease (Yuan et al. 2001, Rodriguez et al. 1996, Hu et al. 2002, Marckmann and Gronbaek 1999, Mozaffarian et al. 2003, Simon et al. 1995, Burr et al. 1989, 1994, Singh et al.1997, and Harrison and Abhyankar 2005) and positive pregnancy outcome (Williams et al. 2001, Jorgensen et al. 2001, Olsen et al. 1992, Olsen et al. 1995, Olsen and Secher 2002, Carlson et al. 1993, Carlson et al. 1996, Fadella et al. 1996, San Giovanni et al. 2000, and Helland et al. 2003). Limited data show a link between fish consumption and a decrease in development of some cancers (SACN 2004). Eating fish has also been associated with impacts on brain function, including protection against cognitive decline (SACN 2004). Cardiovascular disease, cancer, and cognitive decline are serious health problems that affect large portions of the U.S. population. Health benefits of eating fish are associated with low levels of saturated versus unsaturated fats. Saturated fats are linked with increased cholesterol levels and risk of heart disease while unsaturated fats (e.g., omega-3 polyunsaturated fatty acid) are an essential nutrient. Replacing fish in the diet with other sources of protein may reduce exposure to contaminants but could result in increased risk for certain diseases. For example, replacing fish with red meat could increase the risk of cardiovascular disease since red meat has higher levels of saturated fat and cholesterol.

Advisories can be protective (while acknowledging the benefits of eating fish) by recommending decreased consumption of fish known to have high contaminant concentrations in favor of fish that are lower in contaminants. DOH supports the American Heart Association and the U.S. Food and Drug Administration recommendation of at least 12 ounces (about 3 – 4 servings) of fish per week as part of a healthy diet.

Health benefits of eating fish deserve particular consideration when dealing with groups that consume fish for subsistence. Removal of fish from the diet of subsistence consumers may have serious health, social and economic consequences. Such populations are encouraged to consume a variety of fish species, to fish from locations with low contamination, and to follow recommended preparation and cooking methods.

Communicating Risk vs. Benefits

All fish contain some level of persistent and bioaccumulative contaminants. A strict risk assessment approach would provide a meal limit, no matter how large or small, for every fish species. While meal limit calculations are a useful and necessary component of providing advice about eating fish, such messages should not stand alone. DOH considers the health benefits of eating fish to be an important part of consumption advice provided to the public. Since methods are not currently available to quantify these benefits with respect to risk, DOH chooses to promote consumption of fish that are lowest in contaminants. This approach moves away from setting strict limits and moves toward encouraging consumers to eat fish but to be smart about their choices.

EPA has recently revised estimates of per capita seafood consumption and found that the average fish consumption rate in the US is 20 g/day for all respondents (including non-consumers) for anadromous and resident finfish and shellfish from fresh, estuarine, and marine environments (EPA 2002). This equates to 2-3 eight ounce meals per month, which is much lower than the American Heart Association's (AHA) recommendation of at least two fish meals per week. The goal of DOH fish advice is to encourage Washingtonians to eat two fish meals per week (roughly 50 – 65 g/day) while following localized fish advisories and general fish consumption guidance (such as limiting consumption of species high in mercury and/or PCBs).

Some considerations in risk communication include the importance of gender, age, body weight, genetics and culture. Pregnant women and women of child-bearing age are an important population to advise about potential risk of mercury and PCBs in fish because of ongoing neurological development of the fetus. In addition, children often consume larger meals, pound per pound, than adults and so receive a higher dose of contaminants. This consideration applies to adults of various body weights as well; those of higher body weight can eat larger portions while those of lower body weight should eat smaller portions (advice in this report is based on an assumed bodyweight of 60 kg).

It is also important to understand the importance of fish in different cultures and how health messages may need to be adapted culturally. Connecting with culturally diverse communities often requires outreach that goes beyond traditional governmental methods of communicating such as meetings sponsored by agencies, informational mailings and press releases. Some communities prefer visual and verbal communications, for example, use of local access cable.

Meeting with community groups on their own terms demonstrates sincerity and can build trust. Accurate translation of printed material is essential.

DOH believes that recent news articles about limits may scare people from consuming fish and prevent some members of the public from getting the benefits of good fish choices. The public should understand that removing fish from the diet will not eliminate exposure to contaminants and that other sources of protein, such as beef, chicken and dairy products also contain persistent bioaccumulative toxins (PBTs). The best approach is to eat fish but to be smart about fish choices.

Future Considerations

Over the long-term, species sampled as part of PSAMP should continue to be collected and analyzed for PCBs and mercury to determine long-term contaminant trends. Long-term monitoring would also help to identify the presence of emerging contaminants such as PBDEs.

Additional Species

WDFW sampled and analyzed two species of salmon (Chinook and coho) that were expected to reflect contaminant conditions within the Puget Sound food web. They collected muscle tissue without skin for contaminant analyses. Due to life history and diet, other Puget Sound salmon species (sockeye, pink and chum) are expected to have lower concentrations of contaminants than coho or Chinook. Sockeye salmon collected and analyzed from Lake Washington indicated low levels of contaminants (DOH 2004). A limited analysis of Puget Sound pink, chum, and sockeye salmon is recommended for the purpose of confirming that contaminant levels are lower in these species than in Chinook and coho. Finally, contaminant levels in farmed, hatchery-released and pen-reared salmon of any relevant species should be investigated to complete our evaluation of human health impacts from consuming Puget Sound salmon.

Limited analysis of other marine species such as lingcod, cabezon, Dungeness crab, shrimp, and bivalves would also be useful for answering frequent questions from the public on human health impacts from consuming these fish or invertebrates. Currently, PSAMP is collecting and analyzing contaminants in herring with a focus on this species' role as forage fish. DOH will assess the impact on human health of consuming herring once these data are available.

Multi-species/Multi-food Considerations

Another issue to consider is that most consumers and anglers do not eat only one species of fish. Instead, a consumer is advised, for example, to eat either four rockfish meals per month from RMA 7, or four Chinook salmon meals per month. As part of our "either/or" guidance, DOH encourages citizens to eat two fish meals per week, so a consumer should choose accordingly.

DOH recognizes the need to conduct a "market basket" assessment of PCBs and other contaminants in foods. This would include not only fish but also beef, poultry, pork, etc. since available contaminant data are limited.

Additional Analytes

Researchers are interested in obtaining PCB congener data rather than Aroclor mixtures to assess toxicity. In particular, it would be valuable to evaluate the relationship between the two estimates of total PCBs using analysis of all 209 congeners (although not all 209 congeners are likely to be found in tissue samples). Because Aroclor analysis likely overestimates the amount of PCBs present in fish, tissue should be analyzed for all 209 PCB congeners to get a more accurate measure of total PCB concentrations in Puget Sound fish. This may serve to determine whether Aroclor analysis overestimates the amount of total PCBs and whether less expensive Aroclor analysis should be continued.

Existing congener data from PSAMP consists of 15 of 209 congeners. Estimating total PCBs from this limited set of congeners likely underestimates total PCBs. Eight of the 15 congeners analyzed were co-planar dioxin-like PCB congeners and therefore useful for determining PCB dioxin toxic equivalents (TEQs). Four congeners not analyzed by PSAMP also have dioxin toxic equivalency factors (TEFs). The most potent dioxin-like congeners, PCBs 126 and 169, were analyzed by PSAMP but not detected in any fillet sample. More sensitive analytical methods would aid in the ability to quantify health risks associated with dioxin-like PCB congeners in fish.

PSAMP data have no dioxin/furan analysis. Collection of this information is important, particularly in examining cumulative risks from dioxins/furans and PCBs with dioxin-like effects.

Emerging Contaminants: *Polybrominated diphenyl ethers*

A new area of concern for human health is the widespread environmental presence of polybrominated diphenyl ethers (PBDEs), which are flame retardants used in a variety of consumer and industrial products. PSAMP has begun collecting fish tissue data for this analyte. PBDEs were recently identified as bioaccumulative in the environment and have been detected in a variety of human tissues and in other organisms. Given the long life of many PBDE products and the length of time they remain in the environment, exposure can continue for years after their production. Washington State has developed a draft chemical action plan to identify efforts the state may take to reduce threats posed by some PBDEs (Ecology/DOH 2004).

Information on possible health impacts of PBDEs comes primarily from animal toxicity studies (Ecology/Health 2004). In general, specific PBDE congeners found in Penta-PBDE commercial products are more toxic than Octa-PBDE and Deca-PBDE. Deca-PBDE breaks down to Penta-PBDE. The most sensitive toxic effect associated with Penta-PBDE congeners appears to be developmental neurotoxicity, although Penta-PBDE may also impact thyroid and other hormone systems. Octa-PBDE showed fetal toxicity and liver changes in rat and rabbit studies. Dietary intake of Deca-PBDE was associated with liver, pancreas and thyroid tumors at very high doses in rodent studies. Washington State's PBDE chemical action plan states that human health risks are associated with PBDE exposure, although pathways and levels that may result in harm are not clearly understood. While consumption of food, including fish, may be an important exposure pathway for these chemicals, the indoor environment poses a unique exposure pathway for PBDEs unlike pathways for other persistent bioaccumulative toxins.

In the past year, PSAMP measured PBDE levels in selected fish from some areas of Puget Sound. Rockfish (from Elliott Bay) and English sole from Elliott Bay, Sinclair Inlet, Hood Canal, Strait of Georgia, and Vendovi Island had the lowest PBDE levels (sum of 10 congeners) (O'Neill, WDFW, personal communication, 2005). PBDEs were higher in Pacific herring, a pelagic fish – all had levels of PBDEs between 15 – 40 ppb, wet wt. Lingcod, which are benthic and/or demersal fish, had levels between 30 and 40 ppb, wet wt. Puget Sound resident Chinook salmon, or blackmouth, also had higher levels of PBDEs (around 30 ppb, wet wt) compared with English sole and rockfish. The higher levels observed in Chinook salmon were, in general, associated with greater fish length. Relatively low levels in bottom feeding fish as compared to higher levels in pelagic-feeding fish suggests that PBDEs are more available in the pelagic food web than in the benthic community.

Current PBDE toxicity values as provided by EPA do not indicate the need to provide fish consumption advice based on this contaminant (RfDs = 1×10^{-3} mg/kg-day for decabromodiphenyl ether, 3×10^{-3} mg/kg-day for octabromodiphenyl ether, and 2×10^{-3} mg/kg-day for pentabromodiphenyl ether) (mg/kg = ppm). Unfortunately, toxicity data for PBDEs are limited. EPA is currently updating critical toxicity values for PBDEs that consider recent animal studies showing similar adverse neurodevelopmental effects as observed with mercury and PCBs. If necessary, DOH will adjust fish consumption advice as more PBDE toxicity information becomes available.

At present, Ecology and DOH are working together on a statewide effort to decrease impacts of persistent and bioaccumulative toxins (PBT) on human health and the environment. To date, the PBT initiative has developed chemical action plans for decreasing levels of mercury and PBDEs in the state. Additionally, Ecology has promulgated a rule to formalize the steps for selecting future PBTs for chemical action plan development. DOH is a full participant in the PBT initiative which represents an important effort to reduce environmental contamination in the state.

Consumption Surveys

Consumption information is available for three Puget Sound Native American Tribes, a broad spectrum of Asian/Pacific Islanders (API) from King County, and recreational anglers (from the 1980s). Although these surveys were conducted using different methods, resulting information is useful to determine who may be consuming fish or shellfish at levels that may lead to overexposure of contaminants and to help direct risk communication efforts. Members of other Puget Sound Tribes may consume fish at rates different than the Tulalip, Squaxin, or Suquamish Tribes and this information would be of use to DOH. Gathering better information on API consumption patterns and information on API consumption from other parts of Puget Sound is also recommended. Since consumption information for recreational fishers is not up-to-date for

Puget Sound, DOH recommends further studies and surveys to address this issue. Such information on tribal, API, and recreational consumption patterns aids in effectively directing risk communication efforts and resources.

Conclusions

Fish is an important part of a healthy diet. It is a good protein source that is low in saturated fats and high in beneficial omega-3 fatty acids and other nutrients. Fish consumption, especially that of oily fish, decreases the risk of cardiovascular disease. Further, increased fish consumption has been shown to produce beneficial effects to pregnant and lactating women. Other reported benefits of fish consumption include a decrease in some cancers and protection against declines in brain function. DOH supports the American Heart Association's (AHA) recommendation for all consumers, including pregnant women, to eat at least 2 portions of fish per week. An increase in population consumption of oily fish would result in significant public health benefits with regard to reduced cardiovascular disease (SACN 2004).

Balanced against the benefits from eating fish are possible negative effects associated with contaminants in fish. Results of the fish tissue analysis conducted under PSAMP indicate the need for advice on ways that consumers of Puget Sound fish can reduce exposure to contaminants. Specifically, results of the PSAMP fish tissue analysis indicate:

- Polychlorinated biphenyls (PCBs) and mercury are at high enough levels in some Puget Sound fish to warrant advice that will minimize exposure while consumers continue to eat Puget Sound fish as part of a healthy diet.

- Salmon are generally low in contaminants and do not require meal limit advice, with the exception of Chinook salmon. Chinook have higher levels of contaminants most likely because of their life cycle. Resident Chinook, also known as blackmouth, have the highest levels of PCBs of any salmon because they spend all of their life in Puget Sound.

- Impact on childhood development following exposure of the fetus is the most sensitive and important health consideration regarding contaminants in fish. These developmental effects relate to subtle changes in learning and behavior and have been found only through careful study of large populations. This fact indicates that women of childbearing age and children are the populations of most concern.

- Emerging contaminants such as polybrominated diphenyl ethers (PBDEs) are being found in Puget Sound fish. Health implications of this result are not yet clear.

- Continued monitoring, especially for emerging contaminants, is warranted in order to assess the health implications of future exposure to contaminants in Puget Sound fish.

Puget Sound fish are not alone with regard to elevated chemicals of concern, but fish purchased in markets also have been found to contain these same contaminants. The level of contamination in fish is dependant upon the species, age, size and/or location where the fish spends its life. Puget Sound salmon are generally lower in contaminants than fish that spend their entire life in Puget Sound urban areas (e.g., bottomfish) or very long-lived species (e.g., some species of rockfish).

Recommendations

The following recommendations provide broad advice to people who eat fish from Puget Sound. These recommendations are based on several factors, including the level and toxicity of contaminants, benefits of eating fish, and the need for a clear health message. The goal of this advice is to encourage Washingtonians to eat fish while at the same time reducing exposure to contaminants by making healthy, informed choices.

Levels of contamination in Puget Sound fish vary and advice varies accordingly. Depending on fish species and catch location, rockfish and bottomfish advice ranges from no fish consumption to no fish meal restrictions. Meal limit advice is provided only when DOH's assessment indicated a need to reduce consumption below two meals per week. While restrictions are not provided in areas of Puget Sound above this point, a consumer's exposure to contaminants is never zero when eating fish or other protein sources such as beef, chicken, and dairy products. Advice given below is meant to guide people toward making informed decisions when selecting fish to eat. People who eat Puget Sound fish that have recommended meal limits (e.g., rockfish) should choose other fish that are lower in contaminants for their heart-healthy second meal per week. Good examples of fish lower in contaminants include coho, sockeye, and chum salmon, and flatfish from non-urban areas of Puget Sound. Further, DOH has compiled a list of store-bought fish low in contaminants based on our own data and previously published data.

General Advice

DOH encourages all Washingtonians to eat at least two fish meals per week as part of a heart healthy diet in accordance with American Heart Association (AHA) recommendations. People may eat fish more than two times weekly, but such frequent consumers should take the following steps to reduce exposure to contaminants in the fish that they eat.

- Eat a variety of fish that are low in contaminants according to guidance provided on our website at http://www.doh.wa.gov/fish.
- Follow advice provided by DOH and local health agencies for water bodies where you fish.
- Young children and small adults should eat proportionally smaller meal sizes.
- Grill, bake, or broil fish so that fat drips off while cooking.
- Eat fillets without the skin.

Rockfish

Contamination of rockfish species in Puget Sound is related to fish age. However, age is not related to length for all species of Puget Sound rockfish throughout their life history. Therefore, guidance for consumption of rockfish based on fish size, a common practice for some species, is not appropriate for rockfish. Consumption advice is organized by marine recreational areas previously determined by WDFW rather than for each site where rockfish were sampled, allowing for coordination with WDFW's rockfish catch limits.

DOH recommends the following with respect to rockfish from Puget Sound:

- No consumption of yelloweye rockfish collected anywhere in Puget Sound. This advice is based on public health concerns and is derived from a very small sample size. For conservation purposes, WDFW currently restricts non-tribal harvest of yelloweye and canary rockfish in Puget Sound.

- For all other species of Puget Sound rockfish, follow the guidance given below.

Table 13. Meal recommendations for rockfish from Puget Sound listed by WDFW recreational marine areas.

Recreational Marine Area (see Figure ES-1)		Consumption Guidance for rockfish from Puget Sound	Exceptions (see Figure ES-2)
6	East Juan de Fuca Strait	No more than 1 meal/week	**None**
7	San Juan Islands	No more than 1 meal/week	**None**
8.1	Deception Pass, Hope Island, and Skagit Bay	No more than 1 meal/week	**None**
8.2	Port Susan and Port Gardner	No more than 1 meal/week - with noted exceptions	**No more than 2 meals per month:** Mukilteo-Everett and Port Gardner.
9	Admiralty Inlet	No more than 1 meal/week	**None**
10	Seattle-Bremerton Area	No more than 1 meal/week - with noted exceptions	**No consumption**: Elliott Bay (east of imaginary boundary from Duwamish Head to Pier 91, including the Duwamish River) and Sinclair Inlet (west of Dyes Inlet and Mitchell Point).
11	Tacoma-Vashon Area	No more than 1 meal/week - with noted exceptions	**No more than 2 meals per month:** Commencement Bay (SE of imaginary boundary between Old Town Dock and Tyee Marina).
12	Hood Canal	No more than 1 meal/week	**None**
13	South Puget Sound	No more than 1 meal/week	**None**

NOTE: Meal size equals eight ounces of uncooked fish for an average-sized adult.

English sole and Other Flatfish

English sole was the only flatfish sampled by PSAMP. Results from English sole tissue analyses were used to develop recommendations for all Puget Sound flatfish. While differences in life history may result in different contaminant concentrations between species, DOH assumes that patterns of contamination for English sole are representative of other Puget Sound flatfish species, including sole, flounder, and sanddab species. WDFW sport fish regulations use the term "bottomfish" to define numerous species, and meal limits specified for flatfish may not be applicable to other bottomfish such as lingcod.

The following table is a summary of consumption guidance for all consumers of Puget Sound English sole and other flatfish. Note that consumption of English sole and other flatfish from urban bays should be limited (Everett, Eagle Harbor, Commencement Bay) or avoided (Duwamish Waterway). Before fishing, anglers should consult WDFW fishing guidance for catch limits.

Table 14. Meal recommendations for English sole and other flatfish from Puget Sound listed by WDFW recreational marine areas.

Recreational Marine Area (see Figure ES-1)		**Consumption Guidance for English sole and other Flatfish from Puget Sound**	**Exceptions** (see Figure ES-3)
6	East Juan de Fuca Strait	**No meal limit**	**None**
7	San Juan Islands	**No meal limit**	**None**
8.1	Deception Pass, Hope Island, and Skagit Bay	**No meal limit**	**None**
8.2	Port Susan and Port Gardner	**No meal limit** – with noted exceptions	**No more than 2 meals per month:** Everett-waterfront from Mukilteo ferry dock to City of Everett. Based on extrapolation from sediment concentrations.
9	Admiralty Inlet	**No meal limit**	**None**
10	Seattle-Bremerton Area	**No meal limit** – with noted exceptions	**No consumption:** Duwamish Waterway (includes Harbor Island East and West Waterways) **No more than 1 meal per month**: Sinclair Inlet (west of Dyes Inlet and Mitchell Point). **No more than 2 meals per month:** Elliott Bay (east of imaginary boundary from Duwamish Head to Pier 91). **No more than 1 meal per wk**: Eagle Harbor and Port Orchard (waterway separating Bainbridge Island and Kitsap Peninsula).
11	Tacoma-Vashon Area	**No meal limit** – with noted exceptions	**No more than 2 meals per month**: Inner Commencement Bay (SE of imaginary boundary between Sperry Ocean dock and Cliff House Restaurant). **No more than 1 meal per wk**: Outer Commencement Bay (SE of imaginary boundary between Boathouse Marina and Brown's Point).
12	Hood Canal	**No meal limit**	**None**
13	South Puget Sound	**No meal limit**	**None**

NOTE: Meal size equals eight ounces of uncooked fish for an average-sized adult.

Puget Sound Salmon

Chinook Salmon

Chinook salmon spend more years at sea than coho salmon and are generally larger with a higher fat content, leading to higher concentrations of bioaccumulative chemicals such as PCBs and mercury. Chinook salmon from south Puget Sound tend to have slightly higher levels of chemicals of concern in their muscle tissue (fillet) than Chinook salmon from north Puget Sound.

- Resident Chinook, also known as blackmouth, are caught by recreational anglers primarily in winter. Preliminary data show that Puget Sound blackmouth have higher concentrations of chemicals than non-resident fish captured in the Puget Sound spring or fall fishery, although blackmouth were not evaluated separately in this report. Anglers who catch resident Chinook in Puget Sound should limit themselves to two eight-ounce meals per month.

- Puget Sound Chinook salmon from other areas may be consumed at a rate of one eight-ounce meal per week (or four times a month). Non-resident Chinook salmon are caught in a marine fishery in late summer and fall by sport, commercial, and tribal fisheries in north, central, and south Puget Sound.

Coho Salmon

Coho salmon typically spend one winter in the ocean before returning to spawn in their stream of origin. Coho are more abundant than Chinook salmon and are important in recreational, commercial, and tribal fisheries throughout Puget Sound. Coho salmon from all areas of Puget Sound, including estuaries and rivers, and coho salmon produced in hatcheries and net pens have low levels of contaminants relative to Puget Sound Chinook salmon. Therefore, DOH has no consumption restrictions on these fish (i.e., coho from Puget Sound may be consumed at a rate of at least two eight-ounce meals per week).

- High-end consumers (e.g., those who eat more than two meals per week) are encouraged to follow general preparation advice to reduce exposure to some contaminants in Puget Sound coho.

Other Salmon Species

Other salmon species were not sampled as part of the PSAMP effort. However, data from other sources show that sockeye, chum, and pink salmon tend to have very low levels of contaminants, most likely a result of life history and diet. Based on limited data from other sources, DOH recommends that:

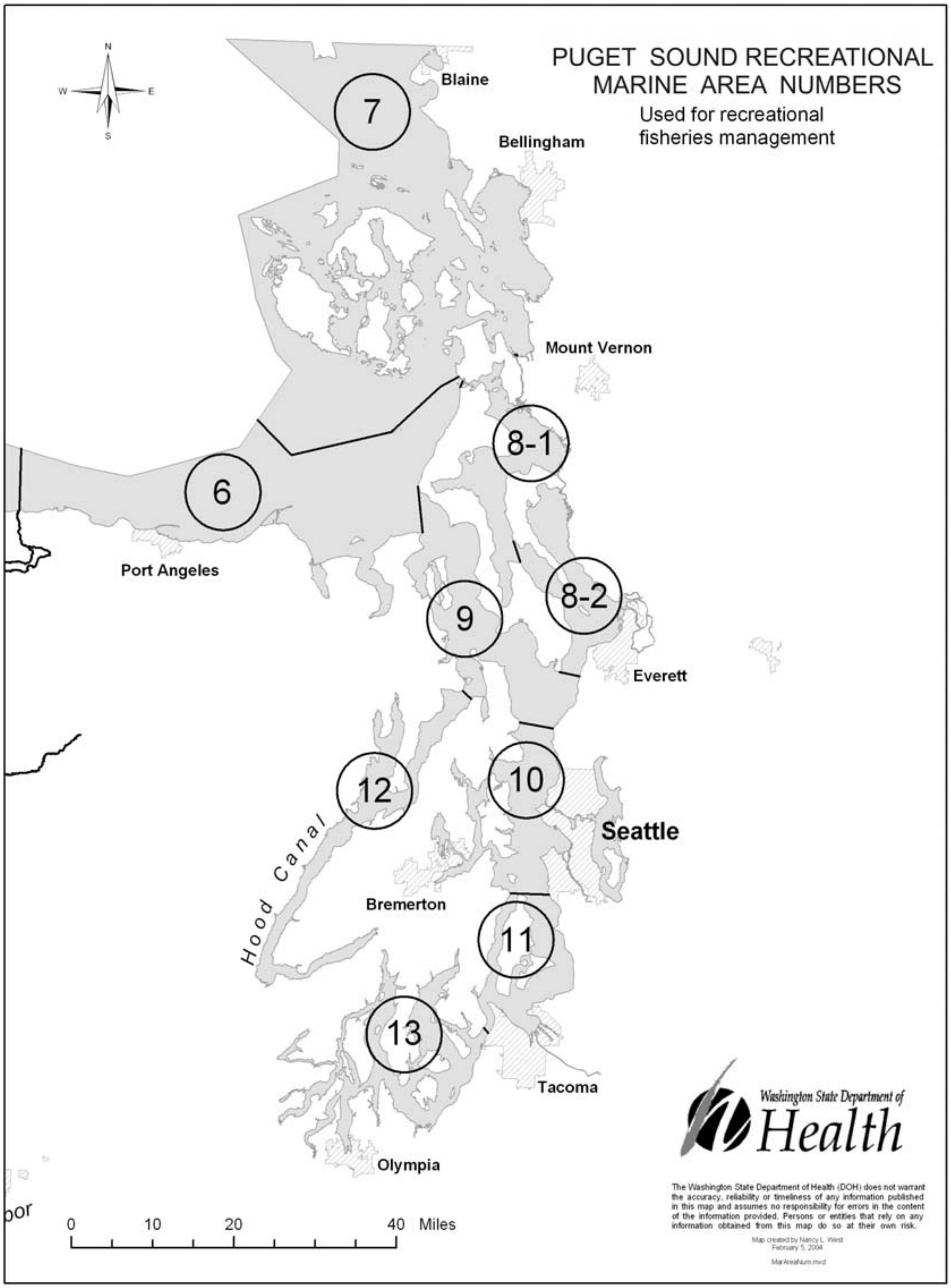
- Puget Sound sockeye, chum, and pink salmon may be consumed at a rate of at least two eight-ounce meals per week (eight meals per month).

Public Health Communication

DOH recognizes that this evaluation is the first step in developing health protective messages for consumers of Puget Sound fish. The next step involves communicating health messages to affected communities. DOH will provide results and recommendations of this evaluation to various economic, ethnic and interested communities through the following means:

- WDFW's annual sport fishing rules pamphlet
- News media
- Fishing magazines
- Web posting at www.doh.wa.gov/fish
- Fact sheets / Healthy fish eating guide
- Presentations to interested parities. For example,
    - Indian Nations
    - Asian and Pacific Islander communities
    - Angler groups
    - DOH Women, Infants and Children Nutrition Program (WIC)

Figure 11. Map of Puget Sound recreational marine areas.



References

ATSDR. 1999. Toxicological Profile for Mercury. U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. March 1999.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. November 2000.

ATSDR. 2004a. Guidance Manual for the Assessment of Joint Toxic Action of Chemical Mixtures. U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. May 2004.

ATSDR. 2004b. Interaction Profile for Persistent Chemicals Found in Fish. U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. May 2004.

Bignert A, Olsson M, Persson W, Jensen S, Zakrisson S, Litzén K, Eriksson U, Häggberg L, and Alsberg T. 1998. Temporal trends of organochlorines in Northern Europe, 1967-1995. Relation to global fractionation, leakage from sediments and international measures. Environmental Pollution. 99: 177-198.

Bouzan C, Cohen JT, Connor WE, Kris-Etherton PM, Gray GM, Konig A, Lawrence RS, Savits DA, and Teutsh SM. 2005. A Quantitative Analysis of Fish Consumption and Stroke Risk. American Journal of Preventive Medicine. 29 (4) 347-352.

Burr ML, Fehily AM, Gilbert JF, Robers S, Holliday RM, Sweetnam PM, Elwood PC and Deadman NM. 1989. Effects of changes in fat, fish, and fibre intakes on death and myocardial reinfarction trial (DART). Lancet. 2:757-761.

Burr ML, Sweetnam PM, and Fehily AM. 1994. Diet and reinfarction. Eur Heart J. 15:1152-3.

Carlson SE, Werkman SH, Rhodes PG, Tolley EA. 1993. Visual-acuity development in healthy preterm infants: effect of marine-oil supplementation. Am J Clin Nutr. 58:35-42.

Carlson SE, Werkman SH, Tolley EA.1996. Effect of long-chain n-3 fatty acid supplementation on visual acuity and growth of preterm infants with and without bronchopulmonary dysplasia. Am J Clin Nutr. 63:687-697.

Cohen JT, Bellinger DC, Connor WE, Kris-Etherton PM, Lawrence RS, Savitz DA, Shaywitz BA, Teutsch SM, and Gray GM. 2005. A Quantitative Risk-Benefit Analysis of Changes in Population Fish Consumption. American Journal of Preventive Medicine. 29 (4) 325-334.

Dellinger JA, Meyers RM, Gebhardt KJ, and Hansen LK. 1996. The Ojibwa health study: Fish residue comparisons for Lakes Superior, Michigan, and Huron. Toxicol Ind Health. 12(3-4):393-402.

DOH 2003. Statewide Bass Advisory. September 2003. http://www.doh.wa.gov/CommunityandEnvironment/Food/Fish/MercuryAdvisories.aspx

DOH. 2004. Evaluation of Contaminants in Fish from Lake Washington, King County Washington. Office of Environmental Health Assessments, Washington State Department of Health. Olympia, WA.

Dutch M. 2004. Personal Communication. Washington State Department of Ecology.

Ecology. 2002. Inorganic Arsenic Levels in Puget Sound Fish and Shellfish from 303(d) Listed Waterbodies and Other Areas. December 2002. Publication No. 02-03-057. Available at URL http://www.ecy.wa.gov/pubs/0203057.pdf

Ecology. 2003. Mercury in Edible Fish Tissue and Sediments from Selected Lakes and Rivers of Washington State. Washington State Department of Ecology, Office of Environmental Assessment Program. Publication No. 03-03-026.

Ecology & DOH. 2004. Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Interim Plan. December 31. Department of Ecology Publication No. 04-03-056, Department of Health Publication No. 333-068. 99 pp.

EPA. 1986a. Guidelines for Carcinogen Risk Assessment. U.S. Environmental Protection Agency, Office of Research and Development. 51 Register 33992 (September 24, 1986).

EPA. 1986b. (revised July 1987). U.S. EPA contract laboratory program statement of work for inorganics analysis, multi-media, multi-concentration. IFB W-87-K025, K026, K027 U.S. EPA, Washington, DC.

EPA. 1992. National Study of Chemical Residues in Fish. Volume I. Office of Science and Technology. Washington, DC. EPA 823-R-92-008a.

EPA. 1993. Integrated Risk Information System entry for Aroclor1254. Revised 7/01/1993. Available at URL http://www.epa.gov/iris/subst/0389.htm

EPA. 1997. Exposure Factors Handbook (EFH). Volume I – General Factors. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment. August 1997. EPA/600/P-95/002Fa.

EPA. 1999a. Polychlorinated biphenyls (PCBs) update: Impact on fish advisories. Office of Water 4305. EPA-823-F-99-019.

EPA. 1999b. Asian and Pacific Islander Seafood Consumption Study in King County, WA. U.S. Environmental Protection Agency, Office of Environmental Assessment. EPA 910/R-99-003.

EPA. 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 2 – Risk Assessment and Fish Consumption Limits, Third Edition. U.S. Environmental Protection Agency, Office of Water. November 2000. EPA 823-B-00-008.

EPA. 2001a. Mercury update: Impact on fish advisories. Office of Water 4305. EPA-823-F-01-011.

EPA. 2001b. Integrated Risk Information System entry for Methylmercury. Revised 7/27/2001. Available at URL http://www.epa.gov/iris/subst/0073.htm.

EPA. 2002. Estimated Per Capita Fish Consumption in the United States. EPA-821-C-02-003.

EPA. 2002b. Columbia River Basin Fish Contaminant Survey: 1996-1998. EPA 910-R-02-006.

EPA. 2005. Guidelines for Carcinogen Risk Assessment and Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. April 2005. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=116283.

Fadella G, Govoni M, Alessandroni R, Marchiani E, Salvioli GP, Biagi PL, Spano C. 1996. Visual evoked potentials and dietary long chain polyunsaturated fatty acids in preterm infants. Arch. Dis Child Fetal Neonatal Ed. 75:F108-F112.

FDA. 2003. Total Diet Survey**.** http://www.cfsan.fda.gov/~comm/tds-ana.html.

FDA. 2006. Mercury levels in commercial fish and shellfish. http://www.cfsan.fda.gov/~frf/frf/sea-mehg.html.

Gerstenberger SL, Gallina MP, Dellinger JA. 1997. Polychlorinated biphenyl congeners and selected organochlorines in Lake Superior Fish. USA. Environmental Toxicology and Chemistry. 16(11):2222-2228.

Giesy JP, Jude DJ, Tillitt DE, Gales RW, Meadows, JC, Zajieck JL, Peterman PH, Verbrugge DA, Sanderson JT, Schwartz TR, Tuchman ML. 1997. Polychlorinated dibenzo-p-dioxins, dibenzofurans, biphenyls and 2,3,7,8-tetrachlorodibenzo-p-dioxin equivalents in fishes from Saginaw Bay, Michigan. Environmental Toxicology and Chemistry. 16(4):713-724.

Harrison N, Abhyankar B. 2005. The Mechanism of Action of Omega-3 Fatty Acids in Secondary Prevention Post-Myocardial Infarction. Curr Med Res Opin. 21(1):95-100.

Hart JL. 1973. Pacific Fishes of Canada. Bulletin 180. Fisheries Research Board of Canada. Ottawa.

Helland IB, Smith L, Saarem K, Saugstad OD, Drevon CA. 2003. Maternal supplementation with very-long-chain n-3 fatty acids during pregnancy and lactation augments children's IQ at 4 years of age. Pediatrics. 111:e39-344.

Hickey J, Batterman S, and Chernyak S. 2006. Trends of chlorinated organic contaminants in Great Lakes trout and walleye from 1970 to 1998. Archives of Environmental Contamination and Toxicology. 50: 97-110.

Hites RA, Foran JA, Carpenter DO, Hamilton MC, Knuth BA, and Schwager SJ. 2004. Global assessment of organic contaminants in farmed salmon. Science. 303(5655):226-9.

Hu FB, Bronner L, Willet WC, Stampfer MJ, Rexrode KM, Albert CM, Hunter D and Manson JE. 2002. Fish and omega-3 fatty acid intake and risk of coronary heart disease in women. JAMA. 287:1815-1821.

Jaffe R, Stemmler EA, Eitzer BD, Hites RA. 1985. Anthropogenic, polyhalogenated, organic compounds in sedentary fish from Lake Huron and Lake Superior tributaries and embayments. J Great Lakes Res. 11:156-162.

Johnson A. 2001. An Ecological Hazard Assessment for PCBs in the Spokane River. Washington State Department of Ecology. Publication Number 01-03-015.

Jorgensen MH, Hernell O, Hughes E, Michaelsen KF. 2001. Is there a relation between docosahexanoic acid concentration in mothers' milk and visual development in term infants? J Pediatr Gastroenterol Nutr. 32:293-6.

Konig A, Bouzan C, Cohen JT, Connor WE, Kris-Etherton PM, Gray GM, Lawrence RS, Savitz DA, and SM Teutsch. 2005. A Quantitative Analysis of Fish Consumption and Coronary Heart Disease Mortality. American Journal of Preventive Medicine. 29 (4) 335-346.

Kuehl DW, Butterworth B, Marquis PJ. 1994. A national study of chemical residues in fish – III: Study results. Chemosphere. 29(3):523-535.

Krahn MM, Ylitalo GM, Buzitis J, Sloan CA, Boyd DT, Chan SL, Varanasi U. 1994. Screening for planar chlorobiphenyl congeners in tissues of marine biota by high-performance liquid chromatography with photodiode array detection. Chemosphere. (1):117-39.

Krahn MM. 2003. Data for pesticides and PCBs in Kenai River salmon and salmon eggs. pp. 27, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Seattle, Washington.

Lamon ECI, Carpenter SR, and. Stow CA. 1999. Rates of decrease of polychlorinated biphenyl concentrations in five species of Lake Michigan salmonids. Canadian Journal of Fisheries and Aquatic Sciences. 56: 53-59.

Landolt M, Hafer F, Nevissi A, van Belle G, Van Ness K, and Rockwell C. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. Rockville, MD.

Landolt M, Kalman D, Nevissi A, van Belle G, Van Ness K, and Hafer F. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: Final Report. NOAA Technical Memorandum NOS OMA 33. Rockville, MD.

Loganathan BG, Kannan K, Watanabe I, Kawano K, Irvine M, Kumar S, Sikka HC. 1995. Isomer-specific determination and toxic evaluation of polychlorinated biphenyls, polychlorinated/brominated dibenzo-p-dioxins and dibenzofurans, polybrominated biphenyl ethers, and extractable organic halogen in carp from the Buffalo River, New York. Environmental Science and Technology. 29(7):1832-1838.

Longnecker M, Wolff M, Gladen B, Brock J, Grandjean P, Jacobson J, Korrick S, Rogan W, Weisglas-Kuperus N, Hertz-Picciotto I, Ayotte P, Stewart P, Winneke G, Charles M, Jacobson S, Dewailly E, Boersma E, Altshul L, Heinzow B, Pagano J, and Jensen A. 2003. Comparison of Polychlorinated Biphenyl Levels across Studies of Human Neurodevelopment. Environmental Health Perspectives. Vol 111(1):65-70.

Lund E, Engeset D, Alsaker E, Skeie G, Hjartaker A, Lundebye AK, and Niebor E. 2004. Cancer risk and salmon intake. Science. 305(5683):476-7.

Malins DC, McCain BB, Brown DW, Sparks AK, Hodgins HO, and Chan S-L. 1982. Contaminant and abnormalities in fish and invertebrates from Puget Sound. NOAA, Boulder, CO.

Marckmann P and Gronbaek M. 1999. Fish consumption and coronary heart disease mortality. A systematic review of prospective cohort studies. Eur J Clin Nutr. 53:585-90.

Maruya KA and Lee RF. 1998. Aroclor 1268 and toxaphene in fish from a southeastern U.S. estuary. Environmental Science and Technology. 32(8):1069-1075.

Matta MB, Mearns AJ, and Buchman MF. 1986. Trends in DDT and PCBs in U.S. west coastal fish and invertebrates. pp. 95 The national status and trends program for marine environmental quality. Pacific Office, National Ocean Service, NOAA, Seattle, Washington.

Matthews KR. 1990. An experimental study of the habitat preferences and movement patterns of copper, quillback and brown rockfishes (Sebastes spp.). Environmental Biology of Fishes. 29:161-178.

Miller MA, Kassulke NM, Walkowski MD. 1993. Organochlorine concentrations in Laurentian Great Lakes salmonines: Implications for fisheries management. Arch Environ Contam Toxicol. 25(2):212-219.

Missildine B, Peters RJ, Chin-leo G, and Houck D. 2005. Polychlorinated biphenyl concentrations in adult Chinook salmon returning to coastal and Puget Sound hatcheries of Washington State. Environmental Science and Technology. 39:6944-6951.

Mozaffarian D, Lemaitre RN, Kuller LH, Burke GL, Tracy RP and Siscovick DS. 2003. Cardiac benefits of fish consumption may depend on the type of fish meal consumed: the Cardiovascular Health Study. Circulation. 107:1372-7.

NESCAUM (Northeast States for Coordinated Air Use Management). 1998. Northeast States and Eastern Canadian Provinces Mercury Study. A Framework for Action. Boston, Massachusetts.

NRC (National Research Council). 2001. A Risk Management Strategy for PCB Contaminated Sediments. National Academy Press. Washington D.C.

Olsen SF, Hansen HS, Secher NJ, Jensen B, Sandstrom B. 1995. Gestation length and birth weight in relation to intake of marine n-3 fatty acids. Br J Nutr. 73:397-404.

Olsen SF and Secher NJ. 2002. Low consumption of seafood in early pregnancy as a risk factor for preterm delivery: prospective cohort study. BMJ. 324(7335):447.

Olsen SF, Sorensen JD, Secher NJ, Hedegaard M, Henriksen TB, Hanse HS, Grant A. 1992. Randomized controlled trial of effect of fish-oil supplementation on pregnancy duration. Lancet. 339:1003-1007.

O'Neill S, West J, and Hoemann J. 1998. Spatial Trends in the Concentration of Polychlorinated Biphenyls (PCBs) in Chinook (*Oncorhynchus tshawytscha*) and Coho Salmon (*O. kisutch*) in Puget Sound and Factors Affecting PCB Accumulation: Results from the Puget Sound Ambient Monitoring Program. Puget Sound Research 1998. Available at URL http://www.psat.wa.gov/Publications/98_proceedings/pdfs/2b_oneill.pdf.

O'Neill S. 2004, 2005, 2006. Personal communication. Washington State Department of Fish and Wildlife.

O'Neill S and West J. 2006. Contaminant Accumulation in Puget Sound Fishes: Key Findings of the Puget Sound Assessment and Monitoring Program. Draft Technical Briefing. Washington State Department of Fish and Wildlife, Olympia, WA. O'Neill, S. 2006. Personal communication. Washington State Department of Fish and Wildlife.

Puget Sound Estuary Program. 1989a. (revised). Recommended guidelines for measuring organic compounds in Puget Sound sediment and tissue samples. *In* Recommended Protocols and Guidelines for Measuring Selected Environmental Variables in Puget Sound. Prepared by PTE Environmental Services, Bellevue, WA. For U.S. Environmental Protection Agency, Region 10, Seattle, AQ. (Looseleaf).

Puget Sound Estuary Program. 1989b. (revised). Recommended guidelines for measuring inorganic compounds in Puget Sound sediment and tissue samples. *In* Recommended Protocols and Guidelines for Measuring Selected Environmental Variables in Puget Sound. Prepared by PTI Environmental Services, Bellevue, WA. For U.S. Environmental Protection Agency, Region 10, Seattle, WA. (Looseleaf).

Rand G. 1995. Fundamentals of Aquatic Toxicology. 2nd Edition. Taylor and Francis.

Rembold 2004. Health benefits of eating salmon. Science. 305(5683):475.

Rodriguez BL, Sharp DS, Abbott RD, Burchfield CM, Masaki K, Chyou PH, Huang B, Yano K, and Curb JD. 1996. Fish intake may limit the increase in risk of coronary heart disease morbidity and mortality among heavy smokers: The Honolulu Heart Program. Circulation. 94:952-956.

Ruggerone G. 2005. Personal communication. Natural Resources Consultants, Inc.

Ryan JJ, Lau PY, Pilon JC, Lewis D, McLeod HA, Gervals A. 1984. Incidence and levels of 2,3,7,8-tetrachlorodibenzo-p-dioxin in Lake Ontario commercial fish. Environ Sci Technol. 18:719-721.

SACN 2004. Advice on fish consumption: benefits and risks. Scientific Advisory Committee on Nutrition. TSO. United Kingdom. 204 pgs.

Sakamoto M, Kubota M. Liu SJ, Murata K, Nakai K, and Satoh H. 2004. Maternal and Fetal Mercury and n-3 Polyunsaturated Fatty Acids as a Risk and Benefit of Fish Consumption to Fetus. Environ. Sci. Technol. 2004. 38:3860-3863.

San Giovanni JP, Partra-Cabrera S, Colditz GA, Berkey CS and Dwyer JT. 2000. Meta-analysis of dietary essential fatty acids and long-chain polyunsaturated fatty acids as they relate to visual resolution acuity in healthy preterm infants. Pediatrics. 105:1292-1298.

Schantz S, Widholm J, and Rice D. 2003. Effects of PCB Exposure on Neuropsychological Function in Children. Environmental Health Perspectives. Vol. 111(3):357-376.

Simon JA, Hodgkins ML, Browner WS, Neuhaus, JM, Bernert JT Jr, and Hulley SB. Serum fatty acids and the risk of coronary heart disease. Am J Epidemiol. 142:469-76.1995.

Singh RB, Niaz MA, Sharma JP, Kumar R, Rastogi V, and Moshiri M. 1997. Randomized, double-blind, placebo-controlled trial of fish oil and mustard oil in patients with suspected acute myocardial infarction: the Indian experiment of infarct survival-4. Cardiovasc Drugs Ther. 11, 485-491.

Stow CA, Carpenter SR, and Amrhein JF. 1994. PCB concentration trends in Lake Michigan coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50: 1384-1390.

Stow, CA, Carpenter SR, Eby LA, Amrhein JF, Hesselberg RJ. 1995. Evidence that PCBs are approaching stable concentrations in Lake Michigan fishes. Ecological Applications. 5(1):248-260.

Strickland R. 1983. The Fertile Fjord. Plankton in Puget Sound. Puget Sound Books. Washington Sea Grant. University of Washington Press. Seattle, London.

Suquamish 2000. Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservation, Puget Sound Region. The Suquamish Tribe, Port Madison Indian Reservation, Fisheries Department, Suquamish, WA. August 2000.

Toy KA, Polissar NL, Liao S, and Gawne-Mittelstaedt GD. 1996. A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region. Tulalip Tribes, Natural Resources Department, Marysville, WA. October 1996.

Tuomisto JT, Tainio M, Niittynen M, Verkasalo P, Vartiainen T, Kiviranta H, and Pekkanen J. 2004. Risk-benefit analysis of eating farmed salmon. Science. 305(5683):476-7.

West, J, O'Neill S, Lippert G, and Quinnell S. 2001. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington: Results of the Puget Sound Assessment Monitoring Program fish component, 1989 – 1999. Technical Report FTP01-14, Washington Department of Fish and Wildlife, Olympia, WA.

Williams C, Birch EE, Emmett PM, Northstone K. 2001. Longitudinal Study of Pregnancy and Childhood Study Team. Stereoacuity at age 3.5 y in children born full-term is associated with prenatal and postnatal dietary factors: a report from a population-based cohort study. Am J Clin Nutr. 73:316-322.

Ylitalo GM, Buzitis J, and Krahn MM. 1999. Analyses of tissues of eight marine species from Atlantic and Pacific coasts for dioxin-like chlorobiphenyls (CBs) and total CBs. Arch Environ Contam Toxicol. 37(2):205-19.

Yuan JM, Ross RK, Gao YT and Yu MC. 2001. Fish and shellfish consumption in relation to death from myocardial infarction among men in Shanghai, China. Am J Epidemiol. 154:809-16.

Zabik ME, Zabik MJ, Booren AM, Daubenmire S, Pascall M, Welch R, Humphrey H. 1995. Pesticides and total polychlorinated biphenyl residues in raw and cooked walleye and white bass harvested from the Great Lakes. Bulletin of Environmental Contamination and Toxicology. 54(3):396-402.

APPENDIX A

Description of Puget Sound Fish Species

Rockfish

Four species of rockfish from Puget Sound were assessed for contaminants. These rocky-reef fish consume a wide variety of benthic, demersal, and pelagic fish and invertebrates. They are widely distributed in the Sound and do not migrate. Thus, according to West et al. (2001), "contaminants found in their tissues are likely to reflect local conditions." Unpublished PSAMP data show that rockfish are some of the longest-lived fish in Puget Sound; quillback and yelloweye rockfish have attained ages of 60 and 90 years. Their exposure to contaminants through consumption of prey may be greater than other fish because they occupy a high position in the food web and thus biomagnify contaminants (West et al. 2001). Since rockfish are targeted by recreational anglers (Landolt et al. 1985, Landolt et al. 1987), "they represent a food-web pathway through which contaminants can move from the Puget Sound ecosystem to humans" (West et al. 2001). The following provides an overview of the individual rockfish species in Puget Sound considered in this report.

- Brown Rockfish (*Sebastes auriculatus*)


Brown Rockfish

Brown rockfish are light brown mottled with dark brown and vague dark bars across the back. Dark blotches are on the upper portion of the operculum. They have a pink or yellowish lower part of the head. Also, they can be recognized by their strong prostrate coronal spines. They are well known in Puget Sound and are widely but sparsely distributed in shallow water. The scientific name is from the Greek *sebastos* (magnificent) and the Latin *auriculatus* (eared) (Hart 1973).

- Copper Rockfish (*Sebastes caurinus*)


Copper Rockfish

Copper rockfish have a body that is variable in color with a light colored stripe along the rear. Copper rockfish have two fins on their back. They are common in many shallow water areas. They grow up to 21.5 inches and are notable for their dark fins. The scientific name is from the Greek *sebastos* (magnificent) and the Latin *caurinus* (northwest) (Hart 1973).

- Quillback Rockfish (*Sebastes maliger*)


Quillback Rockfish

Quillback rockfish have a brown body and a high fin on the back, both with yellow mottling. They may have freckles on the head and throat and have spines on the head. The length of quillback rockfish is up to 24 inches, and they are distributed from central California to southeast Alaska or Gulf of Alaska. They live in inlets and in shallow rockpiles in the northern part of their range. The scientific name is from the Greek *sebastos* (magnificent) and the Latin *malus* (mast) and *gero* (bear) (Hart 1973).

- Yelloweye Rockfish (*Sebastes ruberrimus*)

Yelloweye Rockfish

Yelloweye rockfish are large and are orange-red to yellow in body color. They have a bright yellow eye and their fins may be tinged with black. Other names for the yelloweye are rasphead rockfish and red snapper. In very large fish there may be black mottling around the head. They are caught by most kinds of fishing gear and because they have a swim bladder, as with most rockfish, are killed by pressure change when brought to the surface. Yelloweye rockfish are known to eat crustaceans and lingcod spawn. They are distributed from Ensenada in Baja California, north to the Gulf of Alaska, and are common around reefs in both inside and outside waters. The scientific name is from the Greek *sebastos* (magnificent) and the Latin *ruberrimus* (very red) (Hart 1973).

English sole (*Parophrys vetulus*)

English Sole

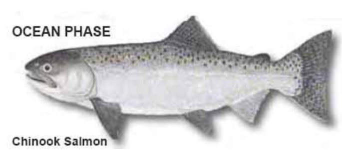
English sole and other flatfish are bottom-dwelling and have a close association with sediments. They consume benthic invertebrates that live in bottom sediments and thus represent a food-web pathway whereby sediment associated contaminants can move from sediments to humans. English sole have a small-mouth and primarily consume clams and clam siphons, other small mollusks, marine worms, small crabs and shrimp, and brittle stars. Consumption studies have shown that English sole are caught and consumed by anglers in Puget Sound (Landolt et al. 1987, Toy et al. 1996). English sole are widely distributed throughout Puget Sound.

English sole have a highly asymmetrical and compressed body with both eyes on the right side. The head is slender, pointed and asymmetrical. Color on the eyed side is in shades of uniform brown.

In early life, sole are found in the intertidal zone and in shallow water. As they grow they move into deeper water. Seasonally, they usually concentrate in shallow water in spring and in deeper water in winter. Studies have shown that major stocks are segregated or isolated. English sole are distributed along coastal waters or the heads of inlets from Baja California to Unimak Island in western Alaska. The scientific name is from the Greek *para* (near) and *ophrys* (eyebrow – narrow interorbital space), and *vetulus* (old man) (Hart 1973).

Salmon

Chinook (*Oncorhynchus tshawytscha*)



Chinook Salmon

Chinook salmon are the largest of the five Pacific salmon species which is why they are also known as "king" salmon. When mature, the Chinook salmon averages about 36 inches in length (range: 16 – 60) and weighs about 22 pounds (range: 2.5 – 125) (Wydoski and Whitney

1979). Chinook are the least abundant salmon on the Pacific coast. They are most abundant in large streams and consequently have suffered most from dam construction. Puget Sound

Chinook salmon are listed as threatened in a recent Endangered Species Act status report on West Coast salmon and steelhead (updated final listing determination as of June 28, 2005).

Chinook salmon are found along the Pacific coast from the Ventura River in southern California to Point Hope, Alaska. Spawning adults are found in most of the larger streams of the upper and lower Columbia River drainage, Washington coastal drainage, and the Puget Sound drainage.

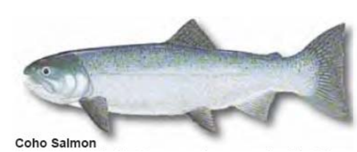
The color of marine adults along the back, top of the head, and upper sides is iridescent green to blue-green with gold flecking or sheen. The body below the lateral line is silvery, and the back upper sides and all fins have at least a few black spots. The lower gums are also black (Scott and Crossman 1973). The body is streamlined and deeper than other species with the head about 20% of total length.

Juvenile Chinook salmon spend about a year in fresh water before smolting and migrating to the Pacific Ocean. Feeding fish generally remain in the ocean from 3 to 4 years (range: 2 - 8 years) before they mature and return to their parent streams to spawn. Females are usually 4 or 5 years old (Scott and Crossman 1973). Adults begin to ascend coastal streams in late May and early June. Principal spawning months are July through September. Fish from the early run are referred to as spring Chinook and spawn in late summer, while fall Chinook migrate up streams in August and September and spawn as soon as spawning grounds are reached. Juveniles remain in fresh water from a few days to 3 years. Usually, juvenile fall Chinook feed for a short time then migrate to the ocean, while most juvenile spring Chinook remain in the stream for one year before migrating. Some individuals may stay in fresh water for longer periods before going to sea, especially in systems with lakes (such as the Lake Washington system) (Wydoski and Whitney 1979).

Young Chinook salmon feed on small invertebrates in fresh and salt water. In fresh water, summer food is primarily aquatic insect larvae and terrestrial insects. In salt water young Chinook feed on small crustaceans and other bottom items. In an Oregon study, maturing Chinook fed mostly on fish such as herring, anchovies, pilchard, sand lance, rockfish, and ratfish. Other food included crab larvae, euphausids, and shrimp.

Oncorhynchus means hooked snout, while *tshawytscha* is the common name of this species in Kamchatka. Common names include Chinook, spring, king, and tyee (Scott and Crossman 1973).

Coho (*Oncorhynchus kisutch*)



Coho salmon are fourth in abundance among the Pacific salmons but provide most of the sport harvest (Wydoski and Whitney 1979). They are taken by hooks more readily when they are concentrating on a fish diet. Adults are caught commercially by trolling, purse seining, and gillnetting from July to September, with a peak in August (Scott and Crossman 1973). Marine anglers catch coho from July to October in the Pacific Northwest. Puget Sound/Strait of Georgia coho salmon are listed as a species of concern in a recent Endangered Species Act status report on West Coast salmon and steelhead (updated final listing determination as of June 28, 2005).

Coho salmon have an elongated body with a large terminal mouth directed forward. Their color is metallic blue on the dorsal surface, silvery on the sides, ventral surface and the caudal peduncle. They have irregular black spots on the back and upper lobe of the caudal fin, a primary key to recognition, along with no black along the base of their needlelike and firmly set teeth. Maturing males in fresh water have bright red on the sides, bright green on the back and head, and are often dark on the belly. Females are less strongly colored. The flesh of coho is pink to red.

Coho occur along the Pacific coast from Monterey Bay, California, to Point Hope, Alaska. Spawning adults are found in most streams of the upper and lower Columbia River drainage, Washington coastal drainage, and the Puget Sound drainage. Coho from the Puget Sound drainage do not go south of the Columbia River or north of Vancouver Island. Coho are anadromous and spawn in fresh water where the young spend from 1 to 2 years before becoming smolts and migrating to the ocean. These salmon usually remain in the ocean for about 18 months before maturing and returning to their stream of origin for spawning. Spawning occurs from September through December, although a late run of large fish spawns in January in the Satsop River, Washington. All coho die after spawning. The young hatch in about 6 to 8 weeks, depending on water temperature.

Juvenile coho grow to about 4 – 7 inches before they become smolts and migrate to the ocean. While in the ocean for 1 – 2 years, coho may reach a length of 38 inches and a weight of 31 pounds. Most adults weigh between 8 to 12 pounds when they return to their parent streams at the end of their life cycle (Wydoski and Whitney 1979).

In reservoirs, juvenile coho feed primarily on zooplankton and emerging insects. In streams, juveniles feed primarily on insects such as Diptera, mayflies, and stoneflies and also on sockeye salmon fry. Food of marine adults is more varied than that of many Pacific salmon (Scott and Crossman 1973). While at sea, coho feed primarily on fish such as herring, pilchard, anchovies, sand lance, rockfish, and ratfish, and invertebrates such as crab larvae, euphausid shrimp, other shrimp, and squid.

The name *Oncorhynchus* means hooked snout. *Kisutch* is the vernacular name for this species in Kamchatka, Russia. Common names are coho salmon, coho, silver salmon, and blueback (Scott and Crossman 1973).

References

Endangered Species Act Listings. www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Index.cfm

Hart JL. 1973. Pacific Fishes of Canada. Bulletin 180. Fisheries Research Board of Canada. Ottawa.

Landolt M, Hafer F, Nevissi A, van Belle G, Van Ness K, and Rockwell C. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. Rockville, MD.

Landolt M, Kalman D, Nevissi A, van Belle G, Van Ness K, and Hafer F. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: Final Report. NOAA Technical Memorandum NOS OMA 33. Rockville, MD.

Scott WB and Crossman EJ. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. Ottawa.

Toy KA, Polissar NL, Liao S, and Gawne-Mittelstaedt GD. 1996. A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region. Tulalip Tribes, Natural Resources Department, Marysville, WA. October 1996.

West J, O'Neill S, Lippert G, and Quinnell S. 2001. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington: Results of the Puget Sound Assessment Monitoring Program fish component, 1989 – 1999. Technical Report FTP01-14, Washington Dept. of Fish and Wildlife, Olympia, WA.

Wydoski R and Whitney R. 1979. Inland fishes of Washington. University of Washington Press. Seattle and London. 220 pgs.

APPENDIX B

Toxicological Profiles for Contaminants of Concern: Mercury and Polychlorinated biphenyls (PCBs)

Washington State Department of Fish and Wildlife (WDFW) analyzed numerous chemicals in fish muscle tissue as part of the Puget Sound Assessment and Monitoring Program (West et al. 2001). All chemicals were found on the U.S. EPA Priority Pollutant List or Hazardous Substance List and included chlorinated pesticides, polychlorinated biphenyls (PCBs), other organic compounds (phenols and substituted phenols, aromatic hydrocarbons, chlorinated aromatic hydrocarbons, phthalates, and others), and metals such as mercury, lead, copper and arsenic. Of these compounds, only PCBs and mercury were detected regularly at levels high enough to indicate the need for an assessment for human health risk as indicated by the screening process (Appendix E). The following is a synopsis of background information on mercury and PCBs from ATSDR documents, EPA IRIS, and journal articles.

Mercury

Background

Mercury is widespread in the environment as a result of natural and anthropogenic releases. Everyone is exposed to small amounts of mercury over the course of a lifetime (Clarkson 1993, and Clarkson 1997, in Goldman and Shannon, 2001). Most atmospheric mercury is elemental mercury vapor and inorganic mercury, and mercury present in water, soil, plants and animals is typically present in organic or inorganic forms. Organic mercury is primarily in the form of methlymercury.

Mercury is released into surface waters from natural weathering of rocks and soils and from volcanic activity. Mercury is also released from human action such as industrial activities, fossil fuel burning, and disposal of consumer products (i.e., mercury thermometers, fluorescent bulbs, dental amalgams). Global cycling of mercury via air deposition occurs when mercury evaporates from soils and surface waters to the atmosphere. From the atmosphere, mercury is redistributed on land and surface water then absorbed by soil or sediments. Once inorganic mercury is released into the environment, bacteria convert it into organic mercury, which is the primary form that accumulates in fish and shellfish (ATSDR 1999).

Exposure

In the aquatic food chain, methylmercury biomagnifies as it is passed from lower to higher trophic levels through consumption of prey organisms. Fish at the top of the food chain can biomagnify methylmercury approximately 1 to 10 million times greater than concentrations in surrounding waters. Nearly all of the mercury found in fish and other aquatic organisms is in the methylmercury form. Long-lived predatory ocean fish may have increased methylmercury content because of exposure to natural and industrial sources of mercury (Goldman and Shannon 2001). Methylmercury content of fish varies by species and size of the fish as well as harvest location. The top ten commercial fish species (canned tuna, shrimp, pollock, salmon, cod, catfish, clams, flatfish, crabs, and scallops) represent about 85% of the seafood market and contain a mean mercury level of approximately 0.1 ug/g (Goldman and Shannon 2001).

Some states have issued advisories about consumption of fish containing mercury. DOH issued a statewide fish consumption advisory for women of childbearing age and young children based on elevated levels of mercury in various commercially purchased fish as well as freshwater bass caught for recreation (DOH 2003) (http://www.doh.wa.gov/fish).

Toxicity

Most organic mercury compounds are readily absorbed by ingestion and appear in the lipid fraction of blood and brain tissue. Organic mercury readily crosses the blood-brain barrier and also crosses the placenta. Fetal blood mercury levels are equal to or higher than maternal levels (Goldman and Shannon 2001). Methylmercury also appears in human milk. Organic mercury compounds are most toxic in the central nervous system and may also affect the kidneys and immune system (Clarkson 1993, and Clarkson 1997, in Goldman and Shannon, 2001).

Methylmercury is toxic to the cerebral and cerebellar cortex in the developing brain and is a known teratogen. In Minamata Bay, Japan, mothers who were exposed to high amounts of mercury but were asymptomatic gave birth to severely affected infants. The infants often appeared normal at birth but developed psychomotor retardation, blindness, deafness, and seizures over time. Since the fetus is susceptible to neurotoxic effects of methylmercury, several studies have focused on subclinical effects among children whose mothers were exposed to high levels of methylmercury. A study in the 1970s of Iraqi children exposed to high levels of methylmercury in contaminated seeds demonstrated motor retardation in children whose mothers had hair mercury levels in the range of 10-20 ppm. Two prospective epidemiologic studies were conducted in the Seychelles and the Faroe Islands. Results from the Faroe Islands suggest that exposure *in utero* to mercury at lower levels is associated with subtle adverse effects on the developing brain (maximum level in hair was 39.1 ppm and in blood was 351 ppb). Memory, attention, and language tests were inversely associated with higher methylmercury exposures in children up to 7 years of age (Grandjean et al. 1997, in Goldman and Shannon 2001). In the Seychelles study, adverse effects on development or IQ have not been found up to 66 months of age. The Faroe Islands and Seychelles studies are continuing in order to provide a long-term developmental evaluation of exposed children. Further support for the developmental effects seen in Faroese children is demonstrated in a study of New Zealand children exposed *in utero* to methylmercury in fish consumed by their mothers.

In 1998, the National Academy of Sciences (NAS) was directed by the United State's Congress to evaluate methylmercury toxicity and provide recommendations on exposure limits (NRC 2000). The study established a reference dose for mercury of 0.1ug/kg-day (ug/kg = ppb). EPA has recently reconfirmed 0.1 ug/kg/day as its Reference Dose (RfD) (EPA IRIS 2003). This RfD is based on health effects data specific to the protection of the developing fetus. As the developing fetus represents the population of greatest concern, the RfD is considered protective of all other populations that are less exposed and/or less sensitive. The current action level of FDA for mercury in fish tissue is 1 ppm (1000 ppb). While FDA has not changed the 1.0 ppm action level in a recent reassessment, the agency is re-evaluating it in light of significant new data on the health effects of methylmercury from consumption of fish. These data have become available since the action level was developed.

Polychlorinated Biphenyls (PCBs)

Background

Polychlorinated Biphenyls (PCBs) are persistent environmental contaminants that are ubiquitous in the environment due to intensive industrial use. PCBs were used as commercial mixtures (Aroclors) that contain up to 209 different chlorinated biphenyl congeners, which are structurally similar compounds that vary in toxicity. A smaller subset of 50 to 60 congeners is commonly found in Aroclor mixtures (NRC 2001). Each congener has a biphenyl ring structure but differs in the number and arrangement of chlorine atoms substituted around the biphenyl ring. PCBs are lipid soluble and very stable; their stability depends on the number of chlorine atoms and their position on the biphenyl molecule. PCBs' lipophilic character and resistance to metabolism enhances concentration in the food web and exposure to humans and wildlife.

The name Aroclor 1254, for example, means that the molecule contains 12 carbon atoms (the first 2 digits) and approximately 54% chlorine by weight (second 2 digits) (ATSDR 2000). Each mixture (1016, 1242, 1254, and 1260) contained many different PCB congeners. In 1971, the sole U.S. producer of PCBs (Monsanto Chemical Company) voluntarily stopped open-ended uses of PCBs and in 1977 ceased their production. Because PCBs do not burn easily and are good insulators, they were commonly used as lubricants and coolants in capacitors, transformers, and other electrical equipment. Old capacitors and transformers that contain PCBs are still in operation. Over the years, PCBs have been spilled, illegally disposed, and leaked into the environment from transformers and other electrical equipment. PCBs in the environment have decreased since the 1970's but are still detectable in our air, water, soil, food, and in our bodies.

The breakdown of PCBs in water, sediment, and soil occurs over many years and is often incomplete. Lower chlorinated PCBs are more easily broken down in the environment, while adsorption of PCBs generally increases as chlorination of the compound increases. The highly chlorinated Aroclors (1248, 1254, and 1260) resist both chemical and biological degradation in the environment. Microbial degradation of highly chlorinated Aroclors to lower chlorinated biphenyls has been reported under anaerobic conditions, as has the mineralization of biphenyl and lower chlorinated biphenyls by aerobic microorganisms. Although they are slow processes, volatilization and biodegradation are the major pathways of removal of PCBs from water and soil (ATSDR 2000), and volatilization is more significant for lower chlorinated congeners. In water, photolysis appears to be the only viable chemical degradation process. The chemical composition of the original Aroclor mixtures released to the environment changes over time since the individual congeners degrade and partition at different rates (ATSDR 2000).

Many PCB congeners persist in ambient air, water, marine sediments, and soil at low levels throughout the world. The half-life of PCBs (the time it takes for one-half of the PCBs to breakdown) in the air is 10 days or more, depending on the type of PCB. PCBs in the air can be carried long distances and may be deposited onto land or water. Once in water, most PCBs tend to adsorb to organic particles and sediments. The rate and extent of degradation is a function of temperature and the degree to which PCBs are bound to organic material and hence unavailable for degradation.

In Puget Sound and other waterbodies, sediment-associated PCBs are accumulated in the bodies of aquatic organisms, which are in turn consumed by creatures higher in the food web. Fish, birds, and mammals tend to accumulate certain congeners over time in their fatty tissue. Concentrations of PCBs can reach levels hundreds of thousand times higher than the levels in water. Bioconcentration is the uptake of a chemical from water alone, while bioaccumulation is the result of combined uptake via food, sediment, and water. These processes can lead to high levels in the fat of predatory animals (ATSDR 2000). Also, PCBs can biomagnify in fresh and saltwater ecosystems. Humans may be exposed to detectable quantities of PCBs when they eat fish, use fish oils in cooking, or consume meat, milk or cheese; the half life of PCBs in humans is estimated to be 2 – 6 years (Shirai and Kissel 1996).

Exposure

The general population is exposed to PCBs by inhaling contaminated air and ingesting contaminated water and food. The dominant source of PCBs to humans is through consumption of meat, seafood, and poultry (Figure 10, main report). Of particular concern to this report is the exposure to citizens from consumption of fish. Some groups may consume greater amounts of fish than others; for example, Native Americans, Asian immigrant populations, and sport anglers are three groups with high rates of seafood ingestion in the Puget Sound area (Landolt et al. 1985, Landolt et al. 1987, Toy et al. 1996, EPA 1999, Suquamish 2000). Further, numerous studies have found PCBs in local seafood (Landolt et al. 1987, PSAMP 1997, O'Neill et al. 1998, West and O'Neill 1998, PSAMP 2000, O'Neill and West 2001, West et al. 2001).

Toxicity

Toxic responses to PCBs include dermal toxicity, immunotoxicity, carcinogenicity, and adverse effects on reproduction, development, and endocrine functions. Several epidemiological studies indicate that consumption of background levels of PCBs may cause slight but measurable impairments in physical growth and learning behavior in children while others have not. Some PCB congeners have a structure and biological activity that is similar to dioxin.

Dioxins are a family of chemicals produced by incomplete burning of organic material through natural and industrial processes (DOH 2003). Like PCBs, dioxins (and a very similar family of chemicals called furans) are persistent in the environment and have been shown to be toxic through a particular mechanism shared by certain PCB congeners. Toxic equivalency factors (TEFs) are used to account for the potential of these PCB congeners to exert dioxin-like toxicity. TEFs are available for twelve dioxin-like PCB congeners (Van den Berg et al. 1998). The larger the TEF, the more toxic the PCB congener is. Each congener is multiplied by its TEF to give the dioxin toxic equivalent value (TEQ). The TEQs for each congener are then summed to give the overall PCB-TEQ. TEFs for each congener are based on the toxicity of one well studied dioxin congener known as 2,3,7,8-tetrachlorodibenzo-p-dioxin.

EPA has determined that PCBs are probable human carcinogens and assigned them the cancer weight-of-evidence classification B2 based on animal studies. Human studies are being updated; current available evidence is inadequate but suggestive regarding cancer to humans. The upper-bound cancer slope factor for PCBs is 2.0 $(mg/kg/day)^{-1}$.

Part of the uncertainty in assessing PCB effects from consuming fish is that PCB congeners selectively bioaccumulate in fish in different patterns than found in commercial mixtures of PCBs or in the environment (Schwartz et al. 1983). Another issue is how to combine cancer risks computed using PCB cancer potency factors based on Aroclors with cancer risks computed using TEFs for dioxin-like PCBs. The congener mix encountered by a fetus during pregnancy and via nursing may be quite different than congener patterns initially released into the environment. Since PCB congeners differ in their potency and in the specific ways they interact with biological systems, health criteria based on data from Aroclor mixtures fed to animals (e.g., the EPA RfD) may not account for biodegradation or selective accumulation by an organism. EPA has addressed this uncertainty by a policy decision to use an upper bound, health-protective estimate of the PCB cancer potency factor when computing cancer risks for PCBs found in fish tissue (EPA 1996). Some information on pattern changes is available from studies in the Great Lakes (Kostyniak et al. 1999, Humphrey et al. 2000. This issue is being investigated at a national and international level.

DOH recently conducted a thorough review of the scientific literature on PCB toxicity in an attempt to set a state standard for PCB exposure through consumption of fish and shellfish. DOH concluded that ATSDR's MRL of 0.02 ug/kg/day for chronic-duration oral exposure to PCBs would be protective of the most sensitive population (fetus) for the most sensitive endpoints reviewed (immune and developmental). The chronic oral MRL is based on a lowest observed adverse effect level (LOAEL) of 0.005 mg/kg-day for immunological effects seen in adult monkeys' exposure to Aroclor 1254 (ATSDR 2000). EPA verified an oral reference dose (RfD) of 0.02 ug/kg-day for Aroclor 1254 (IRIS 2000), based on dermal/ocular and immunological effects in monkeys.

References

ATSDR. 1999. Toxicological Profile for Mercury. U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. March 1999.

ATSDR. 2000. Toxicological Profile for Polychlorinated Biphenyls (PCBs). U.S. Department of Health and Human Services, Public Health Service. Agency for Toxic Substances and Disease Registry. November 2000.

Clarkson TW. 1993. Mercury: major issues in environmental health. Environ Health Perspect. 100:31-8.

Clarkson TW. 1997. The Toxicology of Mercury. Crit Rev Clin Lab Sci. 34(4):369-403.

DOH 2003. Statewide Bass Advisory. September 2003. http://www.doh.wa.gov/ehp/oehas/publications%20pdf/statewide_%20bass_%20advisory-2003.pdf.

EPA. IRIS – Integrated Risk Information System. http://www.epa.gov/iris/index.html.

EPA. 1986. *Guidelines for Carcinogen Risk Assessment*. U.S. Environmental Protection Agency, Office of Research and Development. 51 Federal Register 33992 (September 24, 1986).

EPA. 1996. *Proposed Guidelines for Carcinogen Risk Assessment*. U.S. Environmental Protection Agency, Office of Research and Development. April 1996. EPA/600/P-92/003C.

EPA. 1996. PCBs: Cancer Dose-Response Assessment and Application to Environmental Mixtures. National Center for Environmental Assessment, Office of Research and Development. EPA/600/P 96/001F.

EPA. 1999. Asian and Pacific Islander Seafood Consumption Study in King County, WA. U.S. Environmental Protection Agency, Office of Environmental Assessment. May 1999. EPA 910/R-99-003.

Goldman LR and Shannon MW. 2001. Technical Report: Mercury in the Environment: Implications for Pediatricians. Pediatrics. 108:197-205.

Grandjean P, Weihe P, White R, Debes F, Araki S, Yokoyama K, Murata K, Sorensen N, Dahl R, and Jorgensen P. 1997. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. Neurotoxicol. Teratol. 19(6):417-428.

Humphrey H, Gardiner J, Pandya J, Sweeney A, Gasior D, McCaffrey R, and Schantz S. 2000. PCB congener profile in the serum of humans consuming Great Lakes fish. Environ. Health Perspect. 108(2):167-72.

Kostyniak P, Stinson C, Greizerstein H, Vena J, Buck G, and Mendola P. 1999. Relation of Lake Ontario fish consumption, lifetime lactation, and parity to breast milk polychlorobiphenyl and pesticide concentrations. Environ. Res. 80(2):S166-S174.

Landolt M, Hafer F, Nevissi A, van Belle G, Van Ness K, and Rockwell C. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. Rockville, MD.

Landolt M, Kalman D, Nevissi A, van Belle G, Van Ness K, and Hafer F. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: Final Report. NOAA Technical Memorandum NOS OMA 33. Rockville, MD.

NRC. 2000. Toxicological Effects of Methylmercury. Committee on the Toxicological Effects of Methylmercury, Board on Environmental Studies and Toxicology, Commission on Life Sciences. National Academy of Science National Research Council. National Academy Press. 2000.

NRC. 2001. A Risk Management Strategy for PCB Contaminated Sediments. National Research Council. National Academy Press. Washington D.C.

O'Neill S, West J, and Hoeman J. 1998. Spatial trends in the concentration of polychlorinated biphenyls (PCBs) in Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in Puget Sound and factors affecting PCB accumulation: results from the Puget Sound Assessment Monitoring Program. In R. Strickland (editor). Proceedings of the 1998 Puget Sound Research Conference. Puget Sound Water Quality Action Team, Olympia, WA.

O'Neill S, and West J. 2001. Exposure of Pacific herring (*Clupea pallasi*) to persistent organic pollutants in the Puget Sound and the Georgia Basin. Puget Sound Research '01 Proceedings. Puget Sound Water Quality Action Team, Seattle, WA.

PSAMP 1997. Draft. Summary report of contaminants in Puget Sound fishes and factors affecting contaminant uptake and accumulation. Puget Sound Assessment Monitoring Program, Fish Monitoring Component, Marine Resources Division, Washington Dept. of Fish and Wildlife, Olympia, WA.

PSAMP 2000. Toxic Contaminants in Fish. In 2000 Puget Sound Update: Seventh Report of the Puget Sound Assessment Monitoring Program. Puget Sound Water Quality Action Team. Olympia, WA.

Schwartz P, Jacobson W, Fein G, Jacobson J, and Price H. 1983. Lake Michigan fish consumption as a source of polychlorinated biphenyls in human cord serum, maternal serum, and milk. Am. J. Public Health. 73(3):293-6.

Shirai JH and JC Kissel. 1996. Uncertainty in estimated half-lifes of PCBs in humans: impact on exposure assessment. Science of the Total Environment. 187:199-210.

Suquamish 2000. Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservation, Puget Sound Region. The Suquamish Tribe, Port Madison Indian Reservation, Fisheries Department, Suquamish, WA. August 2000.

Toy KA, Polissar NL, Liao S, and Gawne-Mittelstaedt GD. 1996. A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region. Tulalip Tribes, Natural Resources Department, Marysville, WA. October 1996.

Van den Berg M, Birnbaum L, Bosveld AT, Brunstrom B, Cook P, Feeley M, Giesy JP, Hanberg A, Hasegawa R, Kennedy SW, Kubiak T, Larsen JC, van Leeuwen FX, Liem AK, Nolt C, Peterson RE, Poellinger L, Safe S, Schrenk D, Tillitt D, Tysklind M, Younes M, Waern F, Zacharewski T. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ Health Perspect. 106(12):775-92.

West J and O'Neill S. 1998. Persistent Pollutants and Factors Affecting their Accumulation in Rockfishes (*Sebastes* spp.) from Puget Sound, Washington. In R. Strickland (editor). Puget Sound Research '98 Proceedings. Puget Sound Water Quality Action Team, Seattle, WA.

West J, O'Neill S, Lippert G, and Quinnell S. 2001. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington: Results of the Puget Sound Assessment Monitoring Program fish component, 1989-1999. Technical Report FTP01-14, Washington Dept. of Fish and Wildlife, Olympia, WA.

APPENDIX C

Health Risk Estimates for Consumption of Puget Sound Fish

Introduction

The following tables present non-cancer and cancer risk estimates for consumption of Puget Sound fish species by Native Americans, Asian and Pacific Islander communities and recreational anglers. Estimates are provided for individual sampling stations based on site-specific contaminant levels. Contaminants of concern include mercury and polychlorinated biphenyls (PCBs). Average and upper-bound exposure scenarios were evaluated using the following equations and exposure assumptions to estimate contaminant doses associated with fish consumption (Table C1).

$$\text{Dose}_{\text{(non-cancer (mg/kg-day))}} = \frac{C \times IR \times CF \times EF \times ED}{BW \times AT_{\text{non-cancer}}}$$

$$\text{Dose}_{\text{(cancer (mg/kg-day))}} = \frac{C \times IR \times CF \times EF \times ED}{BW \times AT_{\text{cancer}}}$$

Table C1. Exposure assumptions.

Parameter		Value		Unit	Comments
Concentration (C)		Species - specific		mg/kg	Average detected chemical value in fish from Puget Sound sampling stations.
Chinook Ingestion Rate (IR)	Suquamish [a]	14.00	40.67	g/day	Suquamish 2000
	Tulalip [a]	9.10	20.30		Toy et al. 1996
	Squaxin [a]	18.69	33.32		Toy et al. 1996
	API [a]	12.10	30.50		EPA 1999
	Recreational Angler [b]	51.7	NA		Landolt et al. 1987
Coho Ingestion Rate (IR)	Suquamish [a]	13.37	40.88		Suquamish 2000
	Tulalip [a]	12.46	36.05		Toy et al. 1996
	Squaxin [a]	14.14	34.37		Toy et al. 1996
	API [a]	12.10	30.50		EPA 1999
	Recreational Angler [b]	21.60	NA		Landolt et al. 1987
E. sole Ingestion Rate (IR) Urban, near-urban, non-urban	Suquamish [a]	3.64	14.07		Suquamish 2000
	Tulalip [a]	4.27	10.43		Toy et al. 1996
	Squaxin [a]	4.34	3.08		Toy et al. 1996
	API [a]	7.50	16.30		EPA 1999
	Recreational Angler [b]	11.0	NA		Landolt et al. 1985
Copper , Brown, and Quillback Rockfish Ingestion Rate (IR)	Suquamish [a]	11.83	50.96		Suquamish 2000
	Tulalip [a]	1.26	2.38		Toy et al. 1996
	Squaxin [a]	3.92	10.29		Toy et al. 1996
	API [a]	22.90	49.70		EPA 1999
	Recreational Angler [b, c]	8.4	NA		Landolt et al. 1985

Table C1. (cont.) Exposure assumptions.

Parameter	Value	Unit	Comments
Conversion Factor (CF)	0.001	kg/g	Converts mass of fish from grams (g) to kilograms (kg)
Exposure Frequency (EF)	365	days/year	Assumes daily exposure consistent with units of ingestion rate given in g/day.
Exposure Duration (ED) – Adult	30	years	Number of years living in Puget Sound region (EPA 1997a).
Exposure Duration (ED) – Native American Adult	70	years	Number of years living in Puget Sound region
Body Weight (BW) – Adult	70	kg	EPA 1997b
Averaging Time$_{non\text{-}cancer}$ (AT)	10950	days	30 years
Averaging Time$_{non\text{-}cancer}$ (AT) – Native American	20075		70 years
Averaging Time$_{cancer}$ (AT)	25550		70 year lifetime
Reference Dose (RfD)	Chemical-specific	mg/kg/day	Mercury = 1e-4 (developmental) 3e-4 (immune) PCBs = 2e-5 (immune) 3e-5 (developmental) Source: EPA, ATSDR
Cancer Slope Factor (CSF)	Chemical-specific	mg/kg-day^{-1}	PCBs = 2 EPA IRIS

[a] Consumption rates were reported in grams per kg body weight per day. Consumption rate was adjusted by assuming a 70 kg body weight.

[b] Consumption rate was reported in grams per day during the fishing season. Rates used in dose calculations do not account for length of fishing season (i.e., assumes 365 day fishing season) potentially overestimating consumption.

[c] Recreational consumption rate for yelloweye rockfish is not available.

Non-cancer Risk Calculations (Hazard Quotients)

Non-cancer impacts evaluated in this assessment include developmental and immune effects from exposure to PCBs and mercury. The following tables present hazard quotients based on estimates of PCB or mercury exposure doses. A hazard quotient greater than one signifies a dose that exceeds EPA's reference dose (RfD); an RfD is a dose where no adverse non-cancer health effects are expected. The degree to which a hazard quotient exceeds one indicates the relative potential for an exposure to cause harm.

Table C2. PCB hazard quotients (HQ) based on mean and 90th percentile rockfish consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station and rockfish species).

RMA	Station	Species	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
				Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
7	Orcas Island	Quillback	**7.6**	0.1	0.3	0.0	0.0	0.0	0.1	0.1	0.3	0.0
	San Juan	Quillback	3.7	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.0
		Yelloweye	49.2	0.4	1.8	0.0	0.1	0.1	0.4	0.9	2.0	0.2
8-2	Mukilteo-Everett	Quillback	31.8	0.3	1.2	0.0	0.1	0.1	0.2	0.6	1.3	0.2
		Copper	17.6	0.1	0.6	0.0	0.0	0.0	0.1	0.3	0.7	0.1
	Port Gardner	Copper	**47.8**	0.4	1.7	0.0	0.1	0.1	0.4	0.9	2.0	0.2
9	Double Bluff	Quillback	5.4	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.0
	Foulweather	Quillback	9.9	0.1	0.4	0.0	0.0	0.0	0.1	0.2	0.4	0.0
10	Blakely Rock	Quillback	34.8	0.3	1.3	0.0	0.1	0.1	0.3	0.7	1.4	0.2
	Elliott Bay	Quillback	122	1.0	4.4	0.1	0.2	0.3	0.9	2.3	5.0	0.6
		Brown	**92.7**	0.8	3.4	0.1	0.2	0.3	0.7	1.8	3.8	0.5
	Elliott Bay 2	Quillback	293	2.5	10.7	0.3	0.5	0.8	2.2	5.6	12.1	1.4
	Elliott Bay 4	Quillback	**117**	1.0	4.3	0.1	0.2	0.3	0.9	2.2	4.8	0.6
		Brown	**30.4**	0.3	1.1	0.0	0.1	0.1	0.2	0.6	1.3	0.1
		Copper	**61.0**	0.5	2.2	0.1	0.1	0.2	0.4	1.2	2.5	0.3
	Fuller	Quillback	111	0.9	4.0	0.1	0.2	0.3	0.8	2.1	4.6	0.5
	Sinclair Inlet	Quillback	144	1.2	5.2	0.1	0.2	0.4	1.1	2.7	6.0	0.7
		Brown	326	2.8	11.9	0.3	0.6	0.9	2.4	6.2	13.5	1.6
	Sinclair Inlet 2	Copper	18.4	0.2	0.7	0.0	0.0	0.1	0.1	0.4	0.8	0.1
	Sinclair Inlet Tribal	Brown	77.4	0.7	2.8	0.1	0.1	0.2	0.6	1.5	3.2	0.4
11	Brace Point	Yelloweye	17.3	0.1	0.6	0.0	0.0	0.0	0.1	0.3	0.7	0.1
	Browns Point	Quillback	75.5	0.6	2.7	0.1	0.1	0.2	0.6	1.4	3.1	0.4
	Commence-ment Bay	Brown	**47.2**	0.4	1.7	0.0	0.1	0.1	0.3	0.9	2.0	0.2
	Commence-ment Bay 2	Brown	**43.3**	0.4	1.6	0.0	0.1	0.1	0.3	0.8	1.8	0.2
	Commence-ment Bay 4	Quillback	**128**	1.1	4.7	0.1	0.2	0.4	0.9	2.4	5.3	0.6
		Brown	**97.0**	0.8	3.5	0.1	0.2	0.3	0.7	1.8	4.0	0.5
	Commence-ment Bay 5	Quillback	**16.2**	0.1	0.6	0.0	0.0	0.0	0.1	0.3	0.7	0.1

Table C2. (cont.) PCB hazard quotients (HQ) based on mean and 90th percentile rockfish consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station and rockfish species).

RMA	Station	Species	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
		Brown	**28.7**	0.2	1.0	0.0	0.0	0.1	0.2	0.5	1.2	0.1
	Dalco Passage	Quillback	64.5	0.5	2.3	0.1	0.1	0.2	0.5	1.2	2.7	0.3
	Gig Harbor	Quillback	78.1	0.7	2.8	0.1	0.1	0.2	0.6	1.5	3.2	0.4
	Lakota	Quillback	62.8	0.5	2.3	0.1	0.1	0.2	0.5	1.2	2.6	0.3
12	Hood Canal	Quillback	7.7	0.1	0.3	0.0	0.0	0.0	0.1	0.1	0.3	0.0
		Copper	6.5	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.3	0.0
13	Day Island	Copper	8.3	0.1	0.3	0.0	0.0	0.0	0.1	0.2	0.3	0.0

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded areas indicate a HQ greater than or equal to 1.0.

Table C3. PCB hazard quotients (HQ) based on mean and 90th percentile English sole consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

RMA	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
6	Discovery Bay	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Strait of Juan de Fuca	7.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
7	Bellingham Bay (outer)	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Birch Point	5.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Cherry Point	**13.9**	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	McAurther Bank	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Orcas Island	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Outer Birch Point	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Point Roberts	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Strait of Georgia	5.8	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
	Vendovi Island	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
8-1	Saratoga Passage	20.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
8-2	Port Gardner	17.5	0.0	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1
	Port Susan	**5.5**	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
9	Possession Point	11.7	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Port Ludlow	6.7	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1
	Port Townsend	9.7	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
10	Apple Cove Point	9.8	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Duwamish	168	0.4	1.7	0.5	1.3	0.5	1.5	1.1	2.3	1.3
	Dyes Inlet	28.0	0.1	0.3	0.1	0.2	0.1	0.2	0.2	0.4	0.2
	Eagle Harbor	42.6	0.1	0.4	0.1	0.3	0.1	0.4	0.3	0.6	0.3
	Elliott Bay (Seattle Waterfront)	64.4	0.2	0.6	0.2	0.5	0.2	0.6	0.4	0.9	0.5

Table C3. (cont.) PCB hazard quotients (HQ) based on mean and 90th percentile English sole consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

RMA	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
10	Elliott Bay 2 (Harbor Island)	**85.9**	0.2	0.9	0.3	0.6	0.3	0.8	0.5	1.2	0.7
	Elliott Bay 4 (Myrtle Edwards)	**21.0**	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
	Elliott Bay 5 (Alki)	16.7	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1
	Liberty Bay	23.3	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
	Port Madison	13.3	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Port Orchard	36.8	0.1	0.4	0.1	0.3	0.1	0.3	0.2	0.5	0.3
	Sinclair Inlet	121	0.3	1.2	0.4	0.9	0.4	1.1	0.8	1.6	1.0
	Sinclair Inlet 2 (Outer Sinclair Inlet)	**22.8**	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
	Sinclair Inlet 3	**63.8**	0.2	0.6	0.2	0.5	0.2	0.6	0.4	0.9	0.5
	Sinclair Inlet 4 (Battle Point)	**38.8**	0.1	0.4	0.1	0.3	0.1	0.3	0.2	0.5	0.3
	Sinclair Inlet 5 (Blake Island)	**31.0**	0.1	0.3	0.1	0.2	0.1	0.3	0.2	0.4	0.2
	Shilshole	22.9	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
11	Commencement Bay (Thea Foss)	63.0	0.2	0.6	0.2	0.5	0.2	0.6	0.4	0.9	0.5
	Commencement Bay 2	**82.4**	0.2	0.8	0.3	0.6	0.3	0.7	0.5	1.1	0.6
	Commencement Bay 3 (Ruston)	**34.2**	0.1	0.3	0.1	0.3	0.1	0.3	0.2	0.5	0.3
	Commencement Bay 4 (Old Tacoma)	**43.2**	0.1	0.4	0.1	0.3	0.1	0.4	0.3	0.6	0.3
	Commencement Bay 5 (Brown's Point)	**55.5**	0.1	0.6	0.2	0.4	0.2	0.5	0.3	0.8	0.4
	Dash Point	28.5	0.1	0.3	0.1	0.2	0.1	0.3	0.2	0.4	0.2
	Fern Cove	19.3	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.2
	Outer Commence-ment	41.8	0.1	0.4	0.1	0.3	0.1	0.4	0.3	0.6	0.3
12	Hood Canal (North)	6.4	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1
	Hood Canal Mid (Middle)	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hood Canal South	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
13	Budd Inlet (Dana Passage)	8.8	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Carr Inlet	14.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Case Inlet 1 (South Case Inlet)	16.0	0.0	0.2	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Case Inlet 3 (North Case Inlet)	8.3	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Nisqually	21.5	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
	Pickering Passage	9.2	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Wollochet	26.3	0.1	0.3	0.1	0.2	0.1	0.2	0.2	0.4	0.2

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded areas indicate a HQ greater than or equal to 1.0.

Table C4. PCB hazard quotients (HQ) based on mean and 90th percentile Chinook consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	37.9	0.4	1.1	0.2	0.5	0.5	0.9	0.3	0.8	1.4
	Skagit	40.6	0.4	1.2	0.3	0.6	0.5	1.0	0.4	0.9	1.5
	Duwamish	57.2	0.6	1.7	0.4	0.8	0.8	1.4	0.5	1.2	2.1
	Nisqually	41.9	0.4	1.2	0.3	0.6	0.6	1.0	0.4	0.9	1.5
	Deschutes	60.4	0.6	1.8	0.4	0.9	0.8	1.4	0.5	1.3	2.2
Marine Central Sound	All Central Sound stations	75.7	0.9	2.6	0.6	1.3	1.2	2.2	0.8	2.0	3.4
	Apple Cove Point	90.8	0.9	2.6	0.6	1.3	1.2	2.2	0.8	2.0	3.4
	Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sinclair Inlet	45.5	0.5	1.3	0.3	0.7	0.6	1.1	0.4	1.0	1.7
Marine South Sound	All South Sound Stations	70.6	0.7	2.0	0.5	1.0	0.9	1.7	0.6	1.5	2.6
	Budd Inlet	55.5	0.6	1.6	0.4	0.8	0.7	1.3	0.5	1.2	2.0
	South Sound	95.7	1.0	2.8	0.6	1.4	1.3	2.3	0.8	2.1	3.5

NOTE: PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded areas indicate a HQ greater than or equal to 1.0.

Table C5. PCB hazard quotients (HQ) based on mean and 90th percentile coho consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	24.7	0.2	0.7	0.2	0.6	0.2	0.6	0.2	0.5	0.4
	Skagit	24.0	0.2	0.7	0.2	0.6	0.2	0.6	0.2	0.5	0.4
	Duwamish	39.6	0.4	1.2	0.4	1.0	0.4	1.0	0.3	0.9	0.6
	Nisqually	35.7	0.3	1.0	0.3	0.9	0.4	0.9	0.3	0.8	0.6
	Deschutes	28.3	0.3	0.8	0.3	0.7	0.3	0.7	0.2	0.6	0.4
Marine Central Sound	Agate Pass	**46.8**	0.4	1.4	0.4	1.2	0.5	1.1	0.4	1.0	0.7
	Apple Cove Point	17.3	0.2	0.5	0.2	0.4	0.2	0.4	0.1	0.4	0.3
	Colvos Passage	17.5	0.2	0.5	0.2	0.5	0.2	0.4	0.2	0.4	0.3
	Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sinclair Inlet	26.5	0.3	0.8	0.2	0.7	0.3	0.7	0.2	0.6	0.4
Marine South Sound	All South Sound Stations	46.8	0.4	1.4	0.4	1.2	0.5	1.1	0.4	1.0	0.7
	South Sound	59.7	0.6	1.7	0.5	1.5	0.6	1.5	0.5	1.3	0.9
	South Sound Net Pens	35.8	0.3	1.0	0.3	0.9	0.4	0.9	0.3	0.8	0.6
Hatchery	Minter Creek	**33.7**	0.3	1.0	0.3	0.9	0.3	0.8	0.3	0.7	0.5
	Wallace Creek	**29.6**	0.3	0.9	0.3	0.8	0.3	0.7	0.3	0.6	0.5

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded areas indicate a HQ greater than or equal to 1.0.

Table C6. Mercury hazard quotients (HQ) based on mean and 90th percentile rockfish consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

RMA	Station	Species	Hg (ppm)	Suquamish		Tulalip		Squaxin		API		Rec
				Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
7	Orcas Island	Quillback	0.401	0.7	2.9	0.1	0.1	0.2	0.6	1.5	3.3	0.5
	San Juan	Quillback	0.242	0.4	1.8	0.0	0.1	0.1	0.4	0.9	2.0	0.3
		Yelloweye	0.928	1.6	6.8	0.2	0.3	0.5	1.4	3.5	7.7	NA
8-2	Mukilteo-Everett	Quillback	0.324	0.5	2.4	0.1	0.1	0.2	0.5	1.2	2.7	0.4
		Copper	0.210	0.4	1.5	0.0	0.1	0.1	0.3	0.8	1.7	0.2
	Port Gardner	Copper	0.264	0.4	1.9	0.0	0.1	0.1	0.4	1.0	2.2	0.3
9	Double Bluff	Quillback	0.230	0.4	1.7	0.0	0.1	0.1	0.3	0.9	1.9	0.3
	Foulweather	Quillback	0.291	0.5	2.1	0.1	0.1	0.2	0.4	1.1	2.4	0.4
10	Blakely Rock	Quillback	0.247	0.4	1.8	0.0	0.1	0.1	0.4	0.9	2.0	0.3
		Copper	0.123	0.2	0.9	0.0	0.0	0.1	0.2	0.5	1.0	0.1
	Elliott Bay	Quillback	0.357	0.6	2.6	0.1	0.1	0.2	0.5	1.4	3.0	0.4
		Brown	0.156	0.3	1.1	0.0	0.1	0.1	0.2	0.6	1.3	0.2
	Elliott Bay 2	Quillback	0.301	0.5	2.2	0.1	0.1	0.2	0.4	1.1	2.5	0.4
	Elliott Bay 4	Quillback	0.353	0.6	2.6	0.1	0.1	0.2	0.5	1.3	2.9	0.4
		Brown	0.242	0.4	1.8	0.0	0.1	0.1	0.4	0.9	2.0	0.3
		Copper	0.103	0.2	0.7	0.0	0.0	0.1	0.2	0.4	0.9	0.1
	Fuller	Quillback	0.356	0.6	2.6	0.1	0.1	0.2	0.5	1.4	2.9	0.5
	Sinclair Inlet	Quillback	0.818	1.4	6.0	0.1	0.3	0.5	1.2	3.1	6.8	0.8
		Brown	0.700	1.2	5.1	0.1	0.2	0.4	1.0	2.7	5.8	1.0
	Sinclair Inlet 2	Copper	0.508	0.9	3.7	0.1	0.2	0.3	0.7	1.9	4.2	0.7
	Sinclair Inlet Tribal	Brown	0.850	1.4	6.2	0.2	0.3	0.5	1.2	3.2	7.0	1.0
11	Brace Point	Yelloweye	1.44	2.4	10.5	0.3	0.5	0.8	2.1	5.5	11.9	NA
	Browns Point	Quillback	0.267	0.5	1.9	0.0	0.1	0.1	0.4	1.0	2.2	0.4
	Commence-ment Bay	Brown	0.071	0.1	0.5	0.0	0.0	0.0	0.1	0.3	0.6	0.1
	Commence-ment Bay 2	Brown	0.056	0.1	0.4	0.0	0.0	0.0	0.1	0.2	0.5	0.1
	Commence-ment Bay 4	Quillback	0.254	0.4	1.8	0.0	0.1	0.1	0.4	1.0	2.1	0.3
		Brown	0.330	0.6	2.4	0.1	0.1	0.2	0.5	1.3	2.7	0.5
	Commence-ment Bay 5	Quillback	0.163	0.3	1.2	0.0	0.1	0.1	0.2	0.6	1.3	0.2
		Brown	0.062	0.1	0.5	0.0	0.0	0.0	0.1	0.2	0.5	0.1
	Dalco Passage	Quillback	0.496	0.8	3.6	0.1	0.2	0.3	0.7	1.9	4.1	0.6
	Gig Harbor	Quillback	0.220	0.4	1.6	0.0	0.1	0.1	0.3	0.8	1.8	0.3
	Lakota	Quillback	0.295	0.5	2.1	0.1	0.1	0.2	0.4	1.1	2.4	0.3
12	Hood Canal	Quillback	0.183	0.3	1.3	0.0	0.1	0.1	0.3	0.7	1.5	0.2
		Copper	0.170	0.3	1.2	0.0	0.1	0.1	0.2	0.6	1.4	0.2
13	Day Island	Quillback	0.098	0.2	0.7	0.0	0.0	0.1	0.1	0.4	0.8	0.1
		Copper	0.095	0.2	0.7	0.0	0.0	0.1	0.1	0.4	0.8	0.1

NOTE: Shaded areas indicate a HQ greater than or equal to 1.0.

Table C7. Mercury hazard quotients (HQ) based on mean and 90th percentile English sole consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

RMA	Station	Hg (ppm)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
6	Discovery Bay	0.093	0.0	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.1
	Strait of Juan de Fuca	0.051	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
7	Bellingham Bay (outer)	0.031	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
	Birch Point	0.034	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
	Cherry Point	0.038	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
	McAurther Bank	0.043	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Orcas Island	0.027	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Outer Birch Point	0.047	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Point Roberts	0.020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Strait of Georgia	0.051	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Vendovi Island	0.038	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
8-1	Saratoga Passage	0.072	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
8-2	Mukilteo-Everett	0.040	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Point Gardner	0.048	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Port Susan	0.070	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
9	Possession Point	0.057	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Port Ludlow	0.070	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Port Townsend	0.049	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
10	Apple Cove Point	0.063	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Duwamish	0.064	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Dyes Inlet	0.047	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Eagle Harbor	0.095	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.2
	Elliott Bay (Seattle Waterfront)	0.079	0.0	0.2	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Elliott Bay 2 (Harbor Island)	0.095	0.0	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.1
	Elliott Bay 4 (Myrtle Edwards)	0.080	0.0	0.2	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Elliott Bay 5 (Alki)	0.072	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Liberty Bay	0.046	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Port Madison	0.046	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Port Orchard	0.067	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Sinclair Inlet	0.074	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Sinclair Inlet 2 (Outer Sinclair Inlet)	0.071	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Sinclair Inlet 3	0.063	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Sinclair Inlet 4 (Battle Point)	0.061	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Sinclair Inlet 5 (Blake Island)	0.086	0.0	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1
	Shilshole	0.059	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
11	Commencement Bay (Thea Foss)	0.068	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Commencement Bay 2	0.067	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1

Table C7. (cont.) Mercury hazard quotients (HQ) based on mean and 90th percentile English sole consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

RMA	Station	Hg (ppm)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
11	Commencement Bay 3 (Ruston)	0.049	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Commencement Bay 4 (Old Tacoma)	0.051	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Commencement Bay 5 (Brown's Point)	0.062	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Dash Point	0.082	0.0	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.1
	Fern Cove	0.072	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Outer Commencement	0.075	0.0	0.2	0.0	0.1	0.0	0.1	0.1	0.2	0.1
12	Hood Canal (North)	0.059	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Hood Canal Mid (Middle)	0.038	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
	Hood Canal South	0.030	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
13	Budd Inlet (Dana Passage)	0.035	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.1
	Carr Inlet	0.052	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Case Inlet 1 (South Case Inlet)	0.045	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Case Inlet 3 (North Case Inlet)	0.040	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1
	Nisqually	0.061	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.1
	Pickering Passage	0.032	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1
	Wollochet	0.055	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.1

Table C8. Mercury hazard quotients (HQ) based on mean and 90th percentile Chinook consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	Hg (ppm)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	0.087	0.2	0.5	0.1	0.3	0.2	0.4	0.2	0.4	0.6
	Skagit	0.100	0.2	0.6	0.1	0.3	0.3	0.5	0.2	0.4	0.7
	Duwamish	0.102	0.2	0.6	0.1	0.3	0.3	0.5	0.2	0.4	0.8
	Nisqually	0.085	0.2	0.5	0.1	0.2	0.2	0.4	0.1	0.4	0.6
	Deschutes	0.108	0.2	0.6	0.1	0.3	0.3	0.5	0.2	0.5	0.8
Marine Central Sound	All Central Sound stations	0.074	0.1	0.4	0.1	0.2	0.2	0.4	0.1	0.3	0.5
	Apple Cove Point	0.062	0.1	0.4	0.1	0.2	0.2	0.3	0.1	0.3	0.5
	Central	0.070	0.1	0.4	0.1	0.2	0.2	0.3	0.1	0.3	0.5
	Sinclair Inlet	0.099	0.2	0.6	0.1	0.3	0.3	0.5	0.2	0.4	0.7
Marine South Sound	All South Sound Stations	0.113	0.2	0.7	0.1	0.3	0.3	0.5	0.2	0.5	0.8
	Budd Inlet	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	South Sound	0.113	0.2	0.7	0.1	0.3	0.3	0.5	0.2	0.5	0.8

Table C9. Mercury hazard quotients (HQ) based on mean and 90th percentile coho consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	Hg (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	0.041	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
	Skagit	0.039	0.1	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0.1
	Duwamish	0.030	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
	Nisqually	0.044	0.1	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0.1
	Deschutes	0.049	0.1	0.3	0.1	0.3	0.1	0.2	0.1	0.2	0.2
Marine Central Sound	All Central Sound stations	0.049	0.1	0.3	0.1	0.3	0.1	0.2	0.1	0.2	0.2
	Agate Pass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apple Cove Point	0.040	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1
	Colvos Passage	0.062	0.1	0.4	0.1	0.3	0.1	0.3	0.1	0.3	0.2
	Central	0.052	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.2	0.2
	Sinclair Inlet	0.060	0.1	0.4	0.1	0.3	0.1	0.3	0.1	0.3	0.2
Marine South Sound	South Sound	0.057	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.2	0.2
Hatchery	Minter Creek	0.029	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Wallace Creek	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Cancer Risk Calculations

Cancer risks were calculated for average and high-end Puget Sound fish consumers. These risk estimates were based on consumption of a single fish species at each station. Estimates of cancer risk were mostly low. Estimates of cancer risk exceeded 1in 10,000 for high-end rockfish consumers from Suquamish Tribe and API community at stations near Elliott Bay, Sinclair Inlet, and Commencement Bay. Suquamish high-end consumers of Chinook salmon from Apple Cove Point and South Sound also exceeded 1 in 10,000. EPA's acceptable cancer risks at cleanup sites range from 1 in 10,000 to 1 in 1,000,000.

Table C10. Cancer risk estimates based on mean and 90th percentile rockfish consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station and rockfish species.

RMA	Station	Species	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
				Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
7	Orcas Island	Quillback	**7.6**	2.6E-06	1.1E-05	2.7E-07	5.2E-07	8.5E-07	2.2E-06	2.5E-06	5.4E-06	8.0E-07
	San Juan	Quillback	3.7	1.3E-06	5.4E-06	1.3E-07	2.5E-07	4.1E-07	1.1E-06	1.2E-06	2.6E-06	3.9E-07
		Yelloweye	49.2	1.7E-05	7.2E-05	1.8E-06	3.3E-06	5.5E-06	1.4E-05	1.6E-05	3.5E-05	NA
8-2	Mukilteo-Everett	Quillback	38.6	1.3E-05	5.6E-05	1.4E-06	2.6E-06	4.3E-06	1.1E-05	1.3E-05	2.7E-05	4.1E-06
		Copper	17.6	5.9E-06	2.6E-05	6.3E-07	1.2E-06	2.0E-06	5.2E-06	5.8E-06	1.2E-05	1.5E-06
	Port Gardner	Copper	**47.8**	1.6E-05	7.0E-05	1.7E-06	3.3E-06	5.4E-06	1.4E-05	1.6E-05	3.4E-05	4.0E-06
9	Double Bluff	Quillback	5.4	1.8E-06	7.9E-06	1.9E-07	3.7E-07	6.0E-07	1.6E-06	1.8E-06	3.8E-06	5.7E-07
	Foulweather	Quillback	9.9	3.3E-06	1.4E-05	3.6E-07	6.7E-07	1.1E-06	2.9E-06	3.2E-06	7.0E-06	1.0E-06
10	Blakely Rock	Quillback	34.8	1.2E-05	5.1E-05	1.3E-06	2.4E-06	3.9E-06	1.0E-05	1.1E-05	2.5E-05	3.7E-06
	Elliott Bay	Quillback	122	4.5E-05	2.0E-04	4.8E-06	9.1E-06	1.5E-05	3.9E-05	4.0E-05	8.6E-05	1.3E-05
		Brown	**92.7**	3.1E-05	1.3E-04	3.3E-06	6.3E-06	1.0E-05	2.7E-05	3.0E-05	6.6E-05	9.8E-06
	Elliott Bay 2	Quillback	293	9.9E-05	4.3E-04	1.1E-05	2.0E-05	3.3E-05	8.6E-05	9.6E-05	2.1E-04	3.6E-05
	Elliott Bay 4	Quillback	**117**	4.0E-05	1.7E-04	4.2E-06	8.0E-06	1.3E-05	3.4E-05	3.8E-05	8.3E-05	1.2E-05
		Brown	**30.4**	1.0E-05	4.4E-05	1.1E-06	2.1E-06	3.4E-06	8.9E-06	9.9E-06	2.2E-05	3.2E-06
		Copper	**61.0**	2.1E-05	8.9E-05	2.2E-06	4.1E-06	6.8E-06	1.8E-05	2.0E-05	4.3E-05	6.4E-06
	Fuller	Quillback	111	3.8E-05	1.6E-04	4.0E-06	7.5E-06	1.2E-05	3.3E-05	3.6E-05	7.9E-05	1.2E-05
	Sinclair Inlet	Quillback	144	4.9E-05	2.1E-04	5.2E-06	9.8E-06	1.6E-05	4.2E-05	4.7E-05	1.0E-04	1.7E-05
		Brown	326	1.1E-04	4.7E-04	1.2E-05	2.2E-05	3.7E-05	9.6E-05	1.1E-04	2.3E-04	2.7E-05
	Sinclair Inlet 2	Copper	18.4	6.2E-06	2.7E-05	6.6E-07	1.3E-06	2.1E-06	5.4E-06	6.0E-06	1.3E-05	2.2E-06
	Sinclair Inlet Tribal	Brown	77.4	2.6E-05	1.1E-04	2.8E-06	5.3E-06	8.7E-06	2.3E-05	2.5E-05	5.5E-05	NA
11	Brace Point	Yelloweye	17.3	5.8E-06	2.5E-05	6.2E-07	1.2E-06	1.9E-06	5.1E-06	5.7E-06	1.2E-05	1.8E-06
	Browns Point	Quillback	75.5	2.6E-05	1.1E-04	2.7E-06	5.1E-06	8.5E-06	2.2E-05	2.5E-05	5.4E-05	9.2E-06
	Commence-ment Bay	Brown	**47.2**	1.6E-05	6.9E-05	1.7E-06	3.2E-06	5.3E-06	1.4E-05	1.5E-05	3.3E-05	5.7E-06
	Commence-ment Bay 2	Brown	**43.3**	1.5E-05	6.3E-05	1.6E-06	2.9E-06	4.8E-06	1.3E-05	1.4E-05	3.1E-05	4.6E-06
	Commence-ment Bay 4	Quillback	**128**	4.3E-05	1.9E-04	4.6E-06	8.7E-06	1.4E-05	3.8E-05	4.2E-05	9.1E-05	1.6E-05

Table C10. (cont.). Cancer risk estimates based on mean and 90th percentile rockfish consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station and rockfish species.

RMA	Station	Species	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
11		Brown	**97.0**	3.3E-05	1.4E-04	3.5E-06	6.6E-06	1.1E-05	2.9E-05	3.2E-05	6.9E-05	1.0E-05
	Commence-ment Bay 5	Quillback	**16.2**	5.5E-06	2.4E-05	5.8E-07	1.1E-06	1.8E-06	4.8E-06	5.3E-06	1.1E-05	2.0E-06
		Brown	**28.7**	9.7E-06	4.2E-05	1.0E-06	2.0E-06	3.2E-06	8.4E-06	9.4E-06	2.0E-05	3.0E-06
	Dalco Passage	Quillback	64.5	2.2E-05	9.4E-05	2.3E-06	4.4E-06	7.2E-06	1.9E-05	2.1E-05	4.6E-05	6.8E-06
	Gig Harbor	Quillback	78.1	2.6E-05	1.1E-04	2.8E-06	5.3E-06	8.7E-06	2.3E-05	2.6E-05	5.5E-05	8.2E-06
	Lakota	Quillback	62.8	2.1E-05	9.1E-05	2.3E-06	4.3E-06	7.0E-06	1.8E-05	2.1E-05	4.5E-05	6.6E-06
12	Hood Canal	Quillback	7.7	2.6E-06	1.1E-05	2.8E-07	5.2E-07	8.6E-07	2.3E-06	2.5E-06	5.5E-06	6.4E-07
		Copper	6.5	2.2E-06	9.5E-06	2.3E-07	4.4E-07	7.3E-07	1.9E-06	2.1E-06	4.6E-06	5.4E-07
13	Day Island	Copper	8.2	2.8E-06	1.2E-05	3.0E-07	5.6E-07	9.2E-07	2.4E-06	2.7E-06	5.8E-06	6.8E-07

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded values indicate cancer risk exceeds $1x10^{-4}$.

Table C11. Cancer risk estimates based on mean and 90th percentile English sole consumption rates for three Puget Sound Native Ameirican Tribes, API, and recreational fishers (by station).

RMA	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
6	Discovery Bay	3.9	4.1E-07	1.6E-06	4.8E-07	1.2E-06	4.8E-07	1.4E-06	4.2E-07	9.1E-07	5.3E-07
	Strait of Juan de Fuca	7.0	7.3E-07	2.8E-06	8.5E-07	2.1E-06	8.7E-07	2.5E-06	7.5E-07	1.6E-06	9.4E-07
7	Bellingham Bay (outer)	3.8	4.0E-07	1.5E-06	4.6E-07	1.1E-06	4.7E-07	1.3E-06	4.1E-07	8.8E-07	5.1E-07
	Birch Point	5.1	5.3E-07	2.1E-06	6.2E-07	1.5E-06	6.3E-07	1.8E-06	5.5E-07	1.2E-06	6.9E-07
	Cherry Point	**13.9**	1.4E-06	5.6E-06	1.7E-06	4.1E-06	1.7E-06	4.9E-06	1.5E-06	3.3E-06	1.9E-06
	McAurther Bank	3.2	3.3E-07	1.3E-06	3.9E-07	9.5E-07	4.0E-07	1.1E-06	3.4E-07	7.4E-07	4.3E-07
	Orcas Island	3.7	3.8E-07	1.5E-06	4.5E-07	1.1E-06	4.6E-07	1.3E-06	4.0E-07	8.6E-07	5.0E-07
	Outer Birch Point	3.1	3.2E-07	1.2E-06	3.8E-07	9.2E-07	3.8E-07	1.1E-06	3.3E-07	7.2E-07	4.2E-07
	Point Roberts	4.8	5.0E-07	1.9E-06	5.9E-07	1.4E-06	6.0E-07	1.7E-06	5.1E-07	1.1E-06	6.5E-07
	Strait of Georgia	5.8	6.0E-07	2.3E-06	7.1E-07	1.7E-06	7.2E-07	2.0E-06	6.2E-07	1.3E-06	7.8E-07
	Vendovi Island	5.0	5.2E-07	2.0E-06	6.1E-07	1.5E-06	6.2E-07	1.8E-06	5.4E-07	1.2E-06	6.7E-07
8-1	Saratoga Passage	20.2	2.1E-06	8.1E-06	2.5E-06	6.0E-06	2.5E-06	7.1E-06	2.2E-06	4.7E-06	2.7E-06
8-2	Port Gardner	17.5	1.8E-06	7.0E-06	2.1E-06	5.2E-06	2.2E-06	6.2E-06	1.9E-06	4.1E-06	2.4E-06
	Port Susan	**5.5**	5.7E-07	2.2E-06	6.7E-07	1.6E-06	6.8E-07	1.9E-06	5.9E-07	1.3E-06	7.4E-07
9	Possession Point	11.7	1.2E-06	4.7E-06	1.4E-06	3.5E-06	1.5E-06	4.1E-06	1.3E-06	2.7E-06	1.6E-06
	Port Ludlow	6.7	7.0E-07	2.7E-06	8.2E-07	2.0E-06	8.3E-07	2.4E-06	7.2E-07	1.6E-06	9.0E-07
	Port Townsend	9.7	1.0E-06	3.9E-06	1.2E-06	2.9E-06	1.2E-06	3.4E-06	1.0E-06	2.3E-06	1.3E-06
10	Apple Cove Point	9.8	1.0E-06	3.9E-06	1.2E-06	2.9E-06	1.2E-06	3.4E-06	1.1E-06	2.3E-06	1.3E-06
	Duwamish	168	1.7E-05	6.8E-05	2.0E-05	5.0E-05	2.1E-05	5.9E-05	1.8E-05	3.9E-05	2.3E-05
	Dyes Inlet	28.0	2.9E-06	1.1E-05	3.4E-06	8.3E-06	3.5E-06	9.9E-06	3.0E-06	6.5E-06	3.8E-06
	Eagle Harbor	42.6	4.4E-06	1.7E-05	5.2E-06	1.3E-05	5.3E-06	1.5E-05	4.6E-06	9.9E-06	5.7E-06

Table C11 (cont.) Cancer risk estimates based on mean and 90th percentile English sole consumption rates for three Puget Sound Native Ameirican Tribes, API, and recreational fishers.

RMA	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
10	Elliott Bay (Seattle Waterfront)	82.9	8.6E-06	3.3E-05	1.0E-05	2.5E-05	1.0E-05	2.9E-05	8.9E-06	1.9E-05	1.1E-05
	Elliott Bay 2 (Harbor Island)	**85.9**	8.9E-06	3.5E-05	1.0E-05	2.6E-05	1.1E-05	3.0E-05	9.2E-06	2.0E-05	1.2E-05
	Elliott Bay 4 (Myrtle Edwards)	**21.0**	2.2E-06	8.4E-06	2.6E-06	6.3E-06	2.6E-06	7.4E-06	2.3E-06	4.9E-06	2.8E-06
	Elliott Bay 5 (Alki)	16.7	1.7E-06	6.7E-06	2.0E-06	5.0E-06	2.1E-06	5.9E-06	1.8E-06	3.9E-06	2.2E-06
	Liberty Bay	23.3	2.4E-06	9.4E-06	2.8E-06	6.9E-06	2.9E-06	8.2E-06	2.5E-06	5.4E-06	3.1E-06
	Port Madison	13.3	1.4E-06	5.3E-06	1.6E-06	4.0E-06	1.6E-06	4.7E-06	1.4E-06	3.1E-06	1.8E-06
	Port Orchard	36.8	3.8E-06	1.5E-05	4.5E-06	1.1E-05	4.6E-06	1.3E-05	3.9E-06	8.6E-06	5.0E-06
	Sinclair Inlet	123	1.3E-05	4.9E-05	1.5E-05	3.7E-05	1.5E-05	4.3E-05	1.3E-05	2.9E-05	1.7E-05
	Sinclair Inlet 2 (Outer Sinclair Inlet)	**22.8**	2.4E-06	9.2E-06	2.8E-06	6.8E-06	2.8E-06	8.0E-06	2.4E-06	5.3E-06	3.1E-06
	Sinclair Inlet 3	**63.8**	6.6E-06	2.6E-05	7.8E-06	1.9E-05	7.9E-06	2.2E-05	6.8E-06	1.5E-05	8.6E-06
	Sinclair Inlet 4 (Battle Point)	**38.8**	4.0E-06	1.6E-05	4.7E-06	1.2E-05	4.8E-06	1.4E-05	4.2E-06	9.0E-06	5.2E-06
	Sinclair Inlet 5 (Blake Island)	**31.0**	3.2E-06	1.2E-05	3.8E-06	9.2E-06	3.8E-06	1.1E-05	3.3E-06	7.2E-06	4.2E-06
	Shilshole	22.7	2.4E-06	9.1E-06	2.8E-06	6.8E-06	2.8E-06	8.0E-06	2.4E-06	5.3E-06	3.1E-06
11	Commencement Bay (Thea Foss)	76.0	7.9E-06	3.1E-05	9.3E-06	2.3E-05	9.4E-06	2.7E-05	8.1E-06	1.8E-05	1.0E-05
	Commencement Bay 2	**82.4**	8.6E-06	3.3E-05	1.0E-05	2.5E-05	1.0E-05	2.9E-05	8.8E-06	1.9E-05	1.1E-05
	Commencement Bay 3 (Ruston)	**34.2**	3.6E-06	1.4E-05	4.2E-06	1.0E-05	4.2E-06	1.2E-05	3.7E-06	8.0E-06	4.6E-06
	Commence-ment Bay 4 (Old Tacoma)	**43.2**	4.5E-06	1.7E-05	5.3E-06	1.3E-05	5.4E-06	1.5E-05	4.6E-06	1.0E-05	5.8E-06
	Commencement Bay 5 (Brown's Point)	**55.5**	5.8E-06	2.2E-05	6.8E-06	1.7E-05	6.9E-06	2.0E-05	5.9E-06	1.3E-05	7.5E-06
	Dash Point	28.5	3.0E-06	1.1E-05	3.5E-06	8.5E-06	3.5E-06	1.0E-05	3.1E-06	6.6E-06	3.8E-06
	Fern Cove	19.3	2.0E-06	7.8E-06	2.4E-06	5.8E-06	2.4E-06	6.8E-06	2.1E-06	4.5E-06	2.6E-06
	Outer Commencement	41.8	4.3E-06	1.7E-05	5.1E-06	1.2E-05	5.2E-06	1.5E-05	4.5E-06	9.7E-06	5.6E-06
12	Hood Canal (North)	6.4	6.7E-07	2.6E-06	7.8E-07	1.9E-06	7.9E-07	2.3E-06	6.9E-07	1.5E-06	8.6E-07
	Hood Canal Mid (Middle)	3.5	3.6E-07	1.4E-06	4.3E-07	1.0E-06	4.3E-07	1.2E-06	3.8E-07	8.1E-07	4.7E-07
	Hood Canal South	4.8	5.0E-07	1.9E-06	5.9E-07	1.4E-06	6.0E-07	1.7E-06	5.1E-07	1.1E-06	6.5E-07
13	Budd Inlet (Dana Passage)	8.8	9.2E-07	3.5E-06	1.1E-06	2.6E-06	1.1E-06	3.1E-06	9.4E-07	2.0E-06	1.2E-06
	Carr Inlet	14.1	1.5E-06	5.7E-06	1.7E-06	4.2E-06	1.7E-06	5.0E-06	1.5E-06	3.3E-06	1.9E-06
	Case Inlet 1 (South Case Inlet)	15.9	1.7E-06	6.4E-06	1.9E-06	4.7E-06	2.0E-06	5.6E-06	1.7E-06	3.7E-06	2.1E-06
	Case Inlet 3 (North Case Inlet)	8.3	8.6E-07	3.3E-06	1.0E-06	2.5E-06	1.0E-06	2.9E-06	8.9E-07	1.9E-06	1.1E-06
	Nisqually	21.5	2.2E-06	8.6E-06	2.6E-06	6.4E-06	2.7E-06	7.6E-06	2.3E-06	5.0E-06	2.9E-06
	Pickering Passage	9.2	9.6E-07	3.7E-06	1.1E-06	2.7E-06	1.1E-06	3.2E-06	9.9E-07	2.1E-06	1.2E-06
	Wollochet	26.3	2.7E-06	1.1E-05	3.2E-06	7.8E-06	3.3E-06	9.3E-06	2.8E-06	6.1E-06	3.5E-06

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD.

Table C12. Cancer risk estimates based on mean and 90th percentile Chinook consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	37.9	1.5E-05	4.4E-05	9.9E-06	2.2E-05	2.0E-05	3.6E-05	5.6E-06	1.4E-05	2.4E-05
	Skagit	40.6	1.6E-05	4.7E-05	1.1E-05	2.4E-05	2.2E-05	3.9E-05	6.0E-06	1.5E-05	2.6E-05
	Duwamish	57.2	2.3E-05	6.6E-05	1.5E-05	3.3E-05	3.1E-05	5.4E-05	8.5E-06	2.1E-05	3.6E-05
	Nisqually	41.9	1.7E-05	4.9E-05	1.1E-05	2.4E-05	2.2E-05	4.0E-05	6.2E-06	1.6E-05	2.7E-05
	Deschutes	60.4	2.4E-05	7.0E-05	1.6E-05	3.5E-05	3.2E-05	5.8E-05	8.9E-06	2.3E-05	3.8E-05
Marine Central Sound	All Central Sound Stations	75.7	3.0E-05	8.8E-05	2.0E-05	4.4E-05	4.0E-05	7.2E-05	1.1E-05	2.8E-05	4.8E-05
	Apple Cove Point	90.8	3.6E-05	1.1E-04	2.4E-05	5.3E-05	4.8E-05	8.6E-05	1.3E-05	3.4E-05	5.7E-05
	Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sinclair Inlet	45.5	1.8E-05	5.3E-05	1.2E-05	2.6E-05	2.4E-05	4.3E-05	6.7E-06	1.7E-05	2.9E-05
Marine South Sound	All South Sound Stations	70.5	2.8E-05	8.2E-05	1.8E-05	4.1E-05	3.8E-05	6.7E-05	1.0E-05	2.6E-05	4.5E-05
	Budd Inlet	55.5	2.2E-05	6.4E-05	1.4E-05	3.2E-05	3.0E-05	5.3E-05	8.2E-06	2.1E-05	3.5E-05
	South Sound	95.7	3.8E-05	1.1E-04	2.5E-05	5.6E-05	5.1E-05	9.1E-05	1.4E-05	3.6E-05	6.1E-05

NOTE: PCB values in regular font represent Aroclor concentrations measured by GC/ECD.
Shaded values indicate cancer risk exceeds $1x10^{-4}$.

Table C13. Cancer risk estimates based on mean and 90th percentile coho consumption rates for three Puget Sound Native American Tribes, API, and recreational fishers (by station).

Catch Area	Station	PCB (ppb)	Suquamish		Tulalip		Squaxin		API		Rec
			Avg	90th	Avg	90th	Avg	90th	Avg	90th	Avg
In-river	Nooksak	24.7	9.4E-06	2.9E-05	8.8E-06	2.5E-05	1.0E-05	2.4E-05	3.7E-06	9.2E-06	6.5E-06
	Skagit	24.0	8.8E-06	2.7E-05	8.2E-06	2.4E-05	9.3E-06	2.3E-05	3.6E-06	9.0E-06	6.3E-06
	Duwamish	39.6	1.5E0-05	4.6E-05	1.4E-05	4.0E-05	1.6E-05	3.8E-05	5.9E-06	1.5E-05	1.0E-05
	Nisqually	35.7	1.3E-05	4.0E-05	1.2E-05	3.5E-05	1.4E-05	3.4E-05	5.3E-06	1.3E-05	9.4E-06
	Deschutes	28.3	9.1E-06	2.8E-05	8.5E-06	2.5E-05	9.6E-06	2.3E-05	4.2E-06	1.1E-05	7.5E-06
Marine Central Sound	Agate Pass	**46.8**	1.8E-05	5.5E-05	1.7E-05	4.8E-05	1.9E-05	4.6E-05	6.9E-06	1.7E-05	1.2E-05
	Apple Cove Point	17.3	6.6E-06	2.0E-05	6.2E-06	1.8E-05	7.0E-06	1.7E-05	2.6E-06	6.5E-06	4.6E-06
	Colvos Passage	17.5	6.7E-06	2.0E-05	6.2E-06	1.8E-05	7.1E-06	1.7E-05	2.6E-06	6.5E-06	4.6E-06
	Central	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Sinclair Inlet	26.5	1.0E-05	3.1E-05	9.4E-06	2.7E-05	1.1E-05	2.6E-05	3.9E-06	9.9E-06	7.0E-06
Marine South Sound	All South Sound Stations	46.7	1.8E-05	5.5E-05	1.7E-05	4.8E-05	1.9E-05	4.6E-05	6.9E-06	1.7E-05	1.2E-05
	South Sound	59.7	2.3E-05	7.0E-05	2.1E-05	6.1E-05	2.4E-05	5.9E-05	8.8E-06	2.2E-05	1.6E-05
	South Sound Net Pens	35.8	1.4E-05	4.2E-05	1.3E-05	3.7E-05	1.4E-05	3.5E-05	5.3E-06	1.3E-05	9.5E-06
Hatchery	Minter Creek	**33.7**	1.3E-05	3.9E-05	1.2E-05	3.5E-05	1.4E-05	3.3E-05	5.0E-06	1.3E-05	8.9E-06
	Wallace Creek	**29.6**	1.1E-05	3.5E-05	1.1E-05	3.0E-05	1.2E-05	2.9E-05	4.4E-06	1.1E-05	7.8E-06

NOTE: Bold values represent Aroclor equivalent concentrations calculated from HPLC analyses. PCB values in regular font represent Aroclor concentrations measured by GC/ECD. Shaded values indicate cancer risk exceeds $1x10^{-4}$.

Dioxin Toxic Equivalents (TEQs)

PCBs are complex mixtures, which complicates the evaluation of their risk to humans, fish and wildlife. There is a common mechanism of action for some congeners involving binding to the aryl hydrocarbon (Ah) receptor as an initial step. The concept of toxic equivalency factors (TEFs) was developed to facilitate the assessment of exposure to these mixtures. The toxicity of these compounds relative to that of 2,3,7,8-tetrachlorodibenzo(p)dioxin was determined based on the assumption that combined effects of the different congeners are dose or concentration additive (Van den Berg et al. 1998).

Results

TEQ values were determined for coho, English sole and rockfish at several sites (Table C14). The HPLC/PDA method was used to measure fifteen PCB congeners (77, 101, 105, 110, 118, 126, 128, 138, 153, 156, 157, 169, 170, 180, and 189). This method may underestimate total PCBs because not all 209 congeners were assessed. Average PCB-TEQs were calculated using both half the detection limit and zero when congeners were not detected above the analytical detection limit. The wide gap between TEQ results based on whether congener values were estimated (1/2 DL) or not detected (ND=0) demonstrates that a great number of congeners were not detected, resulting in uncertain PCB TEQ estimates. The two most potent congeners, 126 and 169, were not detected in any samples. Analytical detection limits for these and other dioxin-like congeners are considered too high to reliably estimate cancer risk.

Table C14. Summary of polychlorinated biphenyl dioxin toxic equivalents (PCB-TEQs) for Puget Sound fish species.

	Coho n=165		**English sole** n = 113		**Brown Rockfish** n = 35		**Quillback Rockfish** n = 83	
	ND=0	ND= ½ DL	ND=0	ND= ½ DL	ND=0	ND= ½ DL	ND=0	ND= ½ DL
Mean (ppt)	0.3	3.3	0.3	4.3	0.6	4.1	0.4	3.7
Median (ppt)	0.2	3.0	0.2	4.1	0.4	4.0	0.3	3.2
Minimum (ppt)	0	1.9	0	2.4	0	3.1	0	1.2
Maximum (ppt)	1.5	20.8	1.8	8.8	1.3	5.5	2.0	9.9

NOTE: Zero was assigned to non-detected analytes as indicated by ND = 0. One half of the detected limit was assigned to non-detected analytes as indicated by ND = ½ DL.

References

EPA.1997a. Exposure Factors Handbook Volume III: Activity Factors. U.S. Environmental Protection Agency, Office of Research and Development. August 1997. EPA/600/P-95/002Fc.

EPA. 1997b. Exposure Factors Handbook Volume I: General Factors. U.S. Environmental Protection Agency, Office of Research and Development. August 1997. EPA/600/P-95/002Fa.

EPA. 1999. Asian and Pacific Islander Seafood Consumption Study in King County, WA. U.S. Environmental Protection Agency, Office of Environmental Assessment. May 1999. EPA 910/R-99-003.

Landolt M, Hafer F, Nevissi A, van Belle G, Van Ness K, and Rockwell C. 1985. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound. NOAA Technical Memorandum NOS OMA 23. Rockville, MD.

Landolt M, Kalman D, Nevissi A, van Belle G, Van Ness K, and Hafer F. 1987. Potential toxicant exposure among consumers of recreationally caught fish from urban embayments of Puget Sound: Final Report. NOAA Technical Memorandum NOS OMA 33. Rockville, MD.

Suquamish 2000. Fish Consumption Survey of the Suquamish Indian Tribe of the Port Madison Indian Reservation, Puget Sound Region. The Suquamish Tribe, Port Madison Indian Reservation, Fisheries Department, Suquamish, WA. August 2000.

Toy KA, Polissar NL, Liao S, and Gawne-Mittelstaedt GD. 1996. A Fish Consumption Survey of the Tulalip and Squaxin Island Tribes of the Puget Sound Region. Tulalip Tribes, Natural Resources Department, Marysville, WA. October 1996.

Van den Berg M, Birnbaum L, Bosveld AT, Brunstrom B, Cook P, Feeley M, Giesy JP, Hanberg A, Hasegawa R, Kennedy SW, Kubiak T, Larsen JC, van Leeuwen FX, Liem AK, Nolt C, Peterson RE, Poellinger L, Safe S, Schrenk D, Tillitt D, Tysklind M, Younes M, Waern F, Zacharewski T. 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ Health Perspect. Dec.106(12):775-92.

APPENDIX D

Calculated Meal Limits for Puget Sound Fish

Calculated Meal Limits Based on the RfD for Mercury and PCBs

Meal limits were calculated based on levels of two contaminants of concern (mercury and polychlorinated biphenyls (PCBs)) in seven fish species from Puget Sound. Calculated meal limits are only one consideration used to determine meal guidance for consuming Puget Sound fish. Meal limits were calculated for locations where fish were sampled by Washington State Department of Fish and Wildlife (WDFW) for the fish component of the Puget Sound Assessment and Monitoring Program (PSAMP). Allowable meal limits were calculated using the following equation and exposure assumptions (ug/kg = ppb):

Allowable meal limit = (RfD) * (1/concentration) * (BW) * (UCF), where

RfD = EPA's risk reference dose; 0.1 ug/kg/day (mercury), 0.02 ug/kg/day (PCBs),

Concentration = mean contaminant concentration in fish (using non-weighted individual and composite samples),

BW = Body Weight; 60 kg adult,

UCF = Unit Conversion Factor (g/kg), and

CR = Consumption Rate (number of 8-ounce meals per month).

Meal limits were calculated based on total PCBs (i.e., total Aroclors or calculated Aroclor equivalent concentrations). The RfD for Aroclor 1254 was used as a surrogate reference dose for total PCBs since RfDs are not available for individual PCB congeners or other PCB mixtures. Therefore, toxicity of other PCB mixtures was assumed to be the same as that of Aroclor 1254. Calculated meal limits based on mercury or PCB RfDs can be found below (Tables D1 – D4).

Table D1. Estimated meals per month for rockfish from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Rockfish Species	Type	Mercury			Total PCBs (Aroclors)			Total PCBs (Sum of 15 congeners)		
			N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/ month	N	Mean (ppb)	Meals/ month
Recreational Management Area 7											
Orcas Island	Quillback	I	5	0.401	2	0	NA	NA	5	7.6	21
San Juan	Quillback	I and C	15 I 21 C	0.242	3	15 I 15 C	3.7	43	0	NA	NA
	Yelloweye	I	1	0.928	1	1	49.2	3	0	NA	NA
Recreational Management Area 8-2											
Mukilteo-Everett	Quillback	I	6	0.324	2	5	31.8	5	4	39.5	4
	Copper	I	5	0.210	4	5	17.6	9	0	NA	NA
Port Gardner	Copper	I	15	0.264	3	0	NA	NA	15	47.8	3
Recreational Management Area 9											
Double Bluff	Quillback	I and C	15 I 21 C	0.230	4	15 I 15 C	5.4	30	0	NA	NA
Foulweather	Quillback	I	14	0.291	3	11	9.9	16	14	14.4	11
Recreational Management Area 10											
Blakely Rock	Quillback	I and C	15 I 20 C	0.247	3	15 I 15 C	34.8	5	0	NA	NA
	Copper	C	9	0.123	7	0	NA	NA	0	NA	NA
Elliott Bay	Quillback	I	47	0.357	2	9	122	1	41	77.5	2
	Brown	I	2	0.156	5	0	NA	NA	2	92.7	2
Elliott Bay 2	Quillback	I	14	0.301	3	5	293	None	15	162	1
Elliott Bay 4	Quillback	I	11	0.353	2	0	NA	NA	18	117	1
	Brown	I	1	0.242	3	0	NA	NA	1	30.4	5
	Copper	I	1	0.103	8	0	NA	NA	1	61.0	3
Fuller	Quillback	I and C	18 I 3 C	0.356	2	18 I 3C	111	1	3	54.2	3
Sinclair Inlet	Quillback	I	3	0.818	1	3	144	1	0	NA	NA
	Brown	I	15	0.700	1	6	326	None	10	138	1
Sinclair Inlet 2	Copper	I	1	0.508	2	1	18.4	9	1	16.8	10
Sinclair Inlet Tribal	Brown	I	5	0.85	1	5	77.4	2	5	59.2	3
Recreational Management Area 11											
Brace Point	Yelloweye	I	1	1.44	1	1	17.3	9	0	NA	NA
Browns Point	Quillback	I	2	0.267	3	2	75.5	2	0	NA	NA
Commencement Bay	Brown	I	6	0.071	11	0	NA	NA	7	47.2	3
Commencement Bay 2	Brown	I	5	0.056	14	0	NA	NA	7	43.3	4
Commencement Bay 4	Quillback	I	1	0.254	3	0	NA	NA	1	128	1
	Brown	I	1	0.330	2	0	NA	NA	1	97.0	2
Commencement Bay 5	Quillback	I	2	0.163	5	0	NA	NA	2	16.2	10
	Brown	I	6	0.062	13	0	NA	NA	7	28.7	6
Dalco Passage	Quillback	I	2	0.496	2	2	64.5	2	0	NA	NA
Gig Harbor	Quillback	I	5	0.220	4	5	78.1	2	0	NA	NA

Table D1 (cont.). Estimated meals per month for rockfish from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Rockfish Species	Type	Mercury			Total PCBs (Aroclors)			Total PCBs (Sum of 15 congeners)		
Lakota	Quillback	I	4	0.295	3	4	62.8	3	0	NA	NA
Recreational Management Area 12											
Hood Canal	Quillback	C	8	0.183	4	2	7.7	21	0	NA	NA
	Copper	C	1	0.170	5	1	6.5	25	0	NA	NA
Recreational Management Area 13											
Day Island	Quillback	C	6	0.098	8	0	NA	NA	0	NA	NA
	Copper	C	18	0.095	8	11	8.3	19	0	NA	NA

NOTE: Meal = eight ounces
N = sample size
Type: I = individual sample, C = composite sample
NA = Not available

Table D2. Estimated meals per month for English sole from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Mercury				Total PCBs (Aroclors)			Total PCBs (sum of 15 congeners)		
	Type	N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/ month	N	Mean (ppb)	Meals/ month
Recreational Management Area 6										
Discovery Bay	C	3	0.093	9	3	3.9	41	0	NA	NA
Strait of Juan de Fuca	C	6	0.050	16	6	7.0	23	0	NA	NA
Recreational Management Area 7										
Bellingham Bay (outer)	C	9	0.031	26	9	3.8	42	0	NA	NA
Birch Point	C	6	0.034	24	6	5.1	32	0	NA	NA
Cherry Point	C	3	0.038	21	0	NA	NA	3	13.9	12
McAurther Bank	C	3	0.043	19	3	3.2	50	0	NA	NA
Orcas Island	C	3	0.027	30	3	3.6	45	0	NA	NA
Outer Birch Pt.	C	3	0.047	17	3	3.1	52	0	NA	NA
Point Roberts	C	3	0.020	40	3	4.8	33	0	NA	NA
Strait of Georgia	C	34	0.051	16	21	5.8	28	15	11.2	14
Vendovi Island	I and C	44	0.038	21	23 I 11 C	3.8	42	014	7.8	21
Recreational Management Area 8-1										
Saratoga Passage	C	6	0.072	11	6	20.2	8	0	NA	NA
Recreational Management Area 8-2										
Mukilteo-Everett	C	2	0.040	20	0	NA	NA	0	NA	NA
Port Gardner	C	34	0.048	17	21	17.5	9	8	22.4	7
Port Susan	C	3	0.070	11	0	NA	NA	1	5.5	29
Recreational Management Area 9										
Possession Point	C	6	0.057	14	6	11.7	14	0	NA	NA

Table D2 (cont.). Estimated meals per month for English sole from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Mercury				Total PCBs (Aroclors)			Total PCBs (sum of 15 congeners)		
	Type	N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/ month	N	Mean (ppb)	Meals/ month
Port Ludlow	C	3	0.070	11	3	6.7	24	0	NA	NA
Port Townsend	C	12	0.049	16	12	9.7	17	0	NA	NA
Recreational Management Area 10										
Apple Cove Pt.	C	6	0.063	13	6	9.8	16	0	NA	NA
Duwamish	C	9	0.064	13	6	168	1	3	164	1
Dyes Inlet	C	6	0.047	17	6	28.0	6	0	NA	NA
Eagle Harbor	C	12	0.095	8	6	42.6	4	6	52.3	3
Elliott Bay	C and I	63	0.079	10	29 I 21 C	64.4	2	15	75.8	2
Elliott Bay 2	C	3	0.095	8	2	26.5	6	3	85.9	2
Elliott Bay 4	C	3	0.080	10	0	NA	NA	3	21.0	8
Elliott Bay 5	C	3	0.072	11	3	16.7	10	3	22.4	7
Liberty Bay	C	6	0.046	17	6	23.3	7	0	NA	NA
Port Madison	C	3	0.046	17	3	13.3	12	0	NA	NA
Port Orchard	C	6	0.067	12	6	36.8	4	0	NA	NA
Sinclair Inlet	C and I	58	0.074	11	24 I 21 C	121	1	15	122	1
Sinclair Inlet 2	C	3	0.071	11	0	NA	NA	3	22.8	7
Sinclair Inlet 3	C	3	0.063	13	0	NA	NA	3	63.8	3
Sinclair Inlet 4	C	3	0.061	13	0	NA	NA	3	38.8	4
Sinclair Inlet 5	C	3	0.086	9	0	NA	NA	3	31.0	5
Shilshole	C	6	0.059	14	5	22.9	7	0	NA	NA
Recreational Management Area 11										
Commenceme nt Bay	C and I	57	0.068	12	35 I 20 I	63.0	3	14	79.1	2
Commenceme nt Bay 2	C	3	0.067	12	0	NA	NA	3	82.4	2
Commenceme nt Bay 3	C	3	0.049	16	0	NA	NA	3	34.2	5
Commenceme nt Bay 4	C	3	0.051	16	0	NA	NA	3	43.2	4
Commenceme nt Bay 5	C	3	0.062	13	0	NA	NA	3	55.5	3
Dash Point	C	6	0.082	10	6	28.5	6	0	NA	NA
Fern Cove	C	3	0.072	11	3	19.3	8	0	NA	NA
Outer Commenceme nt	C	6	0.075	11	6	41.8	4	0	NA	NA
Recreational Management Area 12										
Hood Canal	C	36	0.059	14	21	6.4	25	15	11.8	14
Hood Canal M	C	6	0.038	21	6	3.5	46	0	NA	NA
Hood Canal S	C	6	0.030	27	6	4.8	33	0	NA	NA

Table D2 (cont.). Estimated meals per month for English sole from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Mercury				Total PCBs (Aroclors)			Total PCBs (sum of 15 congeners)		
	Type	N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/ month	N	Mean (ppb)	Meals/ month
Recreational Management Area 13										
Budd Inlet	C	9	0.035	23	9	8.8	18	0	NA	NA
Carr Inlet	C	6	0.052	15	6	14.0	11	0	NA	NA
Case Inlet 1	C	6	0.045	18	6	16.0	10	0	NA	NA
Case Inlet 3	C	3	0.040	20	3	8.3	19	0	NA	NA
Nisqually	C	24	0.061	13	12	21.5	7	15	24.0	7
Pickering	C	6	0.032	25	6	9.2	17	0	NA	NA
Wollochet	C	6	0.055	15	6	26.3	6	0	NA	NA

NOTE: Meal = eight ounces
N = sample size
Type: I = individual sample, C = composite sample
NA = Not available

Table D3. Estimated meals per month for Chinook salmon from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Mercury				Total PCBs (Aroclors)		
	Type	N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/month
In-river Fisheries							
Nooksak River	C	18	0.087	9	28	37.9	4
Skagit River	C and I	18 C	0.100	8	3 I 26 C	40.6	4
Duwamish River	C and I	18 C	0.102	8	34 I 31 C	57.2	3
Nisqually River	C and I	12 C	0.085	9	1 I 19 C	41.9	4
Deschutes River	C and I	12 C	0.108	7	12 I 22 C	60.4	3
Marine Fisheries							
Central Sound	C	**22**	**0.074**	**11**	**18**	**75.7**	**2**
Apple Cove Pt.	C	12	0.062	13	12	90.8	2
Central Sound	C	4	0.070	11	0	NA	NA
Sinclair Inlet	C	6	0.099	8	6	45.5	4
South Sound	C	**6**	**0.113**	**7**	**16**	**70.6**	**2**
Budd Inlet	C	0	NA	NA	10	55.5	3
South Sound	C	6	0.113	7	6	95.7	2

NOTE: Meal = eight ounces
N = sample size
Type: I = individual sample, C = composite sample
NA = Not available
Shading = Total sample size, mean, and meals/month for all marine fishery stations in Central and South Sound.

Table D4. Estimated meals per month for coho salmon from Puget Sound, based on contaminant concentrations for each station and chemical.

Location	Mercury				Total PCBs (Aroclors)			Total PCBs (Sum of 15 congeners Aroclor equivalent)		
	Type	N	Mean (ppm)	Meals/ month	N	Mean (ppb)	Meals/ month	N	Mean (ppb)	Meals/ month
In-river Fisheries										
Nooksak River	C	18	0.041	20	38	24.7	7	20	26.6	6
Skagit River	C and I	56C	0.039	21	2 I 26 C	24.0	7	38 C	36.4	4
Duwamish River	C and I	58 C	0.030	27	1 I 44 C	39.6	4	53 C	33.6	5
Nisqually River	C and	41 C	0.044	18	2 I 31 C	35.7	5	28	39.7	4
Central Sound	C	26	0.049	16	20	18.3	9	10	46.8	3
Deschutes River	C and I	10 C	0.049	16	20 I 11 C	28.3	6	0	NA	NA
Marine Fisheries										
Agate Pass	C	0	NA	NA	0	NA	NA	10	46.8	3
Apple Cove Pt.	C	12	0.040	20	12	17.3	9	0	NA	NA
Colvos Passage	C	6	0.062	13	6	17.5	9	0	NA	NA
Central Sound	C	6	0.052	15	0	NA	NA	0	NA	NA
Sinclair Inlet	C	2	0.060	13	2	26.5	6	0	NA	NA
South Sound	C	6	0.057	14	26	46.8	3	32	40.6	4
South Sound	C	6	0.057	14	12	59.7	3	0	NA	NA
South Sound Net Pen	C	0	NA	NA	14	35.8	4	32	40.6	4
Hatcheries										
Minter Creek	C	10	0.029	28	0	NA	NA	26	33.7	5
Wallace Creek	C	0	NA	NA	0	NA	NA	17	29.6	5

NOTE: Meal = eight ounces
N = sample size
Type: I = individual sample, C = composite sample
NA = Not available
Shading = Total sample size, mean, and meals/month for all marine fishery stations in Central and South Sound.

Calculated Meal Limits Based on Exposure to Multiple Contaminants (Mercury and PCBs)

The above human health assessment of Puget Sound fish consumption addresses individual impacts from two chemicals of concern. In reality, a fish consumer is exposed to multiple chemicals at a time. One method of addressing this concern is to add impacts of multiple chemicals for an individual endpoint, in this case for developmental or for immunological effects. Since mercury and PCBs have the potential to impact developmental endpoints in humans, a target hazard index of one was used for the basis of estimating acceptable meal limits based on this endpoint. Since mercury and PCBs have the potential to impact the human immune system, the same approach was used to calculate meal limits based on this endpoint. Meal limits based on the two "additive" endpoints were compared with the most restrictive meal limit (from Tables D1-D4, above) as calculated for each contaminant (mercury or PCBs, using each respective RfD). DOH considered each of the three meal estimates to determine consumption guidance for Puget Sound fish.

Table D5. Meal limits for rockfish based on additive effects of PCBs and mercury using developmental and immune system endpoints.

Location	Rockfish Species	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D1	Lowest meals per month (rounded to single digit)
Recreational Management Area 7					
Orcas Island	Quillback	4.7	1.9	2.0	2
San Juan	Quillback	8.1	3.2	3.3	3
	Yelloweye	1.4	0.7	0.9	1
Recreational Management Area 8-2					
Mukilteo-Everett	Quillback	2.7	1.8	2.5	2
	Copper	5.1	3.0	3.8	3
Port Gardner	Copper	2.5	1.9	3.0	2
Recreational Management Area 9					
Double Bluff	Quillback	7.8	3.2	3.5	3
Foulweather	Quillback	5.5	2.5	2.8	2
Recreational Management Area 10					
Blakely Rock	Quillback	3.1	2.2	3.3	2
	Copper	NA	6.5	6.5	7
Elliott Bay	Quillback	1.1	1.1	1.3	1
	Brown	1.6	1.7	1.7	2
Elliott Bay 2	Quillback	0.5	0.6	0.5	1
Elliott Bay 4	Quillback	1.1	1.1	1.4	1
	Brown	3.5	2.3	3.3	2
	Copper	2.4	2.6	2.6	2
Fuller	Quillback	1.2	1.1	1.4	1
Sinclair Inlet	Quillback	0.8	0.6	1.0	1
	Brown	0.4	0.5	0.5	0
Sinclair Inlet 2	Copper	3.1	1.4	1.6	1
Sinclair Inlet Tribal	Brown	1.2	0.7	0.9	1
Recreational Management Area 11					
Brace Point	Yelloweye	1.4	0.5	0.6	1
Browns Point	Quillback	1.7	1.5	2.1	2
Commencement Bay	Brown	3.1	3.5	3.4	3
Commencement Bay 2	Brown	3.4	4.0	3.7	3
Commencement Bay 4	Quillback	1.1	1.2	1.3	1
	Brown	1.4	1.2	1.7	1

Table D5 (cont.). Meal limits for rockfish based on additive effects of PCBs and mercury using developmental and immune system endpoints.

Location	Rockfish Species	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D1	Lowest meals per month (rounded to single digit)
Commencement Bay 5	Quillback	5.9	3.7	4.9	4
	Brown	4.9	5.1	5.6	5
Dalco Passage	Quillback	1.6	1.1	1.6	1
Gig Harbor	Quillback	1.7	1.7	2.1	2
Lakota	Quillback	1.9	1.6	2.6	2
Recreational Management Area 12					
Hood Canal	Quillback	8.1	3.9	4.4	4
	Copper	9.0	4.2	4.7	4
Recreational Management Area 13					
Day Island	Quillback	NA	8.2	8.2	8
	Copper	11.1	6.6	8.5	7

NOTE: The "lowest" meal limit is the most protective (or restrictive) of the meal recommendations previously calculated in Table D1 for each station using the RfD for mercury and/or PCBs.
Meal = eight ounces
Type: I = individual sample, C = composite sample

Table D6. Meal limits for English sole based on additive effects of PCBs and mercury using developmental and immune endpoints.

Location	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D2	Lowest meals per month (rounded to single digit)
Recreational Management Area 6				
Discovery Bay	15.9	7.6	8.6	8
Strait of Juan de Fuca	15.5	10.8	15.8	11
Recreational Management Area 7				
Bellingham Bay (outer)	27.4	18.4	25.9	18
Birch Point	21.8	15.8	23.6	16
Cherry Point	9.8	9.5	11.6	10
McAurther Bank	26.5	15.0	18.7	15
Orcas Island	29.2	20.4	29.8	20
Outer Birch Point	25.8	14.0	17.1	14
Point Roberts	26.2	22.3	33.5	22
Strait of Georgia	17.5	11.4	15.8	11
Vendovi Island	21.3	14.7	21.1	15
Recreational Management Area 8-1				
Saratoga Passage	6.4	5.8	8.0	6
Recreational Management Area 8-2				
Port Gardner	7.8	7.6	9.2	8
Port Susan	15.8	9.1	11.5	9
Mukilteo-Everett	NA	NA	20	20
Recreational Management Area 9				
Possession Point	10.4	8.4	13.7	8
Port Ludlow	14.1	8.7	11.5	9

Table D6 (cont.). Meal limits for English sole based on additive effects of PCBs and mercury using developmental and immune endpoints.

Location	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D2	Lowest meals per month (rounded to single digit)
Port Townsend	12.4	9.9	16.4	10
Recreational Management Area 10				
Apple Cove Point	11.5	8.4	12.8	8
Duwamish	0.9	1.3	1.0	1
Dyes Inlet	5.2	5.7	5.7	5
Eagle Harbor	3.2	3.3	3.8	3
Elliott Bay (Seattle Waterfront)	1.8	2.3	1.9	2
Elliott Bay 2 (Harbor Island)	1.7	2.1	1.9	2
Elliott Bay 4 (Myrtle Edwards)	6.1	5.4	7.7	5
Elliott Bay 5 (Alki)	7.5	6.3	9.6	6
Liberty Bay	6.1	6.5	6.9	6
Port Madison	9.8	8.9	12.1	9
Port Orchard	3.9	4.2	4.4	4
Sinclair Inlet	1.3	1.7	1.3	1
Sinclair Inlet 2 (Outer Sinclair Inlet)	5.8	5.5	7.0	6
Sinclair Inlet 3	2.4	2.9	2.5	2
Sinclair Inlet 4 (Battle Point)	3.7	4.2	4.1	4
Sinclair Inlet 5 (Blake Island)	4.4	4.2	5.2	4
Shilshole	6.0	6.0	7.1	6
Recreational Management Area 11				
Commencement Bay (Thea Foss)	2.0	2.5	2.1	2
Commencement Bay 2	1.9	2.4	2.0	2
Commencement Bay 3 (Ruston)	4.3	4.9	4.7	4
Commencement Bay 4 (Old Tacoma)	3.4	4.1	3.7	3
Commencement Bay 5 (Brown's Point)	2.7	3.3	2.9	3
Dash Point	4.7	4.5	5.6	5
Fern Cove	6.7	5.9	8.3	6
Outer Commencement	3.4	3.7	3.8	3
Recreational Management Area 12				
Hood Canal (North)	15.6	10.0	13.6	10
Hood Canal (Middle)	26.6	16.2	21.1	16
Hood Canal (South)	23.6	17.5	26.8	17
Recreational Management Area 13				
Budd Inlet (Dana Passage)	14.4	12.5	18.3	12
Carr Inlet	9.1	8.1	11.4	8
Case Inlet 1 (South Case Inlet)	8.5	8.2	10.1	8

Table D6 (cont.). Meal limits for English sole based on additive effects of PCBs and mercury using developmental and immune endpoints.

Location	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D2	Lowest meals per month (rounded to single digit)
Case Inlet 3 (North Case Inlet)	14.7	11.9	19.4	12
Nisqually	6.3	6.1	7.5	6
Pickering Passage	14.2	12.8	17.5	13
Wollochet	5.4	5.6	6.1	5

NOTE: The "lowest" meal limit is the most protective (or restrictive) of the meal recommendations previously calculated in Table D2 for each station using the RfD for mercury and/or PCBs.
Meal = eight ounces
Type: I = individual sample, C = composite sample

Table D7. Meal limits for Chinook salmon based on additive effects of PCBs and mercury using developmental and immune endpoints.

Location	Immune endpoint meals per month	Developmental endpoint meals per month	Lowest meals per month from Table D3	Lowest meals per month (rounded to single digit)
In-river Fisheries				
Nooksak	3.7	3.8	4.2	4
Skagit	3.4	3.4	4.0	3
Duwamish	2.5	2.7	2.8	3
Nisqually	3.4	3.6	3.8	3
Deschutes	2.4	2.6	2.7	2
Marine Fisheries				
All Central Sound Stations	2.0	2.5	2.1	2
Apple Cove Point	1.7	2.2	1.8	2
Central	NA	NA	11	NA
Sinclair Inlet	3.1	3.2	3.5	3
All South Sound Stations	2.1	2.3	2.3	2
Budd Inlet	NA	NA	2.9	NA
South Sound	1.6	1.9	1.7	2

NOTE: The "lowest" meal limit is the most protective (or restrictive) of the meal recommendations previously calculated in Table D3 for each station using the RfD for mercury and/or PCBs.
Meal = eight ounces
Type: I = individual sample, C = composite sample
Shading = Mean meals per month for all marine fishery stations in Central and South Sound.

Table D8. Meal limits for coho salmon based on additive effects of PCBs and mercury using developmental and immune endpoints.

Location	Immune endpoint meals per month	Development endpoint meals per month	Lowest meals per month from Table D4	Lowest meals per month value (rounded to single digit)
In-river Fisheries				
Nooksak	5.9	6.5	6.5	6
Skagit	6.0	6.5	6.7	6
Duwamish	3.9	5.0	4.1	4
Nisqually	4.2	4.9	4.5	4
Deschutes	5.1	5.6	5.7	5
Marine Fisheries				
All Central Sound Stations	5.2	5.7	3[a]	5
Agate Pass	3.4	NA	3.4	3
Apple Cove Point	8.0	8.2	9.3	8
Colvos Passage	7.4	6.7	9.2	7
Central	NA	NA	15	NA
Sinclair Inlet	5.3	5.4	6.1	5
All South Sound Stations	3.2	3.8	3.4	3
South Sound	NA	NA	2.7	3
South Sound Net	NA	NA	4.5	5
Hatcheries				
Minter Creek	4.5	5.7	4.8	5
Wallace Creek	NA	NA	5.4	5

NOTE: The "lowest" meal limit is the most protective (or restrictive) of the meal recommendations previously calculated in Table D4 for each station using the RfD for mercury and/or PCBs.
Meal = eight ounces
Type: I = individual sample, C = composite sample
Shading = mean meals per month for all marine fishery stations in Central and South Sound.
[a] Meal limit is lowest from table D4 but does not represent all stations in Central Sound (only includes Agate Pass).

APPENDIX E

Contaminant Screening

Puget Sound Fish Tissue Contaminant Screening

Over 100 individual chemicals were analyzed in Puget Sound fish tissue collected by Washington State Department of Fish and Wildlife (WDFW) (West et al. 2001). The goal of this evaluation was to focus on contaminants in fish commonly detected in Puget Sound at levels that have the potential to cause public health concern.

Contaminants were not considered for assessment if they were detected in fewer than 10 % of fish tissue samples. Only a few chemicals or chemical groups were detected in more than 10% of the samples analyzed (alpha chlordane, arsenic, benzyl alcohol, copper, DDT and degradation products, DEHP, mercury, and PCBs). Ninetieth percentile contaminant levels in Puget Sound fish tissue were then compared to health-based comparison values.

DOH used EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories to determine health-based comparison values (EPA 2000). Comparison values were based on a consumption rate representative of a subsistence consumer (142.4 g/day) and derived for non-cancer and cancer endpoints. Contaminant levels exceeding comparison values indicate a subsistence consumer receives a dose greater than the RfD, or results in a cancer risk greater than $1x10^{-5}$.

Table E1. Detection frequency of chemicals analyzed in Puget Sound fish tissue, 1989-2001.

Class	Chemical	N	Detected	Percent Detected	Median MDL	Units
Metals	copper	607	607	100.0		ppm
Metals	mercury	1011	1010	99.9		ppm
PCBs	PCB153	280	277	98.9	0.053	ppb
PCBs	PCB101	279	276	98.9	0.055	ppb
Metals	arsenic	613	603	98.4	0.09	ppm
PCBs	PCB138	278	258	92.8	0.05	ppb
PCBs	PCB118	277	257	92.8	0.049	ppb
PCBs	PCB110	225	201	89.3	0.054	ppb
PCBs	PCB180	270	231	85.6	0.043	ppb
PCBs	PCB128	274	233	85.0	0.054	ppb
PCBs	Aroclor 1260	1107	932	84.2	2	ppb
PCBs	Aroclor 1254	1107	840	75.9	2	ppb
PCBs	PCB105	250	186	74.4	0.045	ppb
Pesticides	ppDDE	1196	832	69.6	1	ppb
PCBs	PCB170	262	177	67.6	0.042	ppb
Pesticides	ppDDD	1212	494	40.8	0.5	ppb
PCBs	PCB156	271	82	30.3	0.041	ppb
Phthalates	bis(2-ethylhexyl)phthalate	561	121	21.6	38	ppb
Pesticides	alpha chlordane	932	177	19.0	0.5	ppb
Miscellaneous Organics	benzyl alcohol	561	90	16.0	13	ppb
Pesticides	ppDDT	1181	170	14.4	1.3	ppb
Metals	lead	708	67	9.5	0.03	ppm

Table E1. (cont.) Detection frequency of chemicals analyzed in Puget Sound fish tissue, 1989-2001.

Class	Chemical	N	Detected	Percent Detected	Median MDL	Units
Pesticides	gamma chlordane	932	84	9.0	0.5	ppb
Pesticides	alpha hexachlorocyclohexane	931	67	7.2	0.5	ppb
Miscellaneous Organics	benzoic acid	556	37	6.7	200	ppb
Pesticides	Dieldrin	932	57	6.1	0.67	ppb
Chlorinated Aromatic Hydrocarbons	hexachlorobenzene	834	35	4.2	18	ppb
PCBs	PCB157	276	11	4.0	0.04	ppb
Phthalates	di-n-butylphthalate	561	12	2.1	45	ppb
PCBs	Aroclor 1248	1152	24	2.1	2	ppb
Phthalates	benzylbutylphthalate	561	10	1.8	25	ppb
Pesticides	opDDD	267	4	1.5	0.11	ppb
Phthalates	diethylphthalate	561	8	1.4	10	ppb
Pesticides	gamma hexachlorocyclohexane	932	13	1.4	0.5	ppb
Low Molecular Weight Aromatics	phenanthrene	561	6	1.1	5.2	ppb
PCBs	PCB77	281	2	0.7	0.063	ppb
Pesticides	opDDT	147	1	0.7	0.16	ppb
Phenols	phenol	551	3	0.5	10	ppb
PCBs	PCB189	280	1	0.4	0.042	ppb
Miscellaneous Organics	N-nitrosodiphenylamine	561	2	0.4	26	ppb
Pesticides	beta hexachlorocyclohexane	932	2	0.2	0.67	ppb
Miscellaneous Organics	isophorone	561	1	0.2	5	ppb
Pesticides	beta endosulfan	932	1	0.1	1	ppb
PCBs	Aroclor 1242	1152	1	0.1	10	ppb
PCBs	Aroclor 1232	1152	0	0.0	20	ppb
PCBs	Aroclor 1221	1152	0	0.0	20	ppb
PCBs	Aroclor 1016	1152	0	0.0	20	ppb
PCBs	PCB126	281	0	0.0	0.06	ppb
PCBs	PCB169	281	0	0.0	0.082	ppb
Pesticides	delta hexachlorocyclohexane	932	0	0.0	0.5	ppb
Pesticides	Aldrin	932	0	0.0	0.5	ppb
Pesticides	Endrin	932	0	0.0	1	ppb
Pesticides	endrin aldehyde	932	0	0.0	1	ppb
Pesticides	alpha endosulfan	932	0	0.0	0.5	ppb
Pesticides	endosulfan sulfate	932	0	0.0	1	ppb
Pesticides	Heptachlor	932	0	0.0	0.5	ppb
Pesticides	heptachlor epoxide	932	0	0.0	0.5	ppb

Table E1. (cont.) Detection frequency of chemicals analyzed in Puget Sound fish tissue, 1989-2001.

Class	Chemical	N	Detected	Percent Detected	Median MDL	Units
Pesticides	Methoxychlor	932	0	0.0	5.3	ppb
Pesticides	Toxaphene	932	0	0.0	10	ppb
Chlorinated Aromatic Hydrocarbons	1,2,4-trichlorobenzene	561	0	0.0	5.4	ppb
Chlorinated Aromatic Hydrocarbons	1,2-dichlorobenzene	561	0	0.0	11	ppb
Chlorinated Aromatic Hydrocarbons	1,3-dichlorobenzene	561	0	0.0	11	ppb
Chlorinated Aromatic Hydrocarbons	1,4-dichlorobenzene	561	0	0.0	11	ppb
Chlorinated Aromatic Hydrocarbons	2-chloronaphthalene	561	0	0.0	10	ppb
Chlorinated Semivolatile Halogens	hexachlorobutadiene	561	0	0.0	25.8	ppb
Chlorinated Semivolatile Halogens	hexachlorocyclopentadiene	561	0	0.0	200	ppb
Chlorinated Semivolatile Halogens	hexachloroethane	561	0	0.0	30	ppb
Halogenated Ethers	4-bromophenylphenylether	561	0	0.0	40	ppb
Halogenated Ethers	4-chlorophenylphenylether	561	0	0.0	39	ppb
Halogenated Ethers	bis(2-chloroethoxy)methane	561	0	0.0	10.6	ppb
Halogenated Ethers	bis(2-chloroethyl)ether	561	0	0.0	10	ppb
Halogenated Ethers	bis(2-chloroisopropyl)ether	561	0	0.0	40	ppb
High Molecular Weight Aromatics	benzo(a)anthracene	561	0	0.0	11	ppb
High Molecular Weight Aromatics	benzo(a)pyrene	561	0	0.0	10	ppb
High Molecular Weight Aromatics	benzo(b)fluoranthene	561	0	0.0	11	ppb
High Molecular Weight Aromatics	benzo(g,h,i)perylene	561	0	0.0	25.4	ppb
High Molecular Weight Aromatics	benzo(k)fluoranthene	561	0	0.0	10.6	ppb
High Molecular Weight Aromatics	chrysene	561	0	0.0	10	ppb
High Molecular Weight Aromatics	dibenzo(a,h)anthracene	561	0	0.0	33	ppb
High Molecular Weight Aromatics	fluoranthene	561	0	0.0	5.2	ppb
High Molecular Weight Aromatics	indeno(1,2,3-c,d)pyrene	561	0	0.0	25.4	ppb

Table E1 (cont.)**.** Detection frequency of chemicals analyzed in Puget Sound fish tissue 1989-2001.

Class	Chemical	N	Detected	Percent Detected	Median MDL	Units
High Molecular Weight Aromatics	pyrene	561	0	0.0	5.2	ppb
Low Molecular Weight Aromatics	2-methylnaphthalene	561	0	0.0	20	ppb
Low Molecular Weight Aromatics	acenaphthene	561	0	0.0	5	ppb
Low Molecular Weight Aromatics	acenaphthylene	561	0	0.0	5.2	ppb
Low Molecular Weight Aromatics	anthracene	561	0	0.0	10	ppb
Low Molecular Weight Aromatics	fluorene	561	0	0.0	5.2	ppb
Low Molecular Weight Aromatics	naphthalene	561	0	0.0	5.2	ppb
Miscellaneous Organics	carbazole	504	0	0.0	10.4	ppb
Miscellaneous Organics	coprostanol	372	0	0.0	180	ppb
Miscellaneous Organics	dibenzofuran	561	0	0.0	11	ppb
Miscellaneous Organics	1,2-diphenylhydrazine	561	0	0.0	11	ppb
Miscellaneous Organics	2,4-dinitrotoluene	561	0	0.0	26	ppb
Miscellaneous Organics	2,6-dinitrotoluene	561	0	0.0	18	ppb
Miscellaneous Organics	2-nitroaniline	561	0	0.0	30	ppb
Miscellaneous Organics	3,3-dichlorobenzidine	57	0	0.0	13	ppb
Miscellaneous Organics	3-nitroaniline	534	0	0.0	33	ppb
Miscellaneous Organics	4-chloroaniline	561	0	0.0	36	ppb
Miscellaneous Organics	4-nitroaniline	561	0	0.0	80	ppb
Miscellaneous Organics	aniline	561	0	0.0	45	ppb
Miscellaneous Organics	nitrobenzene	561	0	0.0	11	ppb
Miscellaneous Organics	N-nitrosodimethylamine	551	0	0.0	40	ppb
Miscellaneous Organics	N-nitroso-di-n-propylamine	561	0	0.0	11	ppb
Phenols	2,4-dimethylphenol	561	0	0.0	30	ppb
Phenols	2-methyphenol	561	0	0.0	26	ppb
Phenols	4-methylphenol	561	0	0.0	26	ppb

Table E1 (cont.)**.** Detection frequency of chemicals analyzed in Puget Sound fish tissue 1989-2001.

Class	Chemical	N	Detected	Percent Detected	Median MDL	Units
Phthalates	dimethylphthalate	561	0	0.0	25	ppb
Phthalates	di-n-octylphthalate	561	0	0.0	10	ppb
Substituted Phenols	2,4,5-trichlorophenol	561	0	0.0	20	ppb
Substituted Phenols	2,4,6-trichlorophenol	561	0	0.0	40	ppb
Substituted Phenols	2,4-dichlorophenol	561	0	0.0	26	ppb
Substituted Phenols	2,4-dinitrophenol	534	0	0.0	200	ppb
Substituted Phenols	2-chlorophenol	561	0	0.0	26	ppb
Substituted Phenols	2-nitrophenol	561	0	0.0	25	ppb
Substituted Phenols	4,6-dinitro-o-cresol	534	0	0.0	198	ppb
Substituted Phenols	4-chloro-3-methylphenol	552	0	0.0	26	ppb
Substituted Phenols	4-nitrophenol	542	0	0.0	36	ppb
Substituted Phenols	pentachlorophenol	556	0	0.0	160	ppb

NOTE: MDL = Method detection limit

Table E2. Ninetieth percentile concentration of contaminants detected in at least 10% of Puget Sound fish fillet samples compared to health-based comparison values.

Contaminant	90th percentile (ppb)	Comparison Value (ppb)	Evaluate/Not Evaluate
Arsenic	Arsenic was analyzed as total arsenic. Speciated arsenic data from PSAMP are not available		
Benzyl Alcohol [a]	68	147,000	No
Bis(2ethylhexyl)phthalate [a]	280	351	No
Chlordane	1.3	14	No
Copper	635	19,600	No
DDD	2.6	20	No
DDE	14	14	No
DDT	0.7	14	No
PCBs	99	2	Yes
Mercury	291	49	Yes

[a] Contaminant no longer analyzed by PSAMP.

Summary

Based on these analyses, two chemicals were identified as potential contaminants of concern in Puget Sound fish (PCBs and mercury). Arsenic was not chosen as a contaminant of concern because inorganic concentrations were not identified. Inorganic arsenic, the most toxic form of arsenic, is expected to be low in Puget Sound finfish. All other contaminants detected in at least 10% of tissue samples were below comparison values.

References

EPA. 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Vol. 1. Fish Sampling and Analysis. Third Edition. EPA-823-B-00-007.

West J, O'Neill S, Lippert G, and Quinnell S. 2001. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington: Results of the Puget Sound Assessment and Monitoring Program fish component, 1989-1999. Technical Report FTP01-14, Washington Dept. of Fish and Wildlife, Olympia, WA.