Human Health Evaluation of Contaminants in Puget Sound Dungeness Crab (*Metacarcinus magister*) and Spot Prawn (*Pandalus platyceros*)

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Prepared by

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Acknowledgements

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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.
Bioaccumulation	The buildup of contaminants in an organism's tissues over time via ingestion of prey.
Bioconcentration	An increase in contaminant concentration in organisms relative to their environment.
Biokinetic Slope Factor (BKSF)	An empirically-based estimate of the slope of the linear relationship between blood lead (PbB) concentration and lead uptake (ug/dL per ug/day)
Biomagnification	An increase in contaminant level concentration in predators relative to their prey.
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.
Hazard Quotient	HQ - The ratio of the potential exposure to a substance and the level at which no adverse effects are expected
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.
Persistent Organic Pollutants (POPs)	Organic compounds resistant to degradation that persist in the environment, are capable of long-range transport, and often bioaccumulate in living tissue
Resection	Surgical removal of all or part of an organ, tissue, or structure.
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).
Unlimited	Meal restrictions based on contaminant concentrations that result in greater than eight meals per month.

ACRONYMS AND ABBREVIATIONS

AHA	American Heart Association
API	Asian & Pacific Islanders
ATSDR	Agency for Toxic Substances and Disease Registry
COC	Contaminant of Concern
CSF	Cancer Slope Factor
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
MDL	Method Detection Limit
MRL	Minimum Risk Level
MTCA	Model Toxics Control Act
NOAEL	No Observed Adverse Effect Level
NMFS	National Marine Fisheries Service
OEPHS	Office of Environmental Public Health Sciences
PBDE	Polybrominated Diphenyl Ether
PBT	Persistent Bioaccumulative Toxics
PCB	Polychlorinated Biphenyl
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

Executive Summary

Background

Washington State Department of Fish and Wildlife (WDFW) sampled Dungeness crab (*Metacarcinus magister*) and spot prawn (*Pandalus platyceros*) from Puget Sound during 2011 and 2012 to determine contaminant levels in the two crustacean species. Concentrations of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides as well as mercury, arsenic, cadmium, copper, lead and zinc were analyzed in crab and prawn tissues. Sampling was conducted in nine WDFW Marine Areas (MA) (fishery management areas for marine recreational fishing per WAC 220-56-185) and three urbanized embayments. All crab and prawn met size, sex, and shell hardness criteria set by WDFW fishing regulations.

Two hundred forty Dungeness crab specimens were collected at 54 stations, generating 56 crab muscle and 19 crab hepatopancreas composited samples. Seven hundred seventy-seven spot prawn specimens were collected at 42 stations, generating 43 spot prawn muscle (tail) and 16 spot prawn head-tissue (containing the hepatopancreas[1]) composited samples.

Washington Department of Health Assessment

The Washington State Department of Health (DOH) evaluated contaminant concentrations in Dungeness crab muscle and hepatopancreas and spot prawn muscle and head tissues for potential public health concerns. This evaluation compared tissue concentrations with established screening level values based on non-cancer and cancer health end-points. Values that exceeded screening levels were further evaluated. Meal restrictions were calculated to ensure exposure to contaminants of concern in Puget Sound Dungeness crab or spot prawn are not exceeded by seafood consumers.

Findings

With the exception of a few metals, all contaminant concentrations in the hepatopancreas of Dungeness crab and head tissue of spot prawn were greater than their corresponding muscle tissue. Of the contaminants analyzed, PCBs were detected most frequently in Dungeness crab and spot prawn and were highest in specimens taken from urban areas. DDTs and PAHs in both species and PBDEs in crab were detected frequently at lower concentrations, with highest levels in samples from urban areas. PBDEs were rarely detected in spot prawn from any area. Mercury, arsenic, copper and zinc were the most frequently detected metals in Dungeness crab, while those metals, in addition to cadmium, were most frequently detected in spot prawn. Most metal concentrations in Dungeness crab and spot prawn muscle tissue were relatively evenly distributed throughout all Marine Areas and urban embayments of Puget Sound. Mercury was the only metal that occurred in significantly greater levels in urban than non-urban areas.

1 The digestive gland in crustaceans, where many contaminants may concentrate.

Recommendations

Dungeness Crab from Puget Sound

Based on tissue concentrations, frequency of detection, and toxicity, DOH concluded that Puget Sound Dungeness crab can be safely consumed at unrestricted rates from all Marine Areas with some exceptions (Table ES-1, Figure ES-1). Consumption guidance for crab hepatopancreas was determined and ranges from no consumption to four 8-ounce servings per month (Table ES-1, Figure ES-2).

Table ES-1. Meal recommendations for Dungeness crab muscle tissue and hepatopancreas from Puget Sound listed by Marine Areas.

Recreational Marine Area		Consumption Guidance for Crab Muscle Tissue from Puget Sound	Exceptions for Crab Muscle Tissue	Consumption Guidance for Crab Hepatopancreas from Puget Sound
6	East Juan de Fuca Strait	Unrestricted	Port Angeles Harbor: 4 crab per month	MA 6: 4 per month Port Angeles: No hepatopancreas
7	San Juan Islands	Unrestricted	None	4 per month
8.1	Deception Pass, Hope Island, and Skagit Bay	Unrestricted	None	4 per month
8.2	Port Susan and Port Gardner	Unrestricted	None	1 per month
9	Admiralty Inlet	Unrestricted	None	2 per month
10	Seattle-Bremerton Area	8 meals per month	Elliott Bay: 2 crab per month Sinclair Inlet: 2 crab per month	No hepatopancreas
11	Tacoma-Vashon Area	Unrestricted	Commencement Bay: 4 crab per month	2 per month
12	Hood Canal	Unrestricted	None	2 per month
13	South Puget Sound	Unrestricted	None	1 per month

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

Spot Prawn from Puget Sound

Spot prawn from Puget Sound were assessed for contaminants and DOH concluded that this species can be safely consumed at unrestricted rates from all Marine Areas with three exceptions (Table ES-2, Figure ES-3):

- No more than eight meals of spot prawn tails per month in Elliott Bay, Sinclair Inlet, and Commencement Bay.

However, elevated levels of PCBs, cadmium, and mercury were found in the heads of spot prawn, leading to a range of restrictions (Table ES-2, Figure ES-4).

Table ES-2. Meal recommendations for spot prawn muscle and head tissue from Puget Sound listed by Marine Areas.

Recreational Marine Area		Consumption Guidance for Spot Prawn from Puget Sound	Exceptions for Spot Prawn Muscle Tissue	Consumption Guidance for Spot Prawn Heads from Puget Sound
6	East Juan de Fuca Strait	Unrestricted	None	No more than eight meals with heads per month
7	San Juan Islands	Unrestricted	None	No restrictions
8.1	Deception Pass, Hope Island, and Skagit Bay	Unrestricted	None	No consumption of heads
8.2	Port Susan and Port Gardner	Unrestricted	None	No consumption of heads
9	Admiralty Inlet	Unrestricted	None	No consumption of heads
10	Seattle-Bremerton Area	Unrestricted	Elliott Bay: 8 meals per month Sinclair Inlet: 8 meals per month	No consumption of heads
11	Tacoma-Vashon Area	Unrestricted	Commencement Bay: 8 meals per month	No consumption of heads
12	Hood Canal	Unrestricted	None	No more than eight meals with heads per month
13	South Puget Sound	Unrestricted	None	No consumption of heads

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

Other Recommendations

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

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

Most foods, regardless of source, contain some contaminants. Switching from seafood to other types of food may not eliminate contaminant exposure. One can safely continue to eat the AHA's recommended two seafood meals per week by avoiding species that are high in contaminants. The meal limits above are meant to guide people toward making informed decisions when selecting seafood to eat.

Figure ES-1. Meal limit recommendations for Dungeness crab muscle tissue from Puget Sound. Area designations are consistent with WDFW Sport Fishing Regulation Recreational Marine Areas.

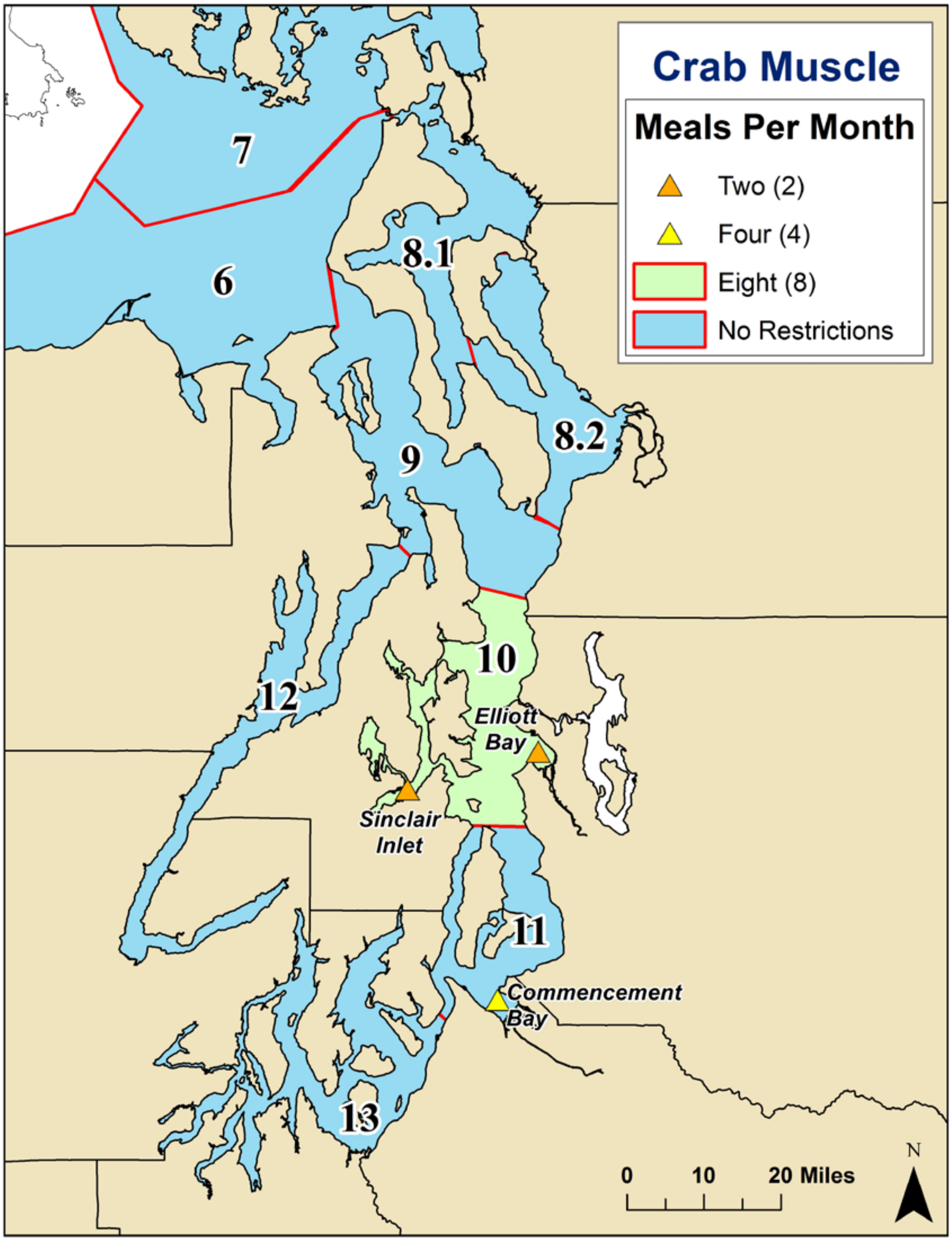


Figure ES-2. Meal limit recommendations for Dungeness Crab Hepatopancreas Tissue from Puget Sound. Area designations are consistent with WDFW Sport Fishing Regulation Recreational Marine Areas.

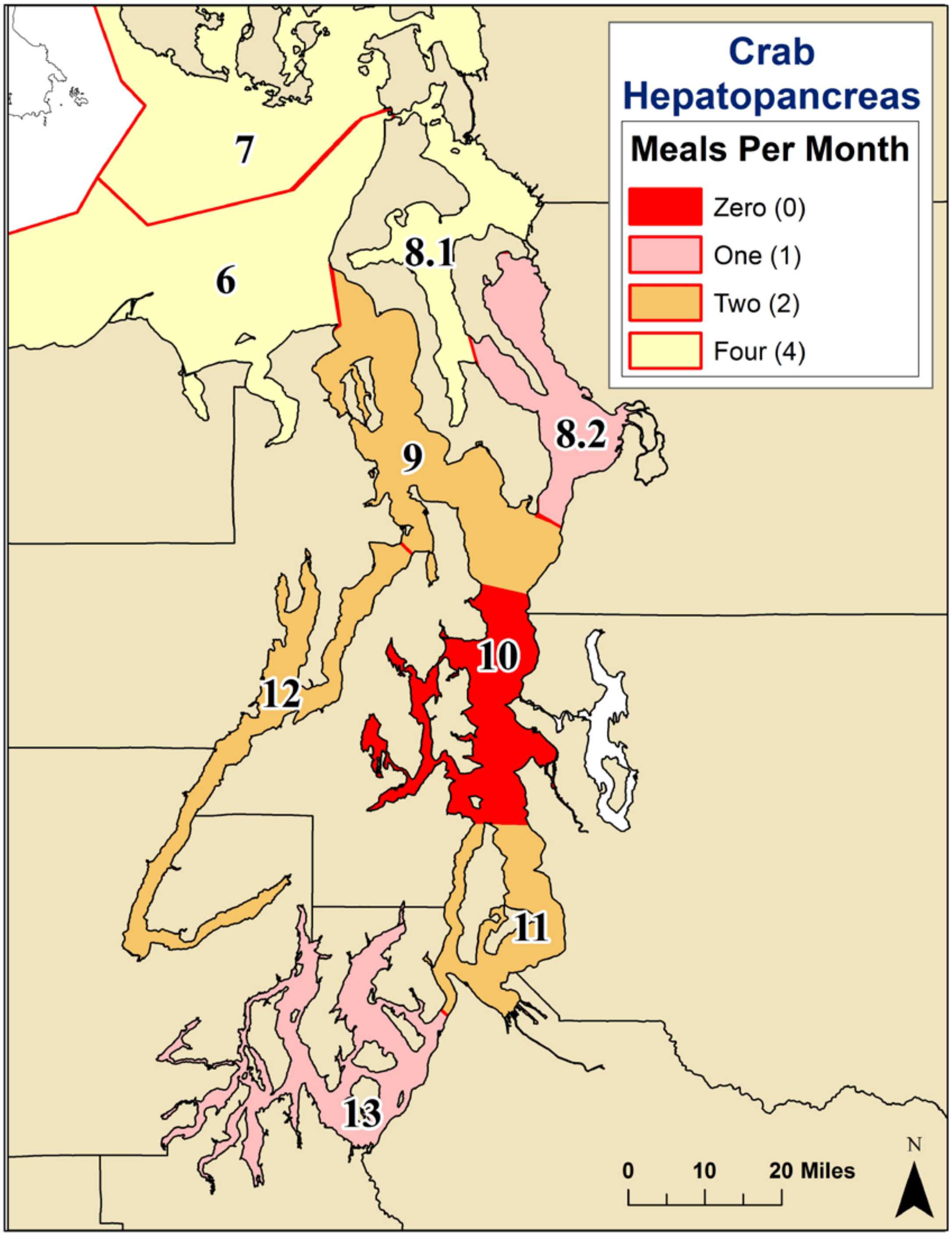


Figure ES-3. Meal limit recommendations for spot prawn muscle tissue from Puget Sound. Area designations are consistent with WDFW Sport Fishing Regulation Recreational Marine Areas.

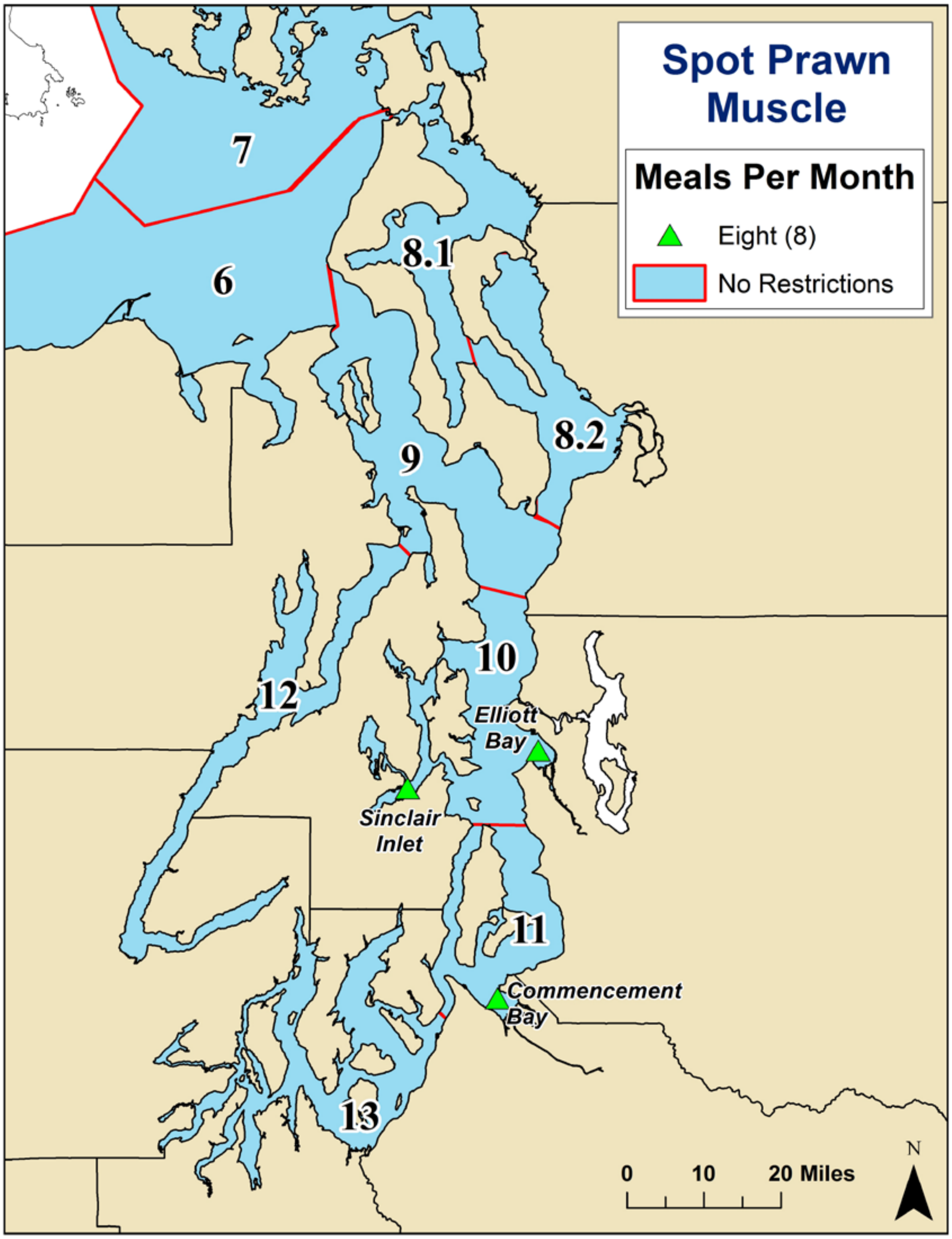
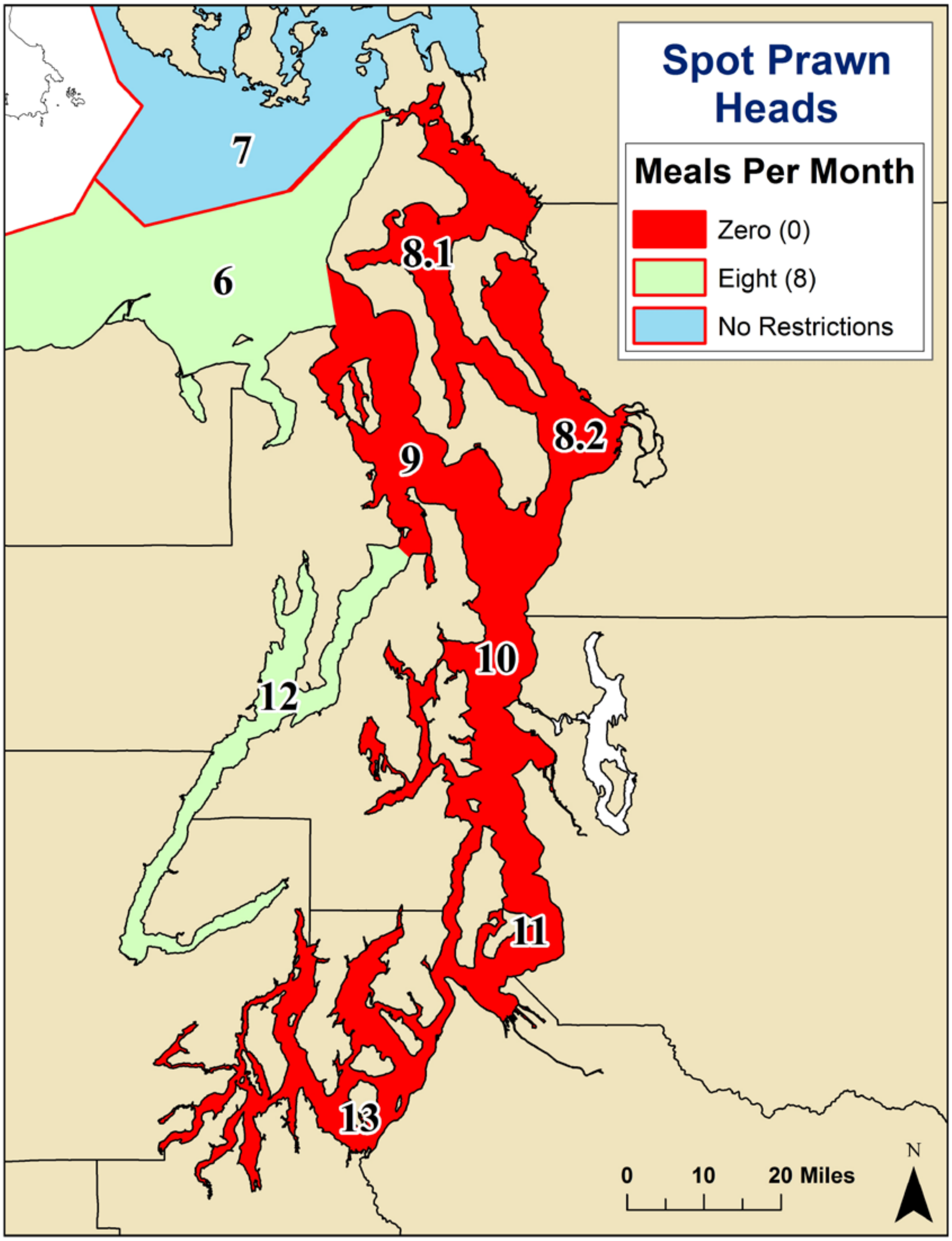


Figure ES-4. Meal limit recommendations for spot prawn head tissue from Puget Sound. Area designations are consistent with WDFW Sport Fishing Regulation Recreational Marine Areas.



Introduction

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 Public Health Sciences (OEPHS) mission is to "use sound science to inform environmental health public health policies and practices." One focus of OEPHS is to provide seafood consumption advice on known toxic chemicals found in fish and shellfish.

Washington 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. Previously, DOH evaluated WDFW tissue data and reported on potential health impacts to humans who eat Puget Sound fish (DOH 2006). In that report, several recommendations were made for future sampling efforts; one was to collect tissue data for Dungeness crab (*Metacarcinus magister*) and spot prawn (*Pandalus platyceros*) from Puget Sound to evaluate potential human health impacts associated with consumption.

Contaminants in Dungeness crab and spot prawn are of particular interest in Puget Sound because of their importance in commercial fisheries and recreational fishing. In 2012, the recreational fishery alone landed an estimated total of 132,000 pounds of spot prawn (nearly 180,000 pounds in 2013) and just over 2 million pounds of Dungeness crab (just under 2 million pounds in 2013). In 2012, the commercial fleet collected almost 15 million pounds of Dungeness crab and 634,000 pounds of spot prawn throughout Puget Sound (E. Kraig, personal communication, June 3, 2014; Carey et al. 2014).

Dungeness crab, or *Metacarcinus magister* (formerly known as *Cancer magister*), is one of the largest edible crabs along the Pacific Coast. This species has a geographic range on the eastern Pacific coast from Point Concepcion, California, to the Pribilof Islands, Alaska (CDFG 1994). Dungeness crab is a decapod, with the distinguishing feature of white-tipped pincers on the claws. This species is usually light reddish brown on the carapace with a pattern of lighter streaks and spots on the back. Males range from 18 to 23 centimeters (cm) (about 7 to 9 inches) in width and 10 to 13 cm (4 to 5 inches) long. The width of the back is about 23 cm (9 inches) (Headstrom 1979) (Appendix A).

Spot prawn, also known as spot shrimp, is the largest shrimp on the west coast of North America (Appendix A). This species may reach a length of more than 23 cm (9 inches), excluding the antennae, with a maximum length of over 30 cm (12 inches). In Puget Sound, spot prawn is most common in Hood Canal, the San Juan Islands, and northern and central Puget Sound. This is one of the most important shrimp species for both sport and commercial harvesters in the region. Spot prawn is usually reddish brown or tan with white lines on the head and distinctive white spots on the first and fifth abdominal segments. It is distinguished from similar species by its large size and white spots.

In 2011 and 2012, WDFW conducted a one-time assessment of contaminants in Dungeness crab and spot prawn to evaluate the geographic extent and magnitude of toxics in these two species in Puget Sound waters (Carey et al. 2014). Analyses were conducted on persistent organic pollutants (POPs) including polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides (OCPs), as well as six metals (mercury, arsenic, cadmium, copper, lead, and zinc) (Appendix B).

WDFW sampled over as wide a geographic area as possible across Marine Areas (MAs) while targeting locations typically fished by sport and tribal fishers (Carey et al. 2014). However, Dungeness crab and spot prawn tissue samples were not collected from all MAs or urban embayments because these species were not abundant everywhere; for example, Dungeness crab hepatopancreas, spot prawn muscle, and spot prawn heads were not analyzed from Sinclair Inlet.

Only crab and spot prawn that met conditions of WDFW fishing regulations were collected for this study. Hard-shelled male Dungeness crab measuring greater than 6.2 inches in carapace width and adult-sized spot prawn measuring greater than 1.1 inches in carapace length were used. Muscle tissue was taken from all samples and hepatopancreas (crab) or head tissue (prawn) was taken from a subset of samples.

The purpose of this report is to review and evaluate potential health risks that may result from exposure to toxic contaminants through the consumption of Puget Sound Dungeness crab and spot prawn based on data collected by WDFW. PCBs, PBDEs, mercury, and cadmium were assessed for non-cancer endpoints. Cancer health endpoints were also evaluated. Other factors such as chemical toxicity, potential exposure (based on estimated consumption rates), and the overall health benefits of eating seafood were weighed by DOH to provide guidance for consuming crab and shrimp.

Methods

Field and Laboratory Analysis

Methods for sampling and analyzing tissue samples in this study followed standard operating procedures detailed in the WDFW's Quality Assurance Project Plan (QAPP): (http://wdfw.wa.gov/publications/01436/wdfw01436.pdf). For more detailed information on sample size and station location, specimen collection efforts, compositing of samples, and Dungeness crab and spot prawn sample preparation, please consult Carey et al. (2014). Information on the total number of composite samples for both species summarized by WDFW MAs is shown, below (Table 1). Further details of station descriptions and locations are listed in Appendix C.

Table 1. Total number of tissue composites created for Dungeness crab and spot prawn by sampling area. NS = not sampled (from Cary et al. 2014)

Location	Dungeness crab			Spot prawn		
	Stations within Sampling Area	Composite Samples		Stations within Sampling Area	Composite Samples	
		Muscle	Hepato-pancreas		Muscle	Head tissue
MA 6	1	1	1	2	2	1
MA 7	5	5	2	5	5	2
Ma 8.1	6	6	1	6	6	1
MA 8.2	6	6	1	6	6	2
MA 9	7	7	2	3	3	0
MA 10	7	7	2	4	4	1
Elliott Bay	5	5	4	6	6	6
Sinclair Inlet	1	3	0	0	NS	NS
MA 11	3	3	1	3	3	0
Commencement Bay	3	3	2	0	NA	NS
MA 12	6	6	1	6	6	1
MA 13	4	4	2	1	2	2
TOTALS	**54**	**56**	**19**	**42**	**43**	**16**

Laboratory analytical methods used by WDFW to analyze Dungeness crab and spot prawn muscle tissue, Dungeness crab hepatopancreas, and spot prawn head/thorax tissue can be found in West et al. 2012 and Carey et al. 2014. Samples were analyzed for persistent organic pollutants and metals at the National Oceanic and Atmospheric Administration's (NOAA) Northwest Fisheries Science Center (NWFSC) and the King County Environmental Laboratory (KCEL), respectively.

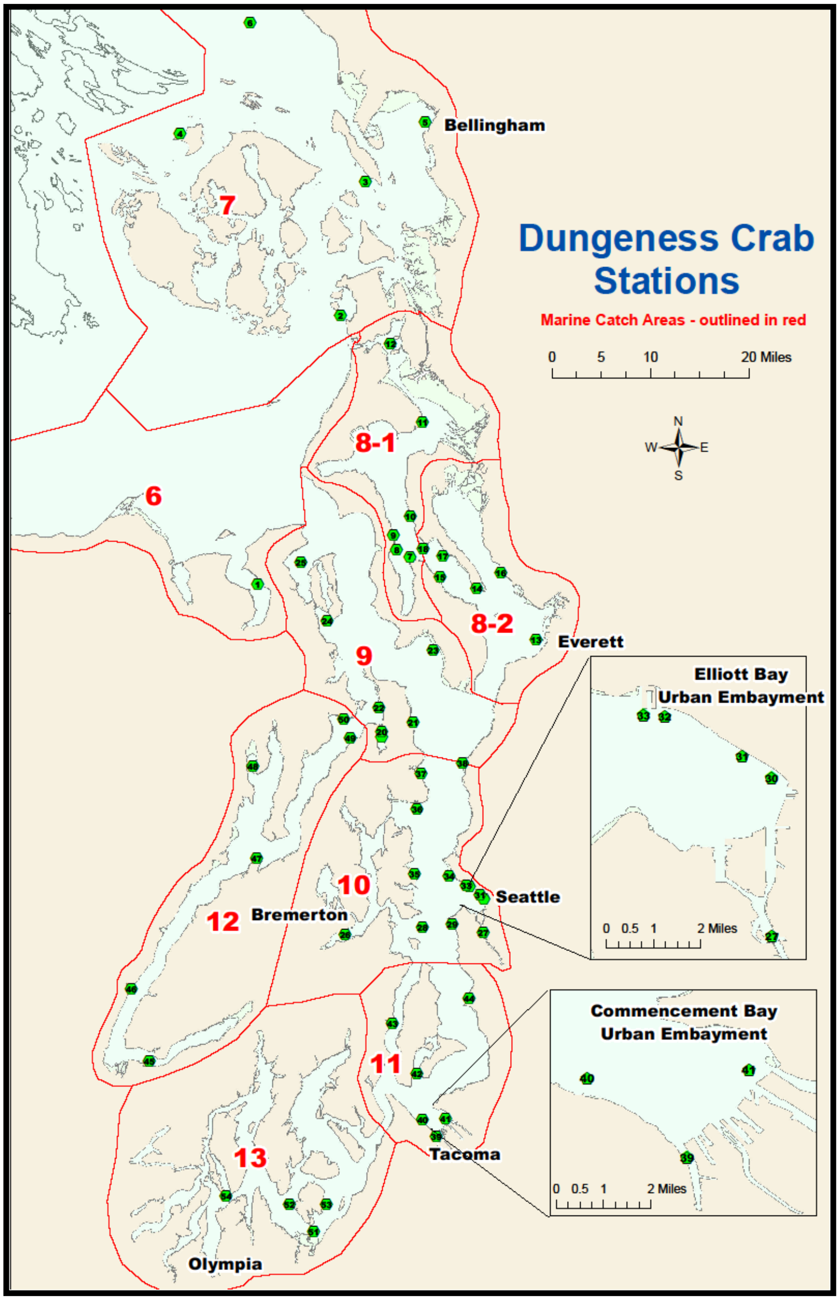


Figure 1. Map of Dungeness crab collection station locations (Carey et al. 2014).

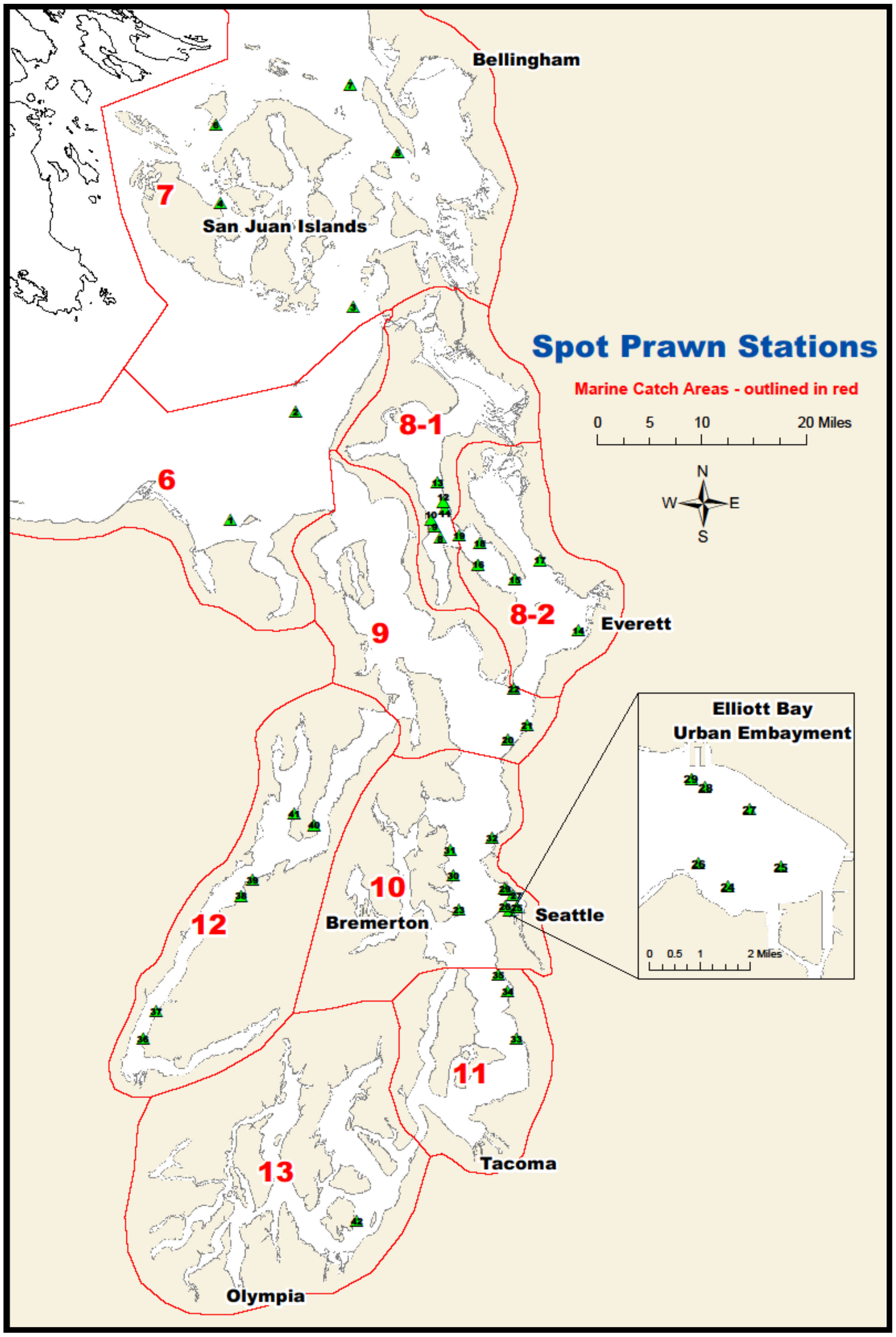


Figure 2. Map of spot prawn collection station locations (Carey et al. 2014).

Health Assessment

DOH's evaluation of chemicals in seafood tissue for possible advisories follows the guidance recommended by EPA for the assessment of cancer and non-carcinogenic toxicity (EPA 2000a).

The following process is used by DOH:

1. Determine mean concentrations of chemicals of concern in crab and prawn tissue.

2. Compare mean tissue chemical concentrations with corresponding health based screening level (SL) concentrations (see Table 2). DOH has established SLs for non-cancer health effects.

3. If crab or spot prawn tissue concentrations exceed SLs, continue to evaluate risk and calculate possible meal restrictions. If tissue concentrations are below SLs, no further evaluation is required.

4. In a further step, DOH calculates acceptable meal limits based on exposure to multiple chemicals, if appropriate, to account for combined toxicity of chemicals acting on the same organ systems.

5. Integrate risk management and risk communication decisions into calculations and provide meal restriction recommendations.

DOH considers results of the above analyses along with other factors, such as the health benefits of eating fish, availability of less contaminated fish or food from other sources, whether contaminants can be reduced by cleaning and cooking techniques, and background contaminant concentrations to formulate health messages to communicate to the public. Advice derived from this evaluation will be geared toward people who eat crab or spot prawn from Puget Sound.

Screening Analysis

Fish tissue chemical SLs were developed as a preliminary screening tool to assist in evaluating chemical levels in seafood that warrant further evaluation. SLs for each chemical contaminant are defined as the chemical concentration in seafood tissue that is of potential public health concern. SL values are used to compare against contaminants found in seafood tissue (EPA 2000a).

For this evaluation, DOH calculated SLs based on a consumption rate of two 8 ounce meals per week. This consumption rate corresponds to advice from the American Heart Association that recommends people consume two meals per week to gain heart health benefits from consuming seafood. While DOH does not formally provide consumption advice on seafood consumption rates greater than two meals per week, DOH does calculate meal recommendations using all available contaminant concentrations measured in a given species. This information is found in the meal restriction Tables 8a-d in this report for use by individuals who consume crab and prawn above the recommended two meals per week.

Non-cancer SLs for the 13 chemical analyses, including seven organic pollutants and six metals, are shown (Table 2). The following equation is used by DOH to derive a non-carcinogen SL:

$$\text{Screening Level } (SL_{nc}) = RfD \times BW \times UCF / CR$$

Where: SL_{nc} = chemical specific noncancer screening concentration (mg/kg)
RfD = chemical specific oral reference dose (mg/kg-day)
BW = mean body weight adult (70 kg) or woman of childbearing age (60 kg)
UCF = unit conversion factor ($1x10^{-3}$ g/kg)
CR = consumption rate (g/day)

Table 2. Non-Cancer screening levels.

Non-Cancer Screening Levels			
Analyte		**RfD* (mg/kg-day)**	**Screening Level (ppm)**
Organics	PCBs (Total)	0.00002	0.023
	PBDE (Total)**	Variable (used PBDE-47) 0.0001	0.101
	DDT (Total)	0.0005	0.503
	Chlordane (Total)	0.0005	0.586
	Hexachlorohexane (Total)	0.0003	0.352
	Hexachlorobenzene	0.0008	0.938
	Total PAHs (Total)	0.004	4.69
Metals	Mercury	0.0001	0.101
	Arsenic (inorganic)‡‡	0.0003	0.352
	Cadmium	0.001	1.173
	Copper	NA	NA
	Lead†	<5 ug/dl	<5 ug/dl
	Zinc‡	0.3	351.8

Reference:
*http://www.epa.gov/iris/index.html
General population consumption rate = 59.7 g/day or eight meals per month
Mercury, total DDT, and PBDEs (neurological endpoints) were assessed using 60 kg BW.
For other chemicals, 70 kg body weight was used.
** EPA's *Reference Dose* (RfD) for four congeners of polybrominated diphenyl ethers:
BDE-47 RfD = 1.0×10^{-4} mg/kg-day
BDE-99 RfD = 1.0×10^{-4} mg/kg-day
BDE-153 RfD = 2.0×10^{-4} mg/kg-day
BDE-209 RfD = 7.0×10^{-3} mg/kg-day
†IEUBK – EPA's Integrated Exposure Uptake Biokinetic Model for Lead in children is used to predict blood lead levels in children.
‡Zinc is an essential nutrient found in almost every cell. The Recommended Daily Allowance (RDA), one of the Dietary Reference Intakes (DRIs), is the average daily dietary intake level that is sufficient to meet the nutrient requirements of nearly all (97-98%) healthy individuals. For infants 0 to 6 months, the DRI is in the form of an Adequate Intake (AI), which is the mean intake of zinc in healthy, breastfed infants. The AI for zinc for infants 0 to 6 months is 2.0 milligrams (mg) per day. The 2001 RDAs for zinc for infants 7 through 12 months, children and adults in mg per day are: 7 months through 3 years, the AI is 3.0 mg per day; 4 to 8 years 5 mg per day; 9 to 13 years is 8 mg per day; 14 and up is 13 mg per day. (Results of two national surveys, the National Health and Nutrition Examination Survey (NHANES III 1988-91) and the

Continuing Survey of Food Intakes of Individuals (CSFII 1994) indicate that most infants, children, and adults consume recommended amounts of zinc).
‡‡Cancer values for inorganic arsenic were not evaluated because there is no data on arsenic speciation in crab and prawns from Puget Sound. The majority of arsenic in fish is presumed to be organic arsenic, which is much less toxic than the inorganic form.

Approach for Assessing Lead Exposures in Children

Potential health effects due to lead exposure were assessed for children and adults. Young children (aged 6-84 months) are usually the population of chief concern for lead exposure because: 1) young children tend to have higher intakes of environmental media (especially for soil and dust) per unit body weight than adults, 2) young children tend to absorb a higher fraction of ingested lead than adults, and 3) young children are inherently more susceptible to adverse effects of lead since their nervous systems are still developing. The biokinetics of lead are different from most toxicants because lead is stored in bone and remains in the body long after it is ingested. Because the biokinetics of lead are different, EPA has not developed an RfD for lead; therefore lead exposures must be evaluated differently than for other chemicals such as PCBs and mercury.

Lead exposure is evaluated using a biokinetic model, and risk is interpreted in terms of blood lead concentration rather than a hazard quotient. To evaluate the potential for harm, public health agencies often use a computer model that can estimate blood lead levels in children younger than seven years of age who are exposed to lead. In this evaluation, children's exposure to lead is evaluated using the Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) developed by the EPA. The IEUBK model predicts blood lead levels in a distribution of exposed children based on the amount of lead that is in environmental media (e.g., soil, air, water, or diet) (EPA 2002) and uses the results to evaluate the risk of lead poisoning for an average child.

At present it is difficult to identify what degree of lead exposure, if any, can be considered safe in young children. Some studies report subtle signs of lead-induced neurobehavioral effects in children beginning at blood lead levels around 10 µg/dL or even lower. In 2012, CDC updated its recommendations on children's blood lead levels and defined a reference value of 5 µg/dL to identify children with elevated blood lead levels (CDC 2012). This reference range value is based on the 97.5th percentile of the 2007-2010 National Health and Nutrition Examination Survey's (NHANES) blood lead distribution in children. In evaluating lead concentrations in crab and prawn, we used the IEUBK model to estimate the percentage of children that could have elevated blood lead levels if they frequently eat lead-contaminated seafood. For children who are regularly exposed to lead-contaminated seafood, the IEUBK model can estimate the probability that any child could have a blood lead concentration that exceeds 5 µg/dl due to their diet. Exceedance of lead exposure is based on EPA's goal that no individual will have greater than a 5% probability of having a blood lead concentration above the target value of 5 µg/dL.

The EPA IEUBK model specifies default input parameters that include lead soil concentrations, outdoor and indoor dust lead concentrations, outdoor air lead concentration, lead drinking water concentrations, dietary lead intake as well as default lead bioavailability values when site specific values are not available. This assessment focuses primarily on lead exposure from the consumption of crab or prawn and whether lead concentrations in either of these Puget Sound species would result in exceedance of CDC's target value. Outdoor soil lead concentrations were changed to 20 ppm. This concentration is based on Puget Sound area wide soil monitoring results (Ecology 1994). Other default parameters (i.e., outdoor air lead concentration of 0.1 µg/m^3, and drinking water lead concentration of 4 µg/kg) were retained. Default bioavailability values were also used to estimate the percentage of lead uptake from the gut or lungs. To assess the lead hazard associated with seafood consumption, the IEUBK model requires information on the percentage of total seafood consumption consisting of locally caught fish (i.e., average-end recreational estimate for a child or non-tribal high-end consumers) as a percentage of a child's overall meat diet as well as the average lead concentration in locally caught fish tissue. This evaluation assumes conservative (i.e., protective) exposure values by using a seafood ingestion rate of 46.7 g/day that encompasses 50% of a child's total meat intake that contains the mean lead concentration of either crab or prawn.

It is important to note that the IEUBK model is not expected to accurately predict the blood lead level of a child (or a small group of children) at a specific point in time. In part, this is because a child (or group of children) may behave differently and therefore have different amounts of exposure to contaminated soil and dust than the average group of children used by the model to calculate blood lead levels. For example, the model does not take into account reductions in exposure that could result from community education programs. The IEUBK model was also not designed to assess the short-term, periodic, or acute exposures, or the deliberate ingestion (e.g., pica) of soil in which there are excessive soil ingestion rates. Instead, the role of the IEUBK model is to simulate blood lead (PbB) concentrations associated with continuous exposures of sufficient duration to result in a quasi-steady state (EPA 2002). Infrequent and non-continuous exposures (i.e., less than 1 day per week over a minimum duration of 90 days) would be expected to produce oscillations in blood lead concentrations associated with the absorption and subsequent clearance of lead from the blood between each exposure event. The IEUBK model, therefore, can only provide an approximation of quasi-steady-state PbB concentrations during non-continuous exposure scenarios (EPA 2003). Despite this limitation, the IEUBK model is a useful tool to help prevent lead poisoning because of the information it can provide about the hazards of environmental lead exposure.

Approach for Assessing Lead Exposures in Adults

The adult lead model (ALM, Version June 2009) was used to estimate the probability that a fetus born to a mother who frequently eats lead-contaminated seafood could have elevated blood lead levels (BLL). The EPA's adult blood lead model is useful to predict blood lead levels in adult women and their fetuses. The adult model uses well established default values and differs from the Children's IEUBK Model in that the adult model estimates fetal exposure based on maternal exposure to lead. The adult model considers lead exposure through the ingestion of soil and food. In this application, ingestion of lead from the consumption of Puget Sound resident crab or prawn was used to represent maternal exposure. The dose of lead received through this pathway was then converted to a blood lead level by using the ratio of blood lead to lead dose, the biokinetic slope factor (BKSF). As part of the model, the default maternal BLL in the absence of site-specific lead exposure pathways (1.0 µg/dL) was incorporated into the calculation. The adult exposure was based on consuming 29.9 g/day of seafood along with the mean lead tissue concentration in either resident crab or prawn species for 365 days per year.

Calculating Meal Limits for Individual Chemical Exposures

When estimated exposures for any given population exceed comparison values considered to be protective (i.e. RfDs or acceptable cancer risks), meal limits are calculated to inform any advice that might be provided to consumers. DOH calculates allowable meal limits based on EPA's RfD, ATSDR's MRL, or EPA's Cancer Slope Factor (CSF), the average body weight of an individual, and the known contaminant concentration in seafood. These calculations allow DOH to formulate advice that will be useful to consumers.

By using the known concentration of a contaminant in a seafood species, it is possible to calculate a meal limit for that species that will result in a dose equivalent to the RfD for that contaminant. In this approach, the RfD is used to calculate the quantity of seafood a person of a given body weight can safely consume given varying contaminant concentrations found in seafood tissue. The equation used to calculate a safe consumption rate is shown below, with exposure parameters defined by EPA (EPA 2000b) (Table 3):

Non-cancer meal equation:

$$Meal\ per\ month = \frac{RfD\ x\ BW\ x\ CF1\ x\ CF2}{MS\ x\ C}$$

Table 3. Exposure parameters for calculating seafood meal limits.

Parameter	Value	Units	Comments	Source
Reference Dose (RfD)	Variable	mg/kg-day	Chemical specific	EPA IRIS or ATSDR MRL
Body Weight (BW)	60 or 70	kg	70 kg adult, 60 kg adult female	EPA Exposure Factors Handbook
Conversion Factor (CF1)	30.44	Days/month		
Conversion Factor (CF2)	1000	gm/kg		
Meal Size (MS)	227	gm	8 oz. meal	DOH
Concentration in fish (C)	Mean contaminant concentration	mg/kg	Specific to species	

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.

As mentioned previously, considerations are given to factors in addition to calculated meal limits that will influence consumption recommendations. These include but are not limited to chemical background concentrations, the ability to reduce chemical concentrations through cleaning and cooking techniques, chemical concentrations in other food, known benefits of fish consumption, and ease of messaging. To address ease of messaging, calculated meal limits are given in straightforward, easy to understand rates that include one meal per month, two meals per month, four meals per month, eight meals per month, or unlimited consumption. To accomplish this, calculated meal limits are rounded up or down to fit into these rate categories.

Results

Of all contaminants analyzed, only PCBs, PBDEs, mercury (Hg), and cadmium (Cd) were identified at levels of potential concern to human health based on frequency of detection, contaminant concentrations, and associated toxicity. Minimum and maximum contaminant concentrations from tissue samples are shown, below (Table 4). Crab hepatopancreas had higher levels of contaminants than crab muscle tissue (exceptions were mercury and zinc). Similarly, spot prawn heads had higher levels of contaminants than prawn muscle tissue (exceptions were arsenic and mercury).

Table 4. Range of contaminant concentrations in Puget Sound Dungeness crab muscle tissue and hepatopancreas and in spot prawn muscle and head tissue.

	Range of Concentrations (POPs µg/kg wet weight) (metals mg/kg wet weight) by Tissue Type			
Chemical	**Crab Muscle**	**Crab Hepatopancreas**	**Spot Prawn Muscle**	**Spot Prawn Head**
PCBs	1-180	49-2200	0.85-27	10-690
Total PBDEs	0.20-7.3	3.9 - 200	0.11-0.68	0.87-19
Total DDTs	0.21 -4.8	8.6-140	0.24	0.21-4.6
Total Chlordanes	0.18 -1.8	1.3 - 33	ND	0.16-2.3
Total HCHs	0.15-1.8	1.4-19	ND	0.19-1.3
HCB	0.23	0.87-4.0	ND	0.16-0.74
Total PAHs	0.27 -6.0	0.50-67.5	0.30 -3.7	1.89-32.2
Arsenic	3.44-20.5	2.9-14	8.0-31.4	8.6-30
Mercury	0.018 -0.25	0.0224-0.127	0.027-0.12	0.0247-0.0491
Lead	0.0038-0.023	0.011-0.466	0.0045	0.0296-0.136
Cadmium	0.0019 -0.019	0.0978-2.83	0.013-0.041	0.67-2.52
Copper	4.22-13.2	7.6-47	4.18-12.4	51-81
Zinc	26-61.2	8.1-20	10.9 -14.2	18-31

Exceedances of Screening Levels

Tables 5a-d show mean contaminant concentrations of the 13 chemicals detected in Dungeness crab muscle and hepatopancreas, and spot prawn muscle and head tissue samples collected across nine Puget Sound MAs as well as three urban bays. The shaded areas in Tables 5a-d depict numbers of samples where a chemical was not detected; the MDL was used for non-detected chemicals. Values above the corresponding SL for a particular contaminant are highlighted in each table by bold lines around the appropriate cell. Only four contaminants - total PCBs, total PBDEs, mercury, and cadmium - exceed any SL.

SLs were exceeded for Dungeness crab muscle samples for total PCBs and mercury in Elliott Bay and Sinclair Inlet (Table 5a). Dungeness crab hepatopancreas tissue samples exceeded SLs in all nine MAs and three urban embayments, and mean cadmium concentrations exceeded SLs in MAs 6, 10, 11, and 12 (Table 5b).

No SL exceedances were observed for spot prawn muscle tissue samples in any of the MAs or urban bays (Table 5c). Spot prawn head tissue samples exceeded total PCB SLs in MAs 6, 8.1, 8.2, 10, 12, 13, and in Elliott Bay. In addition, spot prawn head tissue samples also exceeded SLs for cadmium in MAs 6, 7, 12 and 13 (Table 5d).

Table 5a. Dungeness crab muscle mean concentration

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	1.9	3.3	3.5	5.5	2.8	18.4	5.2	2.3	6.1	29	**119**	**27**
Total PBDEs	0.34	0.22	0.26	0.54	0.25	0.99	1	0.27	0.44	3.6	2.2	0.97
Total DDTs	0.47	0.29	0.29	0.48	0.38	0.86	0.5	0.41	0.48	1.7	2.5	0.71
Total Chlordanes	0.33	0.21	0.26	0.22	0.24	0.3	0.23	0.27	0.32	0.81	0.75	0.26
Total HCHs	0.33	0.21	0.26	0.22	0.38	0.39	1.3	0.27	0.71	0.25	0.3	0.32
HCB	0.33	0.21	0.26	0.22	0.24	0.21	0.23	0.27	0.32	0.27	0.3	0.26
Total PAHs	0.49	1.1	0.47	0.34	0.41	0.37	0.44	0.62	0.95	2.3	2.5	0.86
Mercury	0.072	0.042	0.048	0.051	0.036	0.068	0.064	0.049	0.058	0.08	**0.11**	**0.21**
Arsenic	16.1	7.95	10.9	12.2	7.63	8.44	7.43	9.49	10.1	6.31	7.65	11.3
Cadmium	0.0072	0.0029	0.0024	0.006	0.0033	0.0057	0.01	0.0069	0.0045	0.0036	0.0041	0.0023
Copper	8.25	8.72	9.12	10.6	7.83	8.32	8.29	8.94	11.3	8.84	8.81	9.1
Lead	0.0039	0.0044	0.004	0.0042	0.0041	0.0078	0.005	0.004	0.004	0.014	0.014	0.012
Zinc	44	42	50	43	43	45	47.7	46	44	41.7	44	41

Detection frequency = 0 (reported as the detection level) or 1
POPs reported as ug/kg (ppb), metals reported as mg/kg (ppm)
Bold value > Screening Level
For methods used to sum chemicals, see Carey et al. 2014

Table 5b. Dungeness crab hepatopancreas mean concentration

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	**52**	**70**	**49**	**210**	**105**	**590**	**120**	**110**	**190**	**885**	**1733**	na
Total PBDEs	4.4	12	3.9	26	6.1	28	14	10	13	**131**	54	na
Total DDTs	8.6	23	11	21	11	31	11	27	14	85	52	na
Total Chlordanes	1.4	3.1	1.3	6.4	1.8	5.6	2.8	4.2	3.4	22	11	na
Total HCHs	3.1	2.2	1.4	2	9.2	5.7	19	2.7	9.2	3.9	2.3	na
HCB	8.7	1.6	1.1	3.4	2.1	1.5	1.7	1.8	1.5	3.2	1.5	na
Total PAHs	1.7	7.2	0.5	7.4	2.8	9	2	0.91	2.73	13	52	na
Mercury	0.055	0.026	0.044	0.04	0.023	0.05	0.068	0.035	0.044	0.052	0.08	na
Arsenic	14	5.1	7.1	4.9	5.5	5.9	4.8	8.3	10	5.3	6	na
Cadmium	**1.5**	0.1	0.33	1.1	0.4	**1.7**	**1.2**	**2.8**	1.1	1.1	0.68	na
Copper	12	13	12	44	9	13	13	15	39	27	40	na
Lead	0.063	0.034	0.022	0.053	0.047	0.1	0.15	0.011	0.023	0.13	0.27	na
Zinc	17	12	13.8	15.4	11.2	16	14	17.3	18	16	17	na

Detection frequency = 1

POPs reported as ug/kg (ppb), metals reported as mg/kg (ppm)

Bold value > Screening Level

na = not available

For methods used to sum chemicals, see Carey et al. 2014

Table 5c. Spot prawn muscle mean concentration

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	1.3	1.3	3.1	4.4	10	7.6	7	1.8	3.7	na	18	na
Total PBDEs	0.16	0.14	0.16	0.4	0.51	0.39	0.35	0.21	0.36	na	0.27	na
Total DDTs	0.15	0.13	0.15	0.16	0.25	0.29	0.31	0.21	0.21	na	0.27	na
Total Chlordanes	0.15	0.13	0.15	0.16	0.24	0.28	0.31	0.21	0.21	na	0.27	na
Total HCHs	0.15	0.13	0.15	0.16	0.24	0.28	0.31	0.21	0.21	na	0.27	na
HCB	0.15	0.13	0.15	0.16	0.24	0.28	0.31	0.21	0.21	na	0.27	na
Total PAHs	0.55	1	0.79	0.69	0.79	0.73	0.83	0.69	2	na	1.6	na
Mercury	0.081	0.071	0.086	0.08	0.044	0.045	0.043	0.038	0.059	na	0.051	na
Arsenic	15	13	26	14	9.7	14	14	21	22	na	13	na
Cadmium	0.027	0.024	0.023	0.023	0.015	0.017	0.019	0.031	0.025	na	0.022	na
Copper	7.4	6.3	9.9	6.9	6.1	6.4	7.5	7.9	7.1	na	8.9	na
Lead	0.004	0.0041	0.0039	0.004	0.004	0.004	0.004	0.004	0.0039	na	0.0041	na
Zinc	12	12	13	12	11	13	13	13	14	na	13	na

Detection frequency = 0 (reported as the detection level) or 1

POPs reported as ug/kg (ppb), metals reported as mg/kg (ppm)

na = not available

For methods used to sum chemicals, see Carey et al. 2014

Table 5d. Spot prawn head mean concentration

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	**24**	12	**80**	**170**	na	**160**	na	**29**	**155**	na	**603**	na
Total PBDEs	0.99	1.3	4.9	17	na	19	na	2.2	10	na	15	na
Total DDTs	0.21	0.49	2	3.8	na	1.7	na	0.85	1.4	na	3	na
Total Chlordanes	0.16	0.22	0.35	2.3	na	1.4	na	0.41	1.2	na	1.7	na
Total HCHs	0.22	0.22	0.73	1	na	0.68	na	0.75	1	na	0.98	na
HCB	0.16	0.22	0.44	0.61	na	0.39	na	0.36	0.41	na	0.45	na
Total PAHs	6.57	2.3	3.6	6.6	na	22.8	na	2.25	10.4	na	23.4	na
Mercury	0.043	0.033	0.043	0.042	na	0.031	na	0.025	0.04	na	0.031	na
Arsenic	11	11	30	9.6	na	10	na	19	16	na	10	na
Cadmium	**1.4**	**1.5**	0.89	0.67	na	0.75	na	**2.5**	**1.2**	na	0.77	na
Copper	64	51	56	66	na	62	na	55	64	na	75	na
Lead	0.064	0.05	0.03	0.057	na	0.076	na	0.047	0.09	na	0.095	na
Zinc	20	21	25	23	na	24	na	26	25	na	29	na

Detection frequency = 0 (reported as the detection level) or 1
POPs reported as ug/kg (ppb), metals reported as mg/kg (ppm)
Bold value > Screening Level
na = not available
For methods used to sum chemicals, see Carey et al. 2014

Lead Screening

Estimating Blood Lead Levels in Children

The IEUBK model was used to estimate the percentage of children that could have elevated blood lead levels if they frequently eat lead-contaminated seafood (Table 6). As mentioned above, this evaluation is interested in the impact of seafood consumption on a child's blood lead level. Outdoor soil lead was based on background concentrations in combination with crab or prawn lead concentrations within the model. Other default parameters (i.e., outdoor air lead concentration of 0.1 µg/m^3 and drinking water lead concentration of 4 µg/kg) were retained. Default bioavailability values were also used to estimate the percentage of lead uptake from the gut or lungs. Dietary exposure based on a scenario of a child whose meat diet is comprised of 50% of either Puget Sound crab or prawn coupled with the mean lead concentration measured in each species within Puget Sound.

Table 6. Summary of children's IEUBK Model results for mean lead concentrations in Dungeness crab or spot prawn tissue collected from Puget Sound.

Species/Tissue	Mean Lead Conc. (ppm)	General Population lead level (% Above Blood Lead Level of 5 µg/dL)
Dungeness Crab Muscle	0.0053	0.039
Dungeness Crab Hepatopancreas	0.0983	0.217
Spot Prawn Muscle	0.0021	0.036
Spot Prawn Head	0.0739	0.041

Assuming mean lead concentrations measured in either Dungeness crab or spot prawn, no lead exposures resulted in estimated blood lead levels that exceed EPA's target level of no more than a 5% probability that an individual in the community exceed 5 µg/dL. The percentage of children with BLLs above 5 µg/dL from consuming 50% of a meat diet comprised of Dungeness crab or spot prawn ranged from 0.036 to 0.217%. It should be noted that the exposure scenario chosen likely overestimates actual exposures in the population (i.e., it is unlikely that a child's meat diet would consist of 50% of Puget Sound Dungeness crab or spot prawn at the mean concentration throughout one's childhood). In addition, further analysis using the maximum lead concentration in any of the four tissues did not result in exceedance of EPA's recommendations.

Estimating Blood Lead Levels in Adults

The Adult Lead Model (ALM) was used to estimate the probability of a fetus having elevated blood lead levels (BLL) if his or her mother frequently ate lead-contaminated fish (Table 7). Only the fish portion of the adult lead model was used; the soil ingestion portion was omitted. The adult exposure scenario is based on an adult diet comprised of Puget Sound Dungeness crab or spot prawn consisting of 29.9 grams per day and the mean lead concentration corresponding to each species and tissue type.

Table 7. Adult Lead Model predicted blood lead (PbB) levels.

Species/Tissue	Mean Lead Conc. (ppm)	PbB Adult (µg/dL)	Probability PbB Fetal (%)
Dungeness Crab Muscle	0.0053	1.5	3.9
Dungeness Crab Hepatopancreas	0.0983	1.6	5.0
Spot Prawn Muscle	0.0021	1.5	3.9
Spot Prawn Heads	0.0739	1.6	4.7

Mean lead concentrations resulted in a range of adult blood lead levels ranging from 1.5 to 1.6 µg/dL and a corresponding probability of lead blood levels in the fetus ranging from 3.9 to 5 percent. The resulting probability of a pregnant mother who consumes 50% of her recommended seafood diet of two meals per week consisting of 29.9 g/day of Puget Sound Dungeness crab or spot prawn would not exceed the benchmark (fetal blood lead levels exceeding 5 µg/dL). Based on these results, lead concentrations in Dungeness crab or spot prawn are not deemed of significant public health concern and no further assessment is necessary.

Calculated Meal Limits

Calculated meal limits for Dungeness crab muscle and hepatopancreas tissues and for spot prawn muscle and head tissues were derived using the following equation as described above for each of the nine MAs and three urban embayments using mean contaminant concentrations.

$$Meal\ per\ month = \frac{RfD\ x\ BW\ x\ CF1\ x\ CF2}{MS\ x\ C}$$

Not surprisingly, meal restrictions of eight meals per month or less corresponded with tissue levels that exceeded SLs. For Dungeness crab muscle, meal restrictions of fewer than eight meals per month were determined in the three urban bays due to either total PCB or mercury concentrations. Calculated meal limits due to PCB concentrations in crab muscle tissue ranged from 1.6 to 98.8 meals per month (Table 8a). The three urban bays had more restrictive meal limits for Dungeness crab, with the most restrictive meal limit for Elliott Bay - 1.6 meals per month, due to total PCBs. Mercury concentrations in Dungeness crab from Elliott Bay and Sinclair Inlet resulted in meal restrictions of seven and four meals per month, respectively.

Meal restrictions of eight meals or fewer per month for Dungeness crab hepatopancreas were observed in all locations due to total PCBs, only one location for total PBDEs, and four locations for cadmium (Table 8b). Higher total PCB concentrations in Dungeness crab hepatopancreas compared to crab muscle tissue resulted in more restrictive meal limits, ranging from 0.1 to 3.8 meals per month. Total PCB concentrations in all MAs resulted in meal limits for hepatopancreas lower than eight meals per month.

Total PBDE concentrations in Dungeness crab hepatopancreas collected from Commencement Bay resulted in a six meal per month restriction for Commencement Bay. Cadmium concentrations in four MAs (6, 10, 11, and 12) led to meal restrictions ranging from 3.4 to 7.8 meals per month, based on Dungeness crab hepatopancreas samples (Table 8b).

Table 8a. Dungeness crab muscle calculated meal limits (meals per month)

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	99	57	54	34	67	10.4	36	82	31	**6.5**	**1.6**	**7.0**
Total PBDEs	2366	3657	3095	1490	3218	813	805	2980	1829	223	366	829
Total DDTs	8559	13872	13872	8381	10587	4678	8046	9812	8381	2366	1609	5666
Total Chlordanes	14222	22349	18052	21334	19556	15645	20406	17383	14667	5794	6258	18052
Total HCHs	8533	13410	10831	12800	7411	7221	2166	10430	3966	11264	9387	8800
HCB	22756	35759	28882	34134	31289	35759	32650	27813	23467	27813	25031	28882
Total PAHs	76627	34134	79888	110433	91578	101479	85334	60560	39523	16325	15019	43659
Mercury	11.2	19.2	16.8	15.8	22.3	11.8	12.6	16.4	13.9	10.1	**7.3**	**3.8**
Arsenic	na	na	na	na	na	na	na	na	na	na	na	na
Cadmium	1304	3237	3911	1564	2844	1647	939	1360	2086	2607	2289	4081
Copper	na	na	na	na	na	na	na	na	na	na	na	na
Lead	na	na	na	na	na	na	na	na	na	na	na	na
Zinc	64	67	56	65	65	63	59	61	64	68	64	69

Bold value more restrictive than 8 meals per month
na = Not available
For methods used to sum chemicals, see Carey et al. 2014

Table 8b. Dungeness crab hepatopancreas calculated meal limits (meals per month)

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	**3.6**	**2.7**	**3.8**	**0.9**	**1.8**	**0.3**	**1.6**	**1.7**	**1.0**	**0.2**	**0.1**	na
Total PBDEs	183	67	206	31	132	29	57	80	62	**6.1**	14.9	na
Total DDTs	468	175	366	192	366	130	366	149	287	47	77	na
Total Chlds	3352	1514	3610	733	2607	838	1676	1117	1380	213	427	na
Total HCHs	908	1280	2011	1408	306	494	148	1043	306	722	1224	na
HCB	863	4693	6827	2209	3576	5006	4417	4172	5006	2347	5006	na
Total PAHs	22087	5215	75094	5074	13410	4172	18774	41261	13754	2888	722	na
Mercury	15	31	18	20	35	16	12	23	18	15	10	na
Arsenic	na	na	na	na	na	na	na	na	na	na	na	na
Cadmium	**6.3**	94	28	8.5	23.5	**5.5**	**7.8**	**3.4**	8.5	8.5	13.8	na
Copper	na	na	na	na	na	na	na	na	na	na	na	na
Lead	na	na	na	na	na	na	na	na	na	na	na	na
Zinc	166	235	204	183	251	176	201	163	156	176	166	na

Bold value more restrictive than 8 meals per month
na = Not available
For methods used to sum chemicals, see Carey et al. 2014

None of the mean contaminant concentrations measured in spot prawn muscle resulted in meal restrictions lower than eight meals per month (Table 8c). Mercury concentrations were responsible for the most restrictive meal limit of nine meals per month in MA8.1, higher than DOH's threshold for an advisory (eight meals per month).

Spot prawn head tissue accumulated contaminants at higher concentrations than spot prawn muscle tissue (Tables 5c and 5d). Total PCB concentrations measured in spot prawn head tissue resulted in meal restrictions in seven out of the eight MAs tested and ranged from 0.3 to 15.6 meals per month (Table 8d). Cadmium levels measured in spot prawn head tissue resulted in meal restrictions in four out of the eight MAs tested and ranged from 3.8 to 14.0 meals per month.

Table 8c. Spot prawn muscle calculated meal limits (meals per month)

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	144	144	61	43	19	25	27	104	51	na	10.4	na
Total PBDEs	5029	5747	5029	2011	1578	2063	2299	3831	2235	na	2980	na
Total DDTs	26819	30945	26819	25143	16092	13872	12977	19157	19157	na	14900	na
Total Chlordanes	31289	36103	31289	29334	19556	16762	15140	22349	22349	na	17383	na
Total HCHs	18774	21662	18774	17600	11733	10057	9084	13410	13410	na	10430	na
HCB	50063	57765	50063	46934	31289	26819	24224	35759	35759	na	27813	na
Total PAHs	68268	37547	47528	54416	47528	51434	45238	54416	18774	na	23467	na
Mercury	10	11	9	10	18	18	19	21	13.6	na	15.8	na
Arsenic	na	na	na	na	na	na	na	na	na	na	nc	na
Cadmium	348	391	408	408	626	552	494	303	375	na	427	na
Copper	na	na	na	na	na	na	na	na	na	na	nc	na
Lead	na	na	na	na	na	na	na	na	na	na	nc	na
Zinc	235	235	217	235	256	217	217	217	201	na	217	na

For methods used to sum chemicals, see Carey et al. 2014
na = Not available

Table 8D. Spot prawn head calculated meal limits (meals per month)

Chemical	Location											
	MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Total PCBs	**7.8**	15.6	**2.3**	**1.1**	na	**1.2**	na	**6.5**	**1.2**	na	**0.3**	na
Total PBDEs	813	619	164	47	na	42	na	366	80	na	54	na
Total DDTs	19157	8210	2011	1059	na	2366	na	4733	2874	na	1341	na
Total Chlordanes	29334	21334	13410	2041	na	3352	na	11447	3911	na	2761	na
Total HCHs	12800	12800	3858	2816	na	4141	na	3755	2816	na	2874	na
HCB	46934	34134	17067	12311	na	19255	na	20860	18316	na	16688	na
Total PAHs	5715	16325	10430	5689	na	1647	na	16688	3610	na	1605	na
Mercury	18.7	24	18.7	19.2	na	26	na	32	20	na	26	na
Arsenic	na	na	na	na	na	na	na	na	na	na	nc	na
Cadmium	**6.7**	**6.3**	10.5	14.0	na	12.5	na	**3.8**	**7.8**	na	12.2	na
Copper	na	na	na	na	na	na	na	na	na	na	na	na
Lead	na	na	na	na	na	na	na	na	na	na	na	na
Zinc	141	134	113	122	na	117	na	108	113	na	97	na

Bold value more restrictive than 8 meals per month
na = Not available
For methods used to sum chemicals, see Carey et al. 2014

Calculating Meal Limits Based on Multiple Chemical Exposures

While consuming seafood can expose a person to more than one chemical at a time, assessing the combined effect of multiple exposures is difficult because it is not feasible to measure all possible interactions between chemicals. Furthermore, the potential exists for many chemicals to interact in the body and increase or decrease the potential for adverse health effects. Individual cancer risk estimates can be added since they are measures of probability. However, similar toxic effects must exist between the chemicals if the doses are to be added when estimating non-cancer risk (ATSDR 2004).

In addition to individual contaminant effects discussed in the above section, this assessment also considers the additive non-cancer endpoints of mercury, DDT, PBDEs, and PCB exposure. Because mercury, DDT, PBDEs, and PCBs have similar toxic endpoints (neurological 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:

$$Meals\ per\ month = \left(\frac{BW \cdot CF}{MS}\right) \cdot \left(1/\left(\left(\frac{C_{DDT}}{RfD_{DDT}}\right) + \left(\frac{C_{Mercury}}{RfD_{Mercury}}\right) + \left(\frac{C_{PBDE}}{RfD_{PBDE}}\right) + \left(\frac{C_{PCB}}{RfD_{PCB}}\right)\right)\right)$$

Where: BW = body weight for a woman of childbearing age (60 Kg)
CF = Conversion Factor (30.44 days/month)
MS = Meal Size (0.227 kg/meal)
RfD* = chemical specific oral reference dose (mg/kg-day)
C = Chemical Concentration of mercury, PCBs, DDT, or PBDEs in seafood tissue (mg/kg)
*MRL may be substituted for RfD

As with single contaminant meal calculations, calculated meal limits based on multiple contaminants are rounded up or down to fit one of five meal rate categories used by DOH (one, two, four, eight meals per month, or unlimited consumption).

A summary of meal limits based on individual contaminants and combined neurological health endpoints was calculated (Tables 9a-d). Individually, total DDT and PBDE concentrations resulted in the least restrictive calculated meal limits. Only PBDE concentrations in Dungeness crab hepatopancreas tissue from Commencement Bay resulted in calculated meal restrictions less than eight meals per month. Mercury concentrations were the basis for meal restrictions in a few tissue types and locations. Total PCB concentrations were the cause of the most restrictive meal limits when all four neurodevelopmental contaminants were combined (Tables 9a-d, Columns 3 and 10).

Table 9a. Calculated meal limits due to combined neurological effects in Dungeness crab muscle tissue

WDFW Management Area	Total PCBs (ppm)	Calculated Meals per month (PCBs)	Mercury (ppm)	Calculated Meals per month (Mercury)	DDT (ppm)	Calculated Meals per month (DDT)	PBDE (ppm)	Calculated Meals per month (PBDEs)	Combined Meal Limits
6	0.0019	127	0.072	11.2	0.00047	8559	0.00034	2366	10.2
7	0.0033	73	0.042	19.2	0.00029	13872	0.00022	3657	15.1
8.1	0.0035	69	0.048	16.8	0.00029	13872	0.00026	3095	13.4
8.2	0.0055	44	0.051	15.8	0.00048	8381	0.00054	1490	11.5
9	0.0028	86	0.036	22.3	0.00038	10587	0.00025	3218	17.6
10	0.0184	13.1	0.068	11.8	0.00086	4678	0.00099	813	**6.2**
11	0.0052	46	0.064	12.6	0.0005	8046	0.001	805	9.8
12	0.0023	105	0.049	16.4	0.00041	9812	0.00027	2980	14.1
13	0.0061	40	0.058	13.9	0.00048	8381	0.00044	1829	10.2
11-CB	0.0290	8.3	0.080	10.1	0.0017	2366	0.0036	223	**4.5**
10-EB	0.1192	**2.0**	0.110	**7.3**	0.0025	1609	0.0022	366	**1.6**
10-SI	0.0270	8.9	0.210	**3.8**	0.00071	5666	0.00097	829	**2.7**

PCB MRL 0.00003, Hg RfD 0.0001, DDT RfD 0.0005, PBDE RfD 0.0001, BW 60kg
Bold value = more restrictive than 8 meals per month
nc = not calculated

Table 9b. Calculated meal limits due to combined neurological effects for contaminants in Dungeness crab hepatopancreas tissue

WDFW Management Area	Total PCBs (ppm)	Calculated Meals per month (PCBs)	Mercury (ppm)	Calculated Meals per month (Mercury)	DDT (ppm)	Calculated Meals per month (DDT)	PBDE (ppm)	Calculated Meals per month (PBDEs)	Combined Meal Limits
6	0.0520	**4.6**	0.055	14.6	0.0086	467.8	0.004	182.9	**3.4**
7	0.0695	**3.5**	0.026	30.9	0.023	174.9	0.012	67.0	**2.9**
8.1	0.0490	**4.9**	0.044	18.3	0.011	365.7	0.004	206.3	**3.8**
8.2	0.2100	**1.1**	0.040	20.1	0.021	191.6	0.026	30.9	**1.0**
9	0.1050	**2.3**	0.023	35.0	0.011	365.7	0.006	131.9	**2.1**
10	0.5900	**0.4**	0.050	16.1	0.031	129.8	0.028	28.7	**0.4**
11	0.1200	**2.0**	0.068	11.8	0.011	365.7	0.014	57.5	**1.7**
12	0.1100	**2.2**	0.035	23.0	0.027	149.0	0.010	80.5	**1.9**
13	0.1900	**1.3**	0.044	18.3	0.014	287.4	0.013	61.9	**1.2**
11-CB	0.8850	**0.3**	0.052	15.5	0.085	47.3	0.131	**6.1**	**0.3**
10-EB	1.7330	**0.1**	0.080	10.1	0.052	77.4	0.054	14.9	**0.1**
10-SI	nc	nc	nc	nc	nc	nc	nc	nc	nc

PCB MRL 0.00003, Hg RfD 0.0001, DDT RfD 0.0005, PBDE RfD 0.0001, BW 60kg
Bold value = more restrictive than 8 meals per month
nc = not calculated

Table 9c. Calculated meal limits due to combined neurological effects in spot prawn muscle tissue

WDFW Management Area	Total PCBs (ppm)	Calculated Meals per month (PCBs)	Mercury (ppm)	Calculated Meals per month (Mercury)	DDT (ppm)	Calculated Meals per month (DDT)	PBDE (ppm)	Calculated Meals per month (PBDEs)	Combined Meal Limits
6	0.0013	186	0.081	9.9	0.00015	26819	0.00016	5029	9.4
7	0.0013	186	0.071	11.3	0.00013	30945	0.00014	5747	10.7
8.1	0.0031	78	0.086	9.4	0.00015	26819	0.00016	5029	8.3
8.2	0.0044	55	0.08	10.1	0.00016	25143	0.0004	2011	8.5
9	0.0100	24	0.044	18.3	0.00025	16092	0.00051	1578	10.3
10	0.0076	32	0.045	17.9	0.00029	13872	0.00039	2063	11.4
11	0.0070	34	0.043	18.7	0.00031	12977	0.00035	2299	12.1
12	0.0018	134	0.038	21.2	0.00021	19157	0.00021	3831	18.2
13	0.0037	65	0.059	13.6	0.00021	19157	0.00036	2235	11.2
11-CB	nc	nc	nc	nc	n c	nc	n c	nc	nc
10-EB	0.0182	13.3	0.051	15.8	0.00027	14900	0.00027	2980	**7.2**
10-SI	nc	nc	nc	nc	nc	nc	nc	nc	nc

PCB MRL 0.00003, Hg RfD 0.0001, DDT RfD 0.0005, PBDE RfD 0.0001, BW 60kg
Bold value = more restrictive than 8 meals per month
nc = not calculated

Table 9d. Calculated Meal Limits due to Combined Neurological Effects in Spot Prawn Head Tissue

WDFW Marine Area	Total PCBs (ppm)	Calculated Meals per month (PCBs)	Mercury (ppm)	Calculated Meals per month (Mercury)	DDT (ppm)	Calculated Meals per month (DDT)	PBDE (ppm)	Calculated Meals per month (PBDEs)	Combined Meal Limits
6	0.0240	10.1	0.043	18.7	0.00021	19157	0.00099	813	**6.5**
7	0.0120	20	0.033	24	0.00049	8210	0.0013	619	10.8
8.1	0.0800	**3.0**	0.043	18.7	0.002	2011	0.0049	164	**2.6**
8.2	0.1700	**1.4**	0.042	19.2	0.0038	1059	0.017	47	**1.3**
9	nc	nc	nc	nc	n c	nc	n c	nc	nc
10	0.1600	**1.5**	0.031	26	0.0017	2366	0.019	42	**1.4**
11	nc	nc	nc	nc	n c	nc	n c	nc	nc
12	0.0290	8.3	0.025	32	0.00085	4733	0.0022	366	**6.5**
13	0.1550	**1.6**	0.04	20	0.0014	2874	0.01	80	**1.4**
11-CB	nc	nc	nc	nc	n c	nc	n c	nc	nc
10-EB	0.6030	**0.4**	0.031	26	0.003	1341	0.015	54	**0.4**
10-SI	nc	nc	nc	nc	nc	nc	nc	nc	nc

PCB MRL 0.00003, Hg RfD 0.0001, DDT RfD 0.0005, PBDE RfD 0.0001, BW 60kg
Bold value = more restrictive than 8 meals per month
nc = not calculated

Estimated meal restrictions based on combined neurological effects for each of the four tissue types are summarized (Table 10). Meal restrictions from these calculations were the basis of DOH's meal guidance advice in conjunction with weighing other risk management factors such as benefits of eating fish.

Table 10. Summary of calculated meal restrictions based on combined neurological effects or individual contaminant

Species	Tissue	Location											
		MA 6	MA 7	MA 8.1	MA 8.2	MA 9	MA 10	MA 11	MA 12	MA 13	CB	EB	SI
Dungeness Crab	Muscle	NR	NR	NR	NR	NR	8	NR	NR	NR	4	2	2
Dungeness Crab	Hepatopancreas	4	4	4	1	2	0	2	2	1	0	0	nc
Spot Prawn	Muscle	NR	NR	NR	NR	NR	NR	NR	NR	NR	nc	8	nc
Spot Prawn	Head	8	NR	2	1	nc	1	nc	8	1	nc	0	nc
NR = No Restrictions													
nc = not calculated													

Meal restrictions for Dungeness crab muscle tissue were only seen in the three urban embayments with Elliott Bay and Sinclair Inlet being the most restrictive at two meals per month and Commencement Bay at four meals per month. All other marine management areas have no meal restrictions. Contaminants in Dungeness crab hepatopancreas resulted in the most restrictive meal limits of those species and tissues analyzed in this evaluation. No consumption of Dungeness crab hepatopancreas is recommended for Commencement and Elliott Bays (not calculated for Sinclair Inlet due to a lack of data).

No meal restrictions are required for the consumption of spot prawn muscle tissue across all marine management areas with the exception of urban embayments. Contaminant data was only available for Elliott Bay and resulted in meal advice of eight meals per month. Calculated meal restrictions could not be calculated for either Commencement Bay or Sinclair Inlet.

Meal restrictions for spot prawn heads ranged from 0 to no restrictions (Table 10). DOH simplified restriction advice for MA 8.1, 8.2, 9, 10, 11, and 13 to "no consumption" of spot prawn heads for risk communication purposes based on the most restrictive advice for the areas. For MA7, advice is no restrictions on spot prawn head consumption. Advice for consuming spot prawn heads from MAs 6 and 12 is no more than eight meals per month.

Cancer Risk Evaluation

DOH generally does not base meal limits based on potential cancer endpoints because there are more robust toxicological underpinnings to protect sensitive subpopulations based on non-cancer health effects (Stone and Hope, 2010). Cancer risk assessment has limitations for seafood consumption advisories due to competing, evidence-based benefits, the likely over-estimation of risks, and counter-productive risk perception issues. Use of non-cancer endpoints for setting seafood advisories is in concordance with EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume III (EPA 2000a) that emphasizes flexibility in risk management. Furthermore, the combined neurological health endpoint evaluation also protects resident fish consumers within a range of one and a million to one-in ten thousand cancer risk used by EPA in evaluating contaminated sites (EPA 1989).

Cancer endpoints were evaluated for contaminants that have been assigned an EPA Integrated Risk Information System (IRIS) cancer slope factor (CSF). Calculated meal limits were determined across a range of cancer risks from one in one million to one in ten thousand. With few exceptions, DOH generally does not base meal limits on potential cancer risks. Some contaminants may have both cancer and non-cancer health criteria as reported in EPA's IRIS database (i.e., an RfD and a CSF). For contaminants such as PCBs that have an RfD and CSF, DOH relies on the more robust toxicological findings coming from non-cancer studies to protect sensitive subpopulations. Using the non-cancer health endpoint and associated dose (RfD), cancer risks may also be calculated to determine whether risks fall within an acceptable range. The following equation illustrates the cancer risk:

$$Cancer\ Risk = dose\ \times CSF$$

Where:

$$dose = \frac{mg}{kg - day}$$

$$CSF = \left(\frac{mg}{kg - day}\right)^{-1}$$

In the case of PCBs, the calculated cancer risk at a dose equivalent to the RfD is four in one hundred thousand (4.0 x 10-5), which is still within EPA's acceptable risk level.

$$Cancer\ Risk = 2.0\ \times 10^{-5} \times 2.0$$

Where:

$$dose\ (RfD\ for\ PCBs =\ 2x10^{-5}\frac{mg}{kg - day}$$

$$CSF\ for\ PCBs =\ 2\left(\frac{mg}{kg - day}\right)^{-1}$$

Exceptions are for contaminants with only a CSF or a calculated cancer risk based on a contaminant-specific RfD greater than that deemed acceptable by EPA (i.e., cancer risk greater than one in ten thousand). In those cases, meal limits may be based on cancer endpoints.

Further, cancer risk assessment has limitations for seafood consumption advisories due to competing, evidence-based benefits, the likely over-estimation of risks, and counter-productive risk perception issues (Stone and Hope, 2010). Use of non-cancer endpoints for setting seafood advisories is in concordance with EPA's Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories, Volume III (2000), which emphasizes flexibility in risk management. Nonetheless, the combined neurological health endpoint evaluation indicates that crab and spot prawn consumers are protected within the one and a million to one-in-ten thousand cancer risk range used by EPA to evaluate contaminated sites.

Uncertainty

The methodology described above involves many uncertainties. Uncertainty with regard to the risk assessment process refers to the lack of knowledge about factors such as chemical toxicity, human variability, human behavior patterns, and chemical concentrations in the environment. Uncertainty can only be reduced through further study.

The majority of uncertainty comes from our limited knowledge of chemical toxicity. 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 must rely on toxicological experiments performed on animals. Test animals are typically exposed to chemicals at much higher levels than are found in the environment. Critical doses 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, it is important to note that the risk assessment methodology is only a partial guide as to how DOH establishes seafood consumption guidance or advisories in the state.

For this study, screening levels for total PCBs, PBDE, DDT, chlordane, HCH (Lindane), and PAHs were based on a single RfD or cancer slope factor value for the most hazardous component of those mixtures. Thus, the screening value is likely to overestimate the actual cancer and non-cancer risks.

Another source of uncertainty is the limited number of tissue samples that were used to represent conditions in the entire Puget Sound area. Additionally, several locations were represented by a single composite sample. At some locations, contaminant concentrations were reported as non-detected but the associated analytical detection limits were used in the health assessment (Tables 5a – d). Limitations in sample size may result in either an over- or underestimate of the actual concentrations and may not be representative of all locations. The use of detection limits to represent non-detected values may overestimate a contaminant's true concentration when the actual concentration could be quite less.

Discussion

This study addresses potential health risks from exposure to a number of contaminants found in Dungeness crab and spot prawn from Puget Sound. No restrictions are placed on consumption of crab muscle from most areas of the Sound (exceptions are MA 10 with eight meals per month and limited consumption of crab muscle from urban embayments). The other primary finding from this assessment is DOH's advice for unrestricted consumption of spot prawn muscle from most areas of Puget Sound (an exception is eight meals per month of spot prawn from urban embayments). Results of the geographic extent and magnitude of contaminants in these two species fill a previous gap in our knowledge of potential exposure to toxics in regional seafood.

Not surprisingly, restrictions are advised for consumption of crab hepatopancreas (no consumption from crab caught in urban bays, one to four meals per month from crab caught in other areas). PCBs appear to bioaccumulate in this tissue, and resulting concentrations are the reason for most advice limiting consumption. In Puget Sound and other waterbodies, sediment-associated PCBs are accumulated in the tissues of aquatic organisms, which are in turn consumed by organisms 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 to 6 years (Shirai and Kissel 1996).

Of particular concern to this report is the potential exposure to citizens from consumption of crab hepatopancreas and spot prawn heads. Some groups may consume greater amounts of seafood than others; for example, Native Americans, Asian immigrant populations, and recreational consumers 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 other local seafood species (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).

Part of the uncertainty in assessing PCB effects from consuming seafood is that PCB congeners selectively bioaccumulate in fish and shellfish 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 Toxicity Equivalency Factors (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 µg/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 µg/kg-day for Aroclor 1254 (IRIS 2000) based on dermal/ocular and immunological effects in monkeys.

PCBs in Other Foods

PCB contamination in a variety of foods, and in particular seafood, is the most significant source of exposure to this contaminant for most people. Recent studies on fish tissue contaminant levels indicate concentrations of PCBs can range from 10 to 100 parts per million in fish (especially freshwater fish) (McBride 2005). High levels are typically found in top predator fish, in bottom-feeding fish such as carp and largescale suckers, in fish with high fat levels, and in fish living near known sources of PCB contamination. Less is known about PCB concentrations in crab and spot prawn.

PCB levels in meat and dairy products are generally much lower than in seafood, with concentrations in the low parts per billion range (Table 11). An analysis of 2001-2004 National Health and Nutrition Examination Survey (NHANES) data looked at food consumption patterns in a general U.S. population relative to 30 PCB congeners measured in their serum (Xue et al. 2014). The study found a strong correlation between serum PCB levels and reported fish consumption, but no measurable correlation with consumption of meat or milk indicating that seafood may be a primary source of dietary exposure.

PCBs in Freshwater Fish Species from Washington State

PCBs can be highly concentrated in the fish of waters contaminated with even low levels of PCBs. Ecology routinely conducts fish tissue monitoring as part of its Washington State Toxics Monitoring Program (WSTMP) and thousands of fish have been sampled from hundreds of sites across the state. The data set includes 353 total PCB values that range from non-detected concentrations to greater than 26,000 ppb, with a median of 8.7 ppb. The maximum PCB detection (185,000 ppb) is from a single bass collected near the Bonneville Dam in the Columbia River. The distribution of total PCB tissue concentrations from these fish compared with results from Dungeness crab and spot prawn tissues demonstrate that crab hepatopancreas and spot prawn head tissue concentrations are greater than the 90th percentile distribution concentrations in freshwater fish (Figure 3). Dungeness crab and spot prawn muscle tissue PCB concentrations are lower, at approximately the 65th and 40th percentile distribution concentrations, respectively.

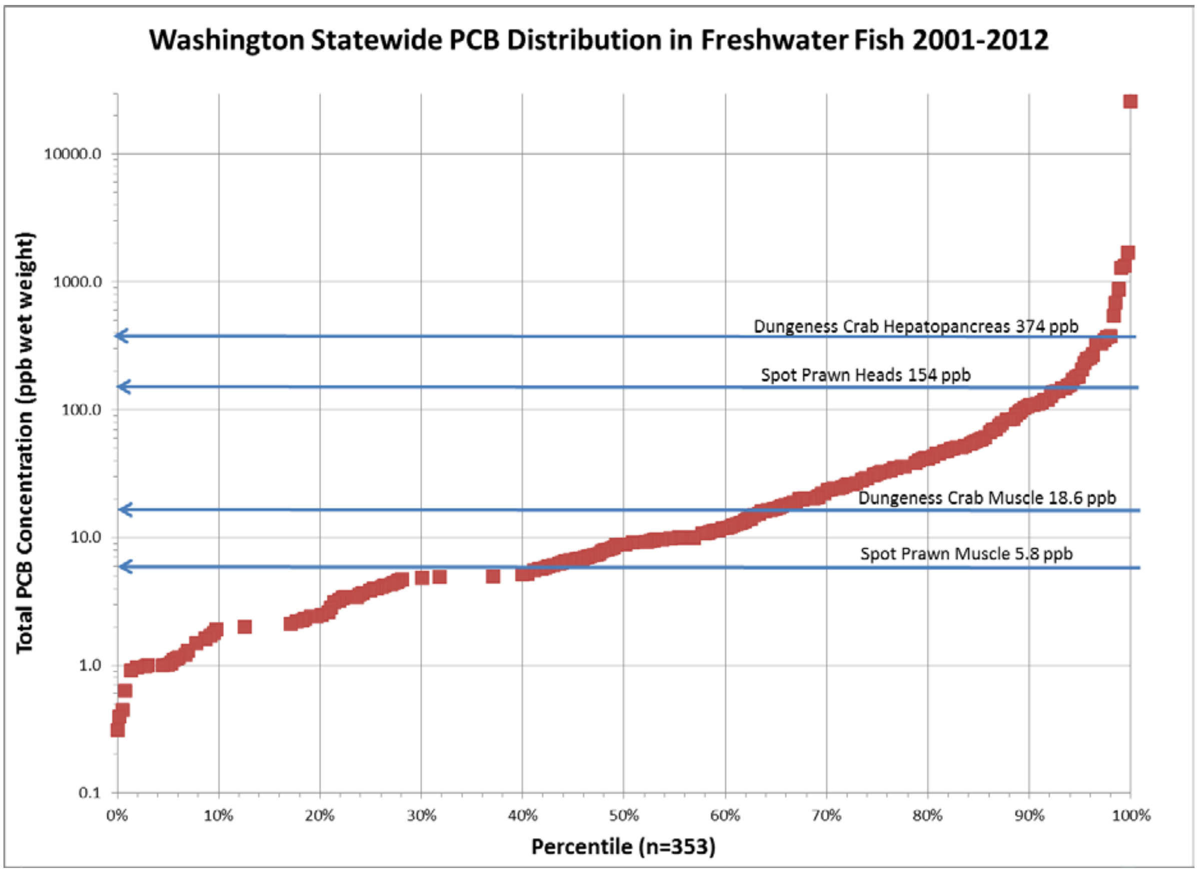


Figure 3. Washington statewide PCB distribution in freshwater fish fillets 2001-2012
Data sources: 2001-2012 total PCB fish tissue concentrations extracted from Ecology's EIM database. EPA's Upper Columbia River site investigation as reported by DOH (DOH 2012), U.S. Department of Energy's 2012 assessment of contaminants in the Mid-Columbia River and fish tissue data provided to DOH by the U.S. Army Corps of Engineers near Bradford Island and the Bonneville Dam on the Columbia River (unpublished data).

PCBs in Commercially Available Fish in Washington State

Data on PCBs in commercially available fish in Washington are also available. The primary source of this data is a DOH study of contaminants in canned tuna and other frequently consumed store bought fish purchased in Washington state grocery stores (McBride et al. 2005). In this study, PCBs (based on Aroclors concentrations) were detected in at least 10% of the samples of store-bought halibut, red snapper, and salmon. Salmon had the highest average PCB concentrations (31.5 ppb PCBs, total Aroclors). Additional data from WDFW on PCB levels in Puget Sound Chinook and coho salmon were also included for this assessment (DOH 2006). A comparison of PCB concentrations in store bought and commercially available fish from Puget Sound waters is summarized below (Figure 4).

Of all fish species, Chinook salmon collected in Puget Sound had the highest PCB concentrations. PCB levels in Chinook salmon returning to Puget Sound waters typically have higher concentrations than coastal salmon or Chinook from Alaska. The higher concentrations in Puget Sound Chinook salmon that migrate to the Pacific Ocean and return and resident blackmouth (resident Chinook salmon) are believed to be due to their residence time in areas of Puget Sound that have greater PCB loads (O'Neill and West 2009). DOH recommends that women of childbearing age and young children eat no more than one meal per week of Puget Sound Chinook salmon (DOH 2006). Most fish species collected from grocery stores were below DOH's general screening level of 23 ppb for PCBs. Again, Dungeness crab hepatopancreas and spot prawn heads had the highest PCB levels compared to other seafood (Figure 4).

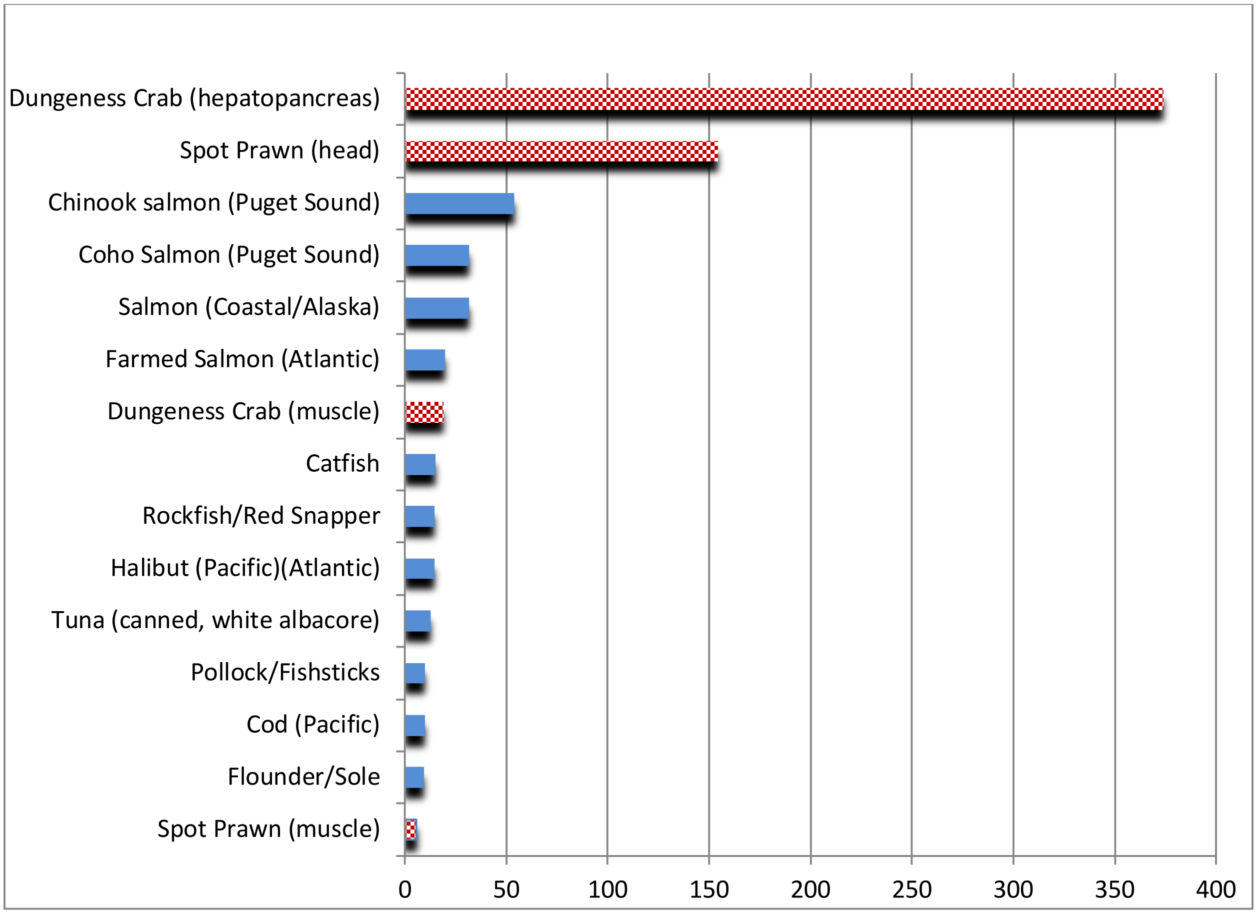


Figure 4. Mean PCB concentrations (total Aroclors) in fish collected from markets and grocery stores in Washington State and from Puget Sound. (Data Source: McBride et al. 2005.)

Other Dietary Sources of PCBs

Humans may be exposed to small but detectable quantities of PCBs in meat, dairy products, and other foods. PCB concentrations in fish, meat, and dairy products vary widely depending on where they are grown and how they are processed or cooked. Sampling for PCB concentrations in Food and Drug Administration's (FDA) Market Basket studies between 1991 and 2003 showed PCB levels are far below FDA limits in a variety of prepared dishes.

The Total Diet Study (TDS), sometimes called the market basket study, is an ongoing FDA program that determines levels of various contaminants and nutrients in foods. http://www.fda.gov/downloads/Food/FoodScienceResearch/TotalDietStudy/UCM184304.pdf. A unique aspect of the TDS is that foods are prepared as they would be consumed (table-ready) prior to analysis, so analytical results provide the basis for realistic estimates of the dietary intake of these analytes. TDS Market Basket surveys are generally conducted four times each year, once in each of four geographic regions of the country. Food samples are purchased from supermarkets, grocery stores, and fast food restaurants in three cities in the region and are shipped to a central laboratory. Foods are then prepared table-ready and the three samples are combined to form a single analytical composite for each food. For each survey, samples of food are collected over a 5-week period (Table 11). Total PCB concentrations are expressed as Aroclor equivalents rather than as the sum of congener-specific measurements. Mean PCB concentrations ranged from 0.09 ppb for chicken potpie to 24.4 ppb for salmon.

PCB concentrations in foods from the market basket survey are much lower than previously reported by the Puget Sound Action Team in 2007 and cited by Ecology's Toxics Cleanup Program (Ecology 2012d). PCB levels in foods reported by the Puget Sound Action Team were based on very small sample sizes of one or two. FDA data are based on average sample sizes of 40 and result in more robust, representative PCB levels. The state of origin of the food sampled is not available.

Table 11. Measured PCB levels as reported by USFDA

Food Description	Sample Size	Results		
		Concentration (ppb)		Detection Frequency %
		Mean	Maximum	
Chicken potpie, frozen, heated	44	0.09	4	2.3
Candy, caramels	40	0.15	6	2.5
Beef roast, chuck, oven-roasted	44	0.23	10	2.3
Pork roast, loin, oven-roasted	44	0.23	10	2.3
Lamb chop, pan-cooked w/oil	44	0.23	10	2.3
Chicken, drumsticks and breasts, breaded and fried, homemade	40	0.23	9	2.5
Corn/hominy grits, enriched, cooked	44	0.23	10	2.3
Cornbread, homemade	44	0.23	10	2.3
Biscuits, refrigerated-type, baked	44	0.23	10	2.3
Raisins	44	0.23	10	2.3
English muffin, plain, toasted	44	0.23	10	2.3
Veal cutlet, pan-cooked	40	0.25	10	2.5
Crackers, butter-type	44	0.25	11	2.3
Pork chop, pan-cooked w/oil	44	0.45	20	2.3
Meatloaf, beef, homemade	44	0.45	20	2.3
Beef (loin/sirloin) steak, pan cooked with added fat	40	0.5	20	2.5
Pancakes made from mix with addition of egg, milk, and oil	40	0.5	20	2.5
Baby food, vegetables, and chicken	44	0.68	30	2.3
Brown gravy, homemade	40	0.75	30	2.5
Tuna, canned in oil, drained	40	1.0	40	2.5

Eggs, fried with added fat	40	1.23	39	5.0
Chicken breast, oven-roasted (skin removed)	44	1.36	30	4.5
Popcorn, popped in oil	40	1.7	30	10.0
Butter, regular (salted)	44	3.18	120	4.5
Catfish, pan-cooked w/ oil	4	4.25	17	25.0
Salmon, steaks/fillets, baked	24	24.38	55	91.7

PCB analytical results of food from the FDA's Total Diet Study program. The information pertains to TDS market baskets 1991-93 through 2003-04. Statistics were calculated using value of zero for results below the detection limit. This document is available on the internet at: http://www.cfsan.fda.gov/~comm/tds-res.html.

Mercury

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 methylmercury.

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 present as methylmercury. 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 for 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).

Conclusions

WDFW has shown in pilot studies that Dungeness crab and spot prawn are valuable bioindicators of toxic contaminants because they readily accumulate contaminants in their muscles and organs, thus reflecting the contaminants present in their surrounding environment (Carey et al. 2014). Crustaceans are able to accumulate metals and contaminants through their food or by absorbing them directly from their surrounding environment (Bryan 1971, Bryan *et al.* 1979, Reichmuth et al. 2010 *in* Carey et al. 2014).

Due to limited data from earlier studies, we were unable to determine contaminant trends in Dungeness crab hepatopancreas or spot prawn heads. However Dungeness crab muscle tissue collected in the Lower Duwamish Waterway in Elliott Bay in 2004 had mean PCB concentrations (240 µg/kg Aroclor) somewhat similar to historical samples (130 µg/kg Aroclor) collected between 1992 and 1999 (ATSDR 2005). All of these Elliott Bay historical samples had higher PCB concentrations than those observed in this study for Dungeness crab muscle tissue. In addition, PCB and mercury concentrations in muscles were lower than concentrations found in other Puget Sound seafood such as Chinook salmon or rockfish (DOH 2006).

Most contaminants in Dungeness crab hepatopancreas and spot prawn head tissue were higher than in muscle tissue, likely related to the higher lipid content of the hepatopancreas (Hellou, et al. 1997) and its detoxification function (Carey et al. 2014). Ylitalo et al. (1999) also observed much greater PCB concentrations in hepatopancreas than in muscle tissue of Dungeness crab, American lobster, and blue crab.

Limited information is available on cooking methods and contaminant levels in Dungeness crab and spot prawn. A study on East Coast blue crabs shows that all cooking procedures reduced PCBs by > 20% (Zabik et al. 1992). The majority of PCBs leach into cooking water when whole crab are boiled or steamed. Removing the hepatopancreas increased PCB loss from body muscle of boiled crab (36% loss without the hepatopancreas and 31% loss if cooked with hepatopancreas). Therefore, DOH recommends that consumers remove and throw away the crab's hepatopancreas (liver) before cooking. The liver has most of the PCBs. A second recommendation is to drain and throw away the cooking water since PCBs come out in cooking liquid. Cooked crab can be used to prepare dishes in the usual manner. DOH recommends future studies to investigate loss of contaminants in Dungeness crab and spot prawn though various cooking methods.

Risk communication outreach efforts will focus on consumption advice for Dungeness crab and spot prawn in urban embayments (Elliott Bay, Sinclair Inlet, and Commencement Bay). The second focus will be on guidance restricting consumption of Dungeness crab hepatopancreas and the surprising result of advising no consumption of spot prawn heads in some Marine Areas and urban embayments.

Summary

- Contaminant concentrations in Dungeness crab muscle tissue, Dungeness crab hepatopancreas, spot prawn muscle tissue, and spot prawn heads from various Puget Sound locations were screened, then meal limits were calculated based on sample concentrations. Contaminants with concentrations that resulted in meal limits more restrictive than eight meals per month were evaluated further for potential human health impacts and for specific meal recommendations.

- Based on PCB analyses for Dungeness crab muscle tissue for most MAs (6, 7, 8.1, 8.2, 9, 11, 12, and 13), DOH advises unrestricted consumption; for MA 10 DOH advises no more than eight meals per month. Exceptions from this general advice for Puget Sound include no more than four meals per month for muscle tissue of Dungeness crab caught in

Commencement Bay (11-CB) and Port Angeles Harbor (6-PA), and no more than two meals per month for muscle tissue of Dungeness crab caught in Elliott Bay (10-EB) and Sinclair Inlet (10-SI) (Table 10a).

- Analysis of contaminants in Dungeness crab hepatopancreas tissue caught in MAs 6, 7, and 8.1 resulted in DOH advising no more than four meals per month. DOH consumption advice for Dungeness crab hepatopancreas for MAs 8.2 and 13 is no more than one meal per month, and for MAs 9, 11, and 12 no more than two meals per month. For urban embayments, DOH advises no consumption of crab hepatopancreas (Table 10b).

- DOH consumption advice for spot prawn caught in all MAs in Puget Sound is for unrestricted consumption of muscle tissue (Table 10c). For urban embayments (Elliott Bay, Sinclair Inlet, and Commencement Bay), DOH advises no more than eight meals per month of spot prawn.

- DOH advises no consumption of spot prawn heads for MAs 8.1, 8.2, 9, 10, 11, and 13. This advice differs slightly from meal calculations (Range: 1 – 2 meals per month or not calculated, Table 10d) and was modified for ease of risk communication. Advice for consuming spot prawn heads from MAs 6 and 12 is no more than eight meals per month. There are no restrictions on consumption of spot prawn heads from MA 7.

- In general, DOH advises consumers to remove and throw away the crab's hepatopancreas (liver) before cooking since the liver has most of the PCBs. If the crab is cooked whole, drain and throw away the cooking water (PCB comes out in the cooking liquid).

References

ALM. 2009. U.S. EPA Adult Lead Methodology, Version June 2009. http://www.epa.gov/superfund/lead/products.htm

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. 2004. Interaction Profile for: Persistent Chemicals Found in Fish (Chlorinated Dibenzo-p-dioxins, Hexachlorobenzene, p'p-DDE, Methymercury, and Polychlorinated Biphyenls). U.S. Department of Health and Human Services, Public Health Service, Agency of Toxic Substances and Disease Registry. May 2004.

ATSDR. 2005. Lower Duwamish Waterway Site: Updated Fish Consumption Advisory and Evaluation of Marine Tissue Collected from the Lower Duwamish Waterway in August and September 2004. Seattle, Washington

Bryan, G.W. 1971. "The Effects of Heavy Metals (other than Mercury) on Marine and Estuarine Organisms." Proceedings of the Royal Society of London. Series B. Biological Sciences 17**7**(1048): 389-410.

Bryan, G. W., M. Waldichuk, R. J. Pentreath, and A. Darracott. 1979. "Bioaccumulation of Marine Pollutants [and Discussion]." Philosophical Transactions of the Royal Society of London. B, Biological Sciences 286(1015): 483-505.

California Dept. of Fish and Game (CDFG). 1994. "Dungeness Crab (*Cancer magister*)" (On-line). Central Valley Bay-Delta Monitoring. Accessed 10/27/04 at http://www.delta.dfg.ca.gov/baydelta/monitoring/cmag.asp

Carey, A.J., L.A. Niewolny, J.A. Lanksbury, and J.E. West. 2014. Toxic contaminants in Dungeness crab (*Metacarcinus magister*) and spot prawn (*Pandalus platyceros*) from Puget Sound, Washington, USA. Washington Department of Fish and Wildlife, Ecology Contract No. 12-1100.

CDC 2012. http://www.cdc.gov/nceh/lead/data/definitions.htm

CSFII. 1994. USDA Continuing Survey of Food Intakes by Individuals. http://www.ars.usda.gov/SP2UserFiles/Place/80400530/pdf/Pynet_94.PDF

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

Clarkson, T.W. 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.

DOH. 2006. Human Health Evaluation of Contaminants in Puget Sound Fish. Washington Department of Health. 1-10-2006. 334-104.

DOH. 2003. http://www.doh.wa.gov/fish

DOH. 2012. Human Health Evaluation of Contaminants in Upper Columbia River Fish. Washington Department of Health. DOH 334-317 August 2012. http://www.doh.wa.gov/Portals/1/Documents/Pubs/334-317.pdf

Ecology. 1994. Natural Background Soil Metals Concentrations in Washington State. Toxics Cleanup Program. October, 1994. Washington State Department of Ecology. Publication #94-115.

Ecology. 2012. Seiders, K., C. Deligeannis, and M. Friese. Washington State Toxics Monitoring Program: Freshwater Fish Tissue Component. Washington State Department of Ecology, Olympia, WA. Publication No. 12-03-023.

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

EPA. 1996b. 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.

EPA. 2000a. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volumes 1-4. November 2000; EPA 823-B-00-008.
http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/guidance.cfm

EPA. 2000b. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories. Volume 2. Risk Assessment and Fish Consumption Limits, Third Edition. November 2000; EPA 823-B-00-008.
http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/risk/volume2_index.cfm

EPA. 2002. U.S. EPA Integrated Exposure Uptake Biokinetic Model for Lead in Children, Version IEUBKwin v1.0 build 263.
http://www.epa.gov/superfund/lead/productsv1b263.htm#ieubk

EPA. 2003. U.S. EPA Integrated Exposure Uptake Biokinetic Model for Lead in Children Superfund Lead-Contaminated Residential Sites Handbook.
http://www.epa.gov/superfund/lead/products/handbook.pdf

Goldman L.R., and Shannon M.W. 2001. Technical Report: Mercury in the Environment: Implications for Pediatricians. Pediatrics. 108:197-205.

Headstrom, R. 1979. Lobsters, Crabs, Shrimps and Their Relatives. New York: A.S. Barnes and Company.

Hellou, J., D. Parsons, and G. Mercer. 1997. "Organochlorine contaminants in northern shrimp, *Pandalus borealis,*collected from the northwest Atlantic." Marine Environmental Research 44(1): 99-113.

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.

IRIS. 2000. Integrated Risk Information System. http://www.epa.gov/iris/index.html.

Jensen, G.C. 1995. *Pacific Coast Crabs and Shrimps*. Sea Challengers, Monterey.

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.

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.

McBride, D., VanDerslice, J., LaFlamme, D, Hailu, A., and Carr, L. 2005. Analysis of Chemical Contaminant Levels in Store-Bought Fish from Washington State. Washington State Department of Health; presented at 2005 National Forum on Contaminants in Fish. http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/2005_index.cfm.

NHANES III. July 1997 Third National Health and Nutrition Examination Survey (NHANES III), 1988-94. ftp://ftp.cdc.gov/pub/health_statistics/nchs/nhanes/nhanes3/1A/exam-acc.pdf

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.

O'Neill, S., and West, J. 2009. Marine Distribution, Life History Traits, and the Accumulation of Polychlorinated Biphenyls in Chinook Salmon from Puget Sound, Washington. Transactions of the American Fisheries Society 138:616-632.

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.

Reichmuth, J. M., P. Weis, and J. S. Weis. 2010. "Bioaccumulation and depuration of metals in blue crabs (Callinectes sapidus Rathbun) from a contaminated and clean estuary." Environmental Pollution 158(2): 361-368.

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.

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

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.

Stone, D., Hope, B.K. 2010. Carcinogenic risk as a basis for fish advisories: a critique. Integr

Environ Assess & Manag. 6(1):180-183.

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, K.A., Polissar, N.L., Liao, S., and Gawne-Mittelstaedt, G.D. 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.

West, J. E., L. Niewolny, S. Quinnell, and J. Lanksbury. 2012. Quality Assurance Project Plan: Toxic contaminants in Dungeness crab (*Cancer magister*) and spot prawn (*Pandalus platyceros*) from Puget Sound, Washington, USA Washington Department of Fish and Wildlife**:** 85.

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.

Xue, J., Liw, S.V., Zartarian, V.G,. Geller, A.M., and Schultz, B.D. 2014. Analysis of NHANES measured blood PCBs in the general US population and application of SHEDS model to identify key exposure factors. J Expo Sci Environ Epidemiol. 24(6):615-21.

Ylitalo, G. M., J. Buzitis, and M. M. Krahn, 1999. "Analyses of tissues of eight marine species from Atlantic and Pacific coasts for dioxin-like chlorobiphenyls (CBs) and total CBs." Archives of Environmental Contamination and Toxicology 37: 206-219.

Zabik, M.E., J.B. Harte, M.J. Zabik, and G. Dickmann. 1992. Effect of preparation and cooking on contaminant distributions in crustaceans: PCBs in blue crab. J. Agric. Food Chem. 40, 1197-1203.

APPENDIX A

Description of Dungeness Crab and Spot Prawn

Dungeness Crab (*Metacarcinus magister*)

Dungeness crab, or *Metacarcinus magister*, is one of the largest edible crabs along the Pacific Coast. This species has a geographic range on the eastern Pacific coast from Point Concepcion, California, to the Pribilof Islands, Alaska (CDFG 1994). Dungeness crab is a decapod, with the distinguishing feature of white-tipped pincers on the claws. Decopods' thoracic segment is fused with that of the head to form the cephalothorax, which is covered by a carapace. A Dungeness crab's body is flat and broad with nine small teeth on each side of the anterior margin of the carapace forming an elliptical curve (USGS 1986). The carapace slopes backward to form a narrow posterior end (Headstrom 1979).

The Dungeness crab has five pairs of thoracic legs. The first pair of legs is larger than the last four and has pinching claws. The last pair of legs is adapted for walking. The top edges of the claws are saw-toothed along the edge and the last three joints of the last pair of walking legs have a fringe of hair on the lower edge.

This species is usually light reddish brown on the carapace with a pattern of lighter streaks and spots on the back. Males range from 18 to 23 centimeters (about 7 to 9 inches) in width and 10 to 13 centimeters (4 to 5 inches) long. The legs and ventral side of this species are yellowish and the underside is whitish to light orange. The width of the back is about 9 inches (Headstrom 1979).

Dungeness crab mate from spring through fall. Each male crab may mate with more than one female (ADFG 2014). Dungeness crab can only successfully mate when the female is newly molted, thus adult male crabs seek female crabs that are likely to molt soon. Females can store sperm for up to two years in internal pouches designed for this purpose (ADFG 2014). Eggs are fertilized about a month after mating when the female's shell is hardened (ADFG 2014). Females begin extruding eggs in the fall and fertilize them with spermatophores stored from spring mating. The eggs, which are held in place with an abdominal flap, are bright orange at first but turn black as they develop and are close to hatching (ODFW 2012). A large female Dungeness crab can carry 2.5 million eggs (MRC 2012; ADFG 2014).

After hatching, six successive larval stages of five zoea and one megalopa live suspended in water and move with currents (ODFW 2012). Juvenile crabs may molt up to six times a year during their first two years; crabs grow each time they molt. Molting slows down to about once a year after crabs become sexually mature at three years. In late spring and early summer, currents carry young crabs to nearshore areas where they can settle. At this stage the crab megalope is an important prey item for larger animals such as coho salmon and grey whales.

Dungeness crab live in sandy bottoms below the tidal mark up to a depth of 230 m. They can also be found at lowtide in sandy or muddy bays with eelgrass. This species is intolerant of low dissolved oxygen and low amounts of ammonia and grows best at temperatures above six degrees Celsius (Kozloff 1973). Dungeness crab is a relatively short-lived species with a maximum life expectancy of about 10 years. Most commercially-caught Dungeness crab are 4 years old and between 6 ¼ and 7 inches wide across their carapace.

Dungeness crab eat a variety of marine invertebrates and fish. Juveniles feed on fish, shrimp, mollusks and crustaceans. At this stage they prefer shallow estuarine areas with pilings, woody debris, and eelgrass. Adults feed on bivalves, crustaceans and fishes. The crabs are able to open shells by chipping away at them with their heavy pinching claws. Adult Dungeness crab forage on a variety of fish and invertebrate species (Batis and Kaelin 2000) and are themselves a prey item of seals, sea lions, and a variety of fish (World Aquaculture. Retrieved May 5, 2015).

In Puget Sound, sport fishers use pots and ring nets to catch over a million pounds of Dungeness crab each year. A license is necessary for Puget Sound and Strait of Juan de Fuca crabbers. Crabbers also have to complete and turn in a catch record card to WDFW so they can estimate recreational harvesting and set future crabbing harvest goals. The Monterey Bay Aquarium Seafood Watch program has given the Dungeness crab a sustainable seafood rating of Best Choice. (Seafood Recommendations: Dungeness Crab. Seafood WATCH. Retrieved December 19, 2009)

References

Alaska Department of Fish and Game (ADFG). 2014. http://www.adfg.alaska.gov/static/education/wns/dungeness_crab.pdf

Batis, J., and A. Kaelin. 2000. "Dungeness Crab" (On-line). World of Aquaculture. Accessed 10/27/04 at http://www7.taosnet.com/platinum/data/light/species/crabdungeness.html

California Dept. of Fish and Game (CDFG). 1994. "Dungeness Crab (*Cancer magister*)" (On-line). Central Valley Bay-Delta Monitoring. Accessed 10/27/04 at http://www.delta.dfg.ca.gov/baydelta/monitoring/cmag.asp

Headstrom, R. 1979. Lobsters, Crabs, Shrimps and Their Relatives. New York: A.S. Barnes and Company.

Kozloff, E. 1973. *Seashore Life of Puget Sound, the Strait of Georgia, and the San Juan Islands*. Seattle: University of Washington Press.

Marine Resources Committee (MRC). 2012.

http://www.mrc.whatcomcounty.org/library/species-fact-sheets

Oregon Department of Fish and Wildlife (ODFW). 2012. Accessed April 22 2014
http://www.dfw.state.or.us/mrp/shellfish/crab/lifehistory.asp

United States Geological Service (USGS). 1986.
http://www.nwrc.usgs.gov/wdb/pub/species_profiles/82_11-063.pdf

Wild, P.W. and R.N. Tasto (eds.). 1983. Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. California Department of Fish and Wildlife, Fish Bull. (172) :1-352.

World Aquaculture. "Dungeness Crab" (On-line). Accessed 10/27/14 at
http://www7.taosnet.com/platinum/data/light/species/crabdungeness.html

Spot Prawn (*Pandalus platyceros*)

Spot prawn, also known as spot shrimp, are the largest shrimp on the west coast of North America. This species may reach a length of more than nine inches (23 cm), excluding the antennae, with maximum length over 12 inches. In Puget Sound, spot prawn are most common in Hood Canal, the San Juan Islands, and northern and central Puget Sound. This is one of the most important shrimp species for both sport and commercial harvesters in the region. Spot prawn are fished commercially using shrimp pots from Alaska to northern California.

Spot prawn are usually reddish brown or tan with white lines on the head and distinctive white spots on the first and fifth abdominal segments. They are distinguished from similar species by their large size and white spots. Spot prawn abdomens are smooth and shiny; their carapace is covered with a layer of short fine setae. Their antenna are only about as long as the carapace and are banded dark red and lighter red or white. Spot prawn have a long rostrum which is longer than the rest of the carapace. (http://www.bcseafood.ca/PDFs/fisheriesinfo/fishery-spot-prawns-by-trap.pdf).

On the eastern Pacific Ocean, this species is found from Alaska to San Diego, California, and in the western Pacific in the Sea of Japan and the Korea Strait. Most are found well below the intertidal zone in subtidal rocky and sandy habitats with a range of depth from low intertidal to 487 meters deep (Jensen 1995). Spot prawn are most frequently captured at depths of 30 to 300 feet around rock piles, crevices, coral, on sponges, under boulders, and debris-covered bottoms. According to Alaska Department of Fish and Game, spot prawn migrate seasonally from deep to shallow waters with juveniles concentrating in shallow inshore areas. As they mature spot prawn migrate offshore (ADFG 2014).

Spot prawn are omnivorous and feed on crustaceans, polychaetes, limpets carcasses, algae, sponges, and other shrimp. They are bottom feeders that tend to feed at night. Large predator fish such as halibut, Pacific cod, walleye pollock, flounders, salmon, yelloweye rockfish, and the giant octopus are important predators of spot prawn (Butler 1970; Lowry 2007).

The life history of spot prawn is somewhat unusual in that they are protandric hermaphrodites, born males, reaching sexual maturity and going through one spawning cycle. They become females after they grow to a certain size, which can be highly variable depending on location within their range (Jensen 1995; Lowry 2007). They mate one or more times as a female and do not seem to survive long after their final brood is hatched (at age 4 or 5 years). Spawning takes place at depths of 500-700 feet. Average life span is 4 years, with a maximum age of 11 years.

Monterey Bay Aquarium Seafood watch characterizes this species as a “best food choice” based on nutrition and sustainability. They are caught with traps that have relatively low bycatch and habitat impacts (Monterey Bay Aquarium 2014). Spot prawns are known for their sweet flavor and firm texture. General nutrition details (http://spotprawns.com/) of one ounce of raw, edible portions of spot prawn are:

Calories: 25
Fat: 0.1 g
Protein: 6 g
Carbohydrates: ~0 g
Cholesterol: 41 mg
Sodium: 32mg

References

Alaska Department of Fish and Game (ADFG). 2014. http://www.adfg.alaska.gov/index.cfm?adfg=spotshrimp.main)

British Columbia (BC) Fishery. http://www.bcseafood.ca/PDFs/fisheriesinfo/fishery-spot-prawns-by-trap.pdf

Butler, T. H. 1970. "Synopsis of biological data on the prawn *Pandalus platyceros* Brandt, 1851." FAO fisheries report 57(4): 1289-1316.

Chef's Choice. http://spotprawns.com/

Jensen, G.C. 1995. *Pacific Coast Crabs and Shrimps*. Sea Challengers, Monterey.

Lowry, N. 2007. "Biology and fisheries for the spot prawn (*Pandalus platyceros*, Brandt 1851)." Ph.D. Dissertation, University of Washington, Seattle, WA 98028. http://fish.washington.edu/research/publications/ms_phd/Lowry_N_PhD_Au07.pdf

Monterey Bay Aquarium. 2014. (http://www.seafoodwatch.org/cr/seafoodwatch/web/sfw_factsheet.aspx?fid=190).

Walla Walla University. 2007. Salish Sea Invertebrates. http://www.wallawalla.edu/academics/departments/biology/rosario/inverts/Arthropoda/Crustacea/Malacostraca/Eumalacostraca/Eucarida/Decapoda/Caridea/Family_Pandalidae/Pandalus_platyceros.html

Washington Department of Fish and Wildlife (WDFW). 2014. http://wdfw.wa.gov/fishing/shellfish/crab/

APPENDIX B

Chemical Specific Toxicity

Washington State Department of Fish and Wildlife (WDFW) analyzed numerous chemicals in Dungeness crab muscle and hepatopancreas tissue and in spot prawn muscle and head tissue as part of a one-time assessment of these species. Chemicals included polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides as well as mercury, arsenic, cadmium, copper, lead, and zinc. The following is a synopsis of background information on these chemicals from ATSDR documents, EPA IRIS, and journal articles.

Arsenic

Arsenic is a naturally occurring element in the earth's soil. Widespread use of arsenic-containing pesticides and emissions from smelters has resulted in high levels of arsenic in many areas of the state. There are two forms of arsenic: organic and inorganic. The EPA-established RfD for arsenic is 0.0003 mg/kg/day based on skin color changes and excessive growth of tissue (human data) (ATSDR 2005b). EPA classifies the inorganic form of arsenic as a human carcinogen. The current EPA slope factor for arsenic is 1.5 per mg/kg/day. The recent EPA IRIS review draft for the Science Advisory Board presented a slope factor for combined lung and bladder cancer of 5.7 per mg/kg/day (EPA 2005). The slope factor calculated from the work by the National Research Council is about 21 per mg/kg/day (NAS 2001). These slope factors could be higher if the combined risks for all arsenic-associated cancers (bladder, lung, skin, kidney, liver, etc.) were evaluated. DOH will not be using the slope factor of 1.5 per mg/kg/day due to the arsenic weight of evidence approach. For this or any other health consultation, DOH will use a slope factor of 5.7 per mg/kg/day, which appears to reflect EPA's Review Draft assessment.

Inorganic arsenic is much more harmful to humans than organic arsenic; therefore, DOH bases any health evaluation on levels of inorganic arsenic present in fish or shellfish samples. Generally, inorganic arsenic in fish and shellfish ranges from about 1%-20% of the total arsenic (ATSDR 2005b, NAS. 2001, Francesconi and Edmonds 1997, FDA 1993). The U.S. Food and Drug Administration (FDA) assumes 10% of the total arsenic estimated as inorganic arsenic (FDA 1993). However, due to the variability seen in seafood in the percentage of inorganic arsenic, DOH only evaluates inorganic arsenic data, which was not analyzed in the WDFW's study on Dungeness crab and spot prawn from Puget Sound.

Cadmium

Cadmium is a naturally occurring element in the earth's crust. Cadmium is used mainly in batteries, pigments, metal coatings, and metal alloys. Cadmium is found in most foods at low levels, with the lowest levels found in fruits and the highest levels found in leafy vegetables and potatoes. Shellfish have higher cadmium levels (up to 1 ppm) than other types of fish or meat. Cadmium is stored in the liver and kidneys and slowly leaves the body in the urine and feces (ATSDR 1999a). However, high levels of cadmium will cause kidney damage and cause bones to become fragile and break easily. Occupational exposure to inhaled cadmium is suspected to be a cause of lung cancer in workers while animal studies have confirmed the ability of cadmium to cause lung tumors via the inhalation route. Studies of workers exposed to airborne cadmium also suggest a link with prostate cancer. The ability of cadmium to cause cancer via the oral route is disputed. The RfD for cadmium ingested with food is 0.001 mg/kg/day.

Copper

Copper is a naturally occurring element in the earth's soil. Background soil copper concentrations in Eastern Washington range from about 4 ppm to 53 ppm (TCP 1994). Copper is an essential element for good health. Once ingested, copper rapidly enters the bloodstream and is distributed throughout the body after ingestion. Copper combines with protein and iron to make hemoglobin, which transports oxygen in the blood from the lungs to other parts of the body. Copper usually takes several days to leave the body in feces and urine. However, exposure to very high doses of copper can cause liver and kidney damage and even death (ATSDR 2001). Water containing high levels of copper may cause nausea, vomiting, stomach cramps, or diarrhea when ingested. In addition, long-term exposure to copper dust can irritate the nose, mouth, and eyes and cause headaches, dizziness, nausea, and diarrhea. The EPA Region 3 established RfD for copper is 0.04 mg/kg/day, based on the Health Effects Assessment Summary Tables (HEAST) (EPA 1997).

Lead

Lead is a naturally occurring chemical element that is normally found in soil. In Washington, normal background concentrations rarely exceed 20 ppm (TCP 1994). However, widespread use of certain products (such as leaded gasoline, lead-containing pesticides, and lead-based paint) and emissions from certain industrial operations (such as smelters) have resulted in significantly higher levels of lead in many areas of the state.

Elimination of lead in gasoline and solder used in food and beverage cans has greatly reduced exposure to lead. Currently, the main pathways of lead exposure in children are ingestion of paint chips, contaminated soil and house dust, and drinking water in homes with old plumbing.

Children less than seven years old are particularly vulnerable to the effects of lead. Compared to older children and adults, younger children tend to ingest more dust and soil, absorb significantly more of the lead that they swallow, and more of the lead that they absorb can enter their developing brains. Pregnant women and women of childbearing age should also be aware of lead in their environment because lead ingested by a mother can affect the unborn fetus.

Exposure to lead can be monitored by measuring the blood lead level (BLL). In general, blood lead rises 1-5 µg/dl for every 1,000 ppm increase in soil or dust concentration (EPA 2006a). The CDC has updated its definition for elevated BLL to greater than, or equal to, 5 µg/dl (CDC 2012). Previously, CDC had defined an elevated BLL as greater than or equal to 10 µg/dl (CDC 1991). However, there is growing evidence that damage to the central nervous system resulting in learning problems can occur at blood lead levels less than 10 µg/dl. U.S. state childhood lead programs 2006 data showed 1.21% of children tested in the U.S. had blood lead levels greater than 10 µg/dl (CDC 2009).

Lead poisoning can affect almost every system of the body and often occurs with no obvious or distinctive symptoms. Depending on the amount of exposure a child has, lead can cause behavior and learning problems, central nervous system damage, kidney damage, reduced growth, hearing impairment, and anemia (ATSDR 1999b).

In adults, lead can cause health problems such as high blood pressure, kidney damage, nerve disorders, memory and concentration problems, difficulties during pregnancy, digestive problems, and pain in the muscles and joints (ATSDR 1999b). These health effects have usually been associated with blood lead levels greater than 30 µg/dl.

Because of chemical similarities to calcium, lead can be stored in bone for many years. Even after exposure to lead has been reduced, lead stored in bone can be released back into the blood where it can have harmful effects. Normally this release occurs relatively slowly. However, certain conditions such as pregnancy, lactation, menopause, and hyperthyroidism can cause more rapid release of the lead, which could lead to a significant rise in BLLs (ATSDR 2000a).

Mercury

Mercury exists in the environment in three forms: elemental, inorganic, and organic. Methylmercury is the form of organic mercury related to exposure in fish. Methylmercury is formed from inorganic mercury in the environment by microorganisms in aquatic systems. 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 contain high levels of methylmercury, which can represent a potential health concern for consumers of fish, depending on concentrations in fish tissue and consumption rates.

Ingested methylmercury is readily absorbed, binds with the cysteine amino acid, and crosses the blood-brain barrier. In Minamata Bay, Japan, mothers who were exposed to high amounts of methylmercury but were asymptomatic gave birth to severely affected infants. Other epidemiologic studies that have shown developmental effects in both animal and human studies are the basis for this primary concern about methylmercury exposure. The EPA-established RfD for mercury is 0.0001 mg/kg/day.

Mercury evaluated in this report represents total mercury as opposed to methylmercury. Dose calculations, however, do not attempt to fractionate the mercury concentrations because almost all mercury in fish is methylmercury; we assumed that Puget Sound crab and prawn results were all methylmercury.

Zinc

Zinc is a naturally-occurring element found in the earth's soil. Background soil zinc concentrations in Eastern Washington range from about 26 ppm to 82 ppm (ACS 2010). Zinc compounds are used as ingredients in many common products such as vitamin supplements, sun blocks, diaper rash ointments, deodorants, athlete's foot preparations, acne and poison ivy preparations, and antidandruff shampoos (ATSDR 2005a). Ingesting high levels of zinc for short periods may cause stomach cramps, nausea, and vomiting. Ingesting high levels of zinc for long periods may cause anemia, damage the pancreas, and decrease levels of high-density lipoprotein (HDL) cholesterol (ATSDR 2005a). The EPA established RfD for zinc is 0.3 mg/kg/day.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) are generated by the incomplete combustion of organic matter, including oil, wood, and coal. They are found in materials such as creosote, coal, coal tar, and used motor oil. Base on structural similarities, metabolism, and toxicity, PAHs are often grouped together when one is evaluating their potential for adverse health effects. EPA has classified some PAHs – called cPAHs – as probable human carcinogens (B2) as a result of *sufficient* evidence of carcinogenicity in animals and *inadequate* evidence in humans (ATSDR 1995).

Benzo(a)pyrene is the only cPAH for which EPA has derived a cancer slope factor. Thebenzo(a)pyrene cancer slope factor was used as a surrogate to estimate the total cancer risk of cPAHs in sediment. It should be noted, benzo(a)pyrene is considered the most carcinogenic of the cPAHs. The use of its cancer slope factor as a surrogate for total cPAH carcinogenicity may overestimate risk. To address this issue, DOH made an adjustment for each cPAH based on the relative potency to benzo(a)pyrene or TEQ (ATSDR 1995).

Dietary sources make up a large percentage of PAH exposure in the U.S. population, and smoked or barbecued meats and fish contain relatively high levels of PAHs. The majority of dietary exposure to PAHs for the average person comes from ingestion of vegetables and grains (cereals) (EPA 1998).

PCBs

PCBs are a mixture of man-made organic chemicals. There are no known natural sources of PCBs in the environment. The manufacture of PCBs stopped in the U.S. in 1977 because of evidence that it could build up in the environment and cause toxic health effects. Although no longer manufactured, PCBs can still be found in certain products such as old fluorescent lighting fixtures, old microscope oil, and old hydraulic oil and electrical devices or appliances containing PCB capacitors made before PCB use was stopped. Prior to 1977, PCBs entered the environment (soil, water, and air) during the manufacture and use of PCBs. Today, PCBs still enter the environment from poorly maintained hazardous waste sites, illegal or improper dumping of PCB wastes such as old hydraulic oil, leaks from electrical transformers that contain PCB oils, and disposal of old consumer products that contain PCBs (ATSDR 2000b).

PCBs enter the environment as mixtures of individual components known as congeners. There are 209 structural variations of PCB congeners, which differ in the number and location of chlorine atoms on the chemical structure. Most PCBs produced commercially in the U.S. were sold under the trade name Aroclor. The name Aroclor 1254, for example, means that the molecule contains 12 carbon atoms (the first 2 digits) and about 54% chlorine by weight (second 2 digits). No Aroclor mixture contains all 209 congeners.

PCBs do not easily breakdown and are found worldwide because of their persistence. Small amounts of PCBs can be found in almost all outdoor and indoor air, soil, sediments, surface water, and animals. PCBs bioaccumulate in the food chain and are stored in fat cells. The major dietary source of PCBs is fish. PCBs are also found in meats and dairy products (ATSDR 2000b).

PCBs can get into people's bodies by ingestion, inhalation, and dermal (skin) contact. Some of the PCBs that enter the body are metabolized and excreted from the body within a few days; others stay in the body fat and liver for months and even years. PCBs collect in milk fat and can enter the bodies of infants through breastfeeding (ATSDR 2000b). Skin irritation, vomiting, nausea, diarrhea, abdominal pain, eye irritation, and liver damage can occur in people acutely exposed to high levels of PCBs in occupational settings (ATSDR 2000b). However, health effects relevant to low-level environmental exposures are immunological effects in monkeys (Aroclor 1254 - RfD of 0.00002 mg/kg/day) and developmental effects in children exposed to PCBs in the womb because mothers ate PCB contaminated fish (ATSDR 2000b). Toxicity equivalency factors (TEFs) have been developed for several dioxin-like PCB congeners.

PBDEs

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. PBDEs are 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 and DOH 2004).

Information on possible health impacts of PBDEs comes primarily from animal toxicity studies (Ecology and DOH 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.

Five congeners (PBDE-47, -99, -100, -153, and -154) predominate in human tissues, usually accounting for more than 90 percent of the total PBDE body burden in most individuals not occupationally exposed. PBDE-47, -99, and -100 are present in the penta- BDE technical mixture, whereas PBDE-153 and -154 are constituents of both the penta- BDE and octa-BDE technical mixtures. Growing evidence suggests that the more highly Spokane River Evaluation 61 brominated congeners of the deca-BDE technical mixture break down in the environment (e.g., lose bromine atoms through sunlight degradation and biotic metabolism) and subsequently form lower brominated PBDE congeners commonly found in humans (Soderstrom et al 2004, Stapleton et al. 2004).

Current PBDE toxicity values, as provided by EPA, do not indicate the need to provide fish consumption advice based on this contaminant (RfDs = 1x 10^{-3} mg/kg-day for decabromodiphenyl ether, 3 x10^{-3} mg/kg-day for octabromodiphenyl ether, and 2 x10^{-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. The U.S. EPA is conducting a peer review of the scientific basis supporting the human health hazard and dose-response assessments of four congeners of polybrominated diphenyl ethers: tetraBDE (BDE-47), pentaBDE (BDE-99), hexaBDE (BDE-153), and decaBDE (BDE-209), that will appear on the Integrated Risk Information System (IRIS) database. Peer review is meant to ensure that science is used credibly and appropriately in derivation of the dose-response assessments and toxicological characterization (EPA 2006b). Based on recent research in animals (rats), EPA's new reference dose (RfD) values are as follows:

- BDE-47 RfD = 1 x 10^{-4} mg/kg-day
- BDE-99 RfD = 0.1 µg/kg-day
- BDE-153 RfD = 2 x 10^{-4} mg/kg-day
- BDE-209 RfD = 7 x 10^{-3} mg/kg-day

References

American Cancer Society. 2010. Cancer Facts & Figures. Atlanta: American Cancer Society; 2010.

Agency for Toxic Substances and Disease (ATSDR). 1995. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs), (update) PB/95/264370. Atlanta: U.S. Department of Health and Human Services. August 1995.

Agency for Toxic Substances and Disease Registry (ATSDR). 1999a Toxicological profile for Cadmium (update) PB/99/166621. Atlanta: U.S. Department of Health and Human Services. July 1999.

Agency for Toxic Substances and Disease Registry (ATSDR). 1999b. Toxicological profile for Lead (update) PB/99/166704. Atlanta: U.S. Department of Health and Human Services. July 1999.

Agency for Toxic Substances and Disease Registry (ATSDR). 2000a. Lead Toxicity (Case studies in environmental medicine Course) SS3059. Atlanta: U.S. Department of Health and Human Services, Public Health Service. October 2000.

Agency for Toxic Substances and Disease Registry (ATSDR). 2000b. Toxicological profile for Polychlorinated Biphenyls (PCBs) (update) PB/2000/108027. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. November 2000.

Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological profile for copper PB 2004-10733. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. September 2004.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005a. Toxicological profile for zinc (update) PB2006-100008. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. August 2005.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005b. Toxicological profile for arsenic (update) PB/2000/108021. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service. September 2005.

Centers for Disease Control and Prevention (CDC). 1991. Preventing lead poisoning in young children: a statement by the Centers for Disease Control, October 1991. Atlanta, Georgia: U.S. Department of Health and Human Services, Public Health Service, CDC. 1991.

Centers for Disease Control and Prevention (CDC). 2009. *Fourth National Report on Human Exposure to Environmental Chemicals*. http://www.cdc.gov/exposurereport/. December 2009.

Centers for Disease Control and Prevention (CDC). 2012. Blood lead levels in children: factsheet by the Centers for Disease Control, 2012. Atlanta, Georgia: U.S. Department of Health and Human

Services, Public Health Service, CDC. 2012.
http://www.cdc.gov/nceh/lead/ACCLPP/Lead_Levels_in_Children_Fact_Sheet.pdf

EPA. 1997. Health Effects Assessment Summary Tables: FY 1997 Update. Office of Research and Development, Washington, DC. EPA 540-R-97-036. July 1997.

EPA. 1998. Integrated Risk Information System, Arsenic, Inorganic. http://www.epa.gov/iris/subst/0278.htmPhillips, D H. Polycyclic Aromatic Hydrocarbons in the diet. Mutation Research 1999; (443) 139-147.

EPA. 2005. Toxicological Review of Inorganic Arsenic: In support of summary information on the Integrated Risk Information System, July 2005. http://www.epa.gov/waterscience/criteria/arsenic/sab/AsDraft_SAB.pdf.

EPA. 2006a. Air Quality Criteria for Lead Volume I. U.S. Environmental Protection Agency, Washington, DC. EPA/600/R-5/144aF, October 2006.

EPA. 2006b. External Peer Review Panel Meeting on IRIS Toxicological Review Documents for Polybrominated Diphenyl Ethers. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=161970

Food and Drug Administration (FDA). 1993. Guidance document for arsenic in shellfish. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Food Safety and Applied Nutrition. Washington, DC. January 1993. Available from URL: http://www.foodsafety.gov/~frf/guid-as.html

Francesconi, K.A., and Edmonds, J.S. 1997. Arsenic and marine organisms. Advances in Inorganic Chemistry 44:147-189.

NAS. 2001. Arsenic in Drinking Water: 2001 Update. National Academy Press. Washington, DC. 2001. Available at: http://books.nap.edu/books/0309076293/html/index.html.

Soderstrom, G., Sellstrom, U., de Wit, C. A., and Tysklind, M. 2004. Photolytic debromination of decabromodiphenyl ether (BDE 209). Environ Sci Technol. 38:127-132.

Stapleton, H. M., Alaee, M., Letcher, R. J., and Baker, J. E. 2004. Debromination of the flame retardant decabromodiphenyl ether by juvenile carp (*Cyprinus carpio*) following dietary exposure. Environ Sci Technol. 38:112-119.

Toxics Cleanup Program. 1994. Department of Ecology: Natural background soil metals concentrations in Washington State Publication No. 94-115. Olympia: Washington State Department of Ecology: October 1994.

Washington Departments of Ecology and Health. 2004. Washington State Polybrominated Diphenyl Ether (PBDE) Chemical Action Plan: Interim Plan. 12-31-2004. Department of Ecology # 04-03-056; Department of Health # 333-068.

Washington Department of Health. 2006. Human Health Evaluation of Contaminants in Puget Sound Fish. 1-10-2006. 334-104.

APPENDIX C

Sampling Stations for Dungeness Crab and Spot Prawn in Puget Sound

Introduction

WDFW collected Dungeness crab and spot prawn through a number of collection efforts. Locations listed below include descriptions, location coordinates, and gear type used to sample species (See Appendix A, Carey et al. 2014).

Table C1. Dungeness crab station descriptions and locations. Location number refers to Marine Area and urban embayments and are represented by their initials (SI = Sinclair Inlet, EB = Elliott Bay, CB = Commencement Bay).

Map Number	Station ID	Location	Basin	Collection Effort ID	Effort Date	Latitude	Longitude	Station Location Coordinate Calculation Method	Gear Type
1	DISCOBAY_TU	6	Strait of Juan de Fuca	12DB_TU-S1	6/28/12	48.05517	-122.85640	GPS - Single Point	Crab Pot
2	ALLANISL_S	7	Strait of Juan de Fuca	12SJST1-H77	5/29/12	48.44963	-122.69114	GPS - Start End Average	Bottom Trawl
3	VENDOVI	7	San Juan Islands	11VD-H08	4/28/11	48.64479	-122.64410	GPS Start End Average - multiple efforts	Bottom Trawl
4	WALDRONISL_N	7	San Juan Islands	12WALD_N-S1A,B,C,D,E	6/26/12	48.70788	-123.05804	GPS- Average from multiple efforts	Crab Pots
5	BHMHARBR	7	North Sound	12BH-S1A,B,C,D,E	6/27/12	48.73466	-122.51459	GPS- Average from multiple efforts	Crab Pots
6	STRTGEOR	7	Strait of Georgia	12GBNU2-H40	5/15/12	48.87209	-122.90997	GPS - Start End Average	Bottom Trawl
7	BABYISLAND	8.1	North Sound	12BBY-S2	6/12/12	48.10128	-122.52367	GPS - Single Point	Crab Pot
8	GREENBANK	8.1	North Sound	12GBNK-S1	6/1/12	48.11079	-122.55334	GPS - Single Point	Crab Pot
9	NORTHBLUFF_N	8.1	North Sound	12NBL_N-S2	6/12/12	48.13230	-122.56152	GPS - Single Point	Crab Pot
10	CAMANOCITY_S	8.1	North Sound	12CCS-S2	6/12/12	48.15995	-122.52547	GPS - Single Point	Crab Pot
11	STRAWBERRYPT	8.1	North Sound	12STRPT-S1	6/1/12	48.29723	-122.50386	GPS - Single Point	Crab Pot
12	SKAGITIS	8.1	North Sound	12SKIS-S1	6/1/12	48.41035	-122.57871	GPS - Single Point	Crab Pot
13	PTGARDNR	8.2	North Sound	11PG-H05(A-B)	4/25/11	47.98529	-122.24391	GPS Start End Average - multiple efforts	Bottom Trawl
14	CAMANOHEAD	8.2	North Sound	12CH-S2	6/6/12	48.05698	-122.37582	GPS - Single Point	Crab Pot
15	LANGLEY_N	8.2	North Sound	12LYN-S2	6/12/12	48.07237	-122.45727	GPS - Single Point	Crab Pot
16	PTSUSAN	8.2	North Sound	12PS-S2	6/14/12	48.08162	-122.32363	GPS - Single Point	Crab Pot

17	MABANA_N	8.2	North Sound	12MB_N-WINU H31,H32	5/10/12	48.10347	-122.45214	GPS - average	Bottom Trawl
18	LOWELLPOINT	8.2	North Sound	12LPT-WINV H29	5/10/12	48.11338	-122.49547	GPS - average	Bottom Trawl
19	PTGAMBLE_3	9	North Sound	12PG3-S1	8/13/12	47.83803	-122.57556	GPS - Single Point	Crab Pot
20	PTGAMBLE_1	9	North Sound	12PG1-S1	8/13/12	47.84600	-122.57628	GPS - Single Point	Crab Pot
21	EGLON	9	North Sound	12ELN-S1A,B,C	5/23/12	47.86038	-122.50792	GPS- Average from multiple efforts	Crab Pots
22	PTGAMBLE_N	9	North Sound	12PTGB_N-S1	6/2/12	47.88007	-122.58368	GPS - Single Point	Crab Pot
23	USELESSBAY_M	9	North Sound	12UB_M-S1	6/13/12	47.96605	-122.46863	GPS - Single Point	Crab Pot
24	OAKBAY	9	North Sound	12OAKB-S1	6/13/12	48.00403	-122.70168	GPS - Single Point	Crab Pot
25	PTTWNSND_GC	9	North Sound	12PT_GC-S1	6/14/12	48.08912	-122.76245	GPS - Single Point	Crab Pot
26	SCLINLET	SI	Central Sound	11SI-H04(A-C)	4/20/11	47.54814	-122.64353	GPS Start End Average - multiple efforts	Bottom Trawl
27	DUWAMISH	EB	Central Sound	11DU-H09(A-C)	5/16/12	47.55740	-122.34402	GPS Start End Average - multiple efforts	Bottom Trawl
28	BLAKEISLAND_N	10	Central Sound	12CSMV1-H81, 2-H82	5/30/12	47.56217	-122.47695	GPS Start End Average - multiple efforts	Bottom Trawl
29	ALKIPOINT_S	10	Central Sound	12AKP_S-S01A,B	5/22/12	47.56768	-122.41206	GPS- Average from multiple efforts	Crab Pots
30	ELLTBAY	EB	Central Sound	11EB-H10	5/17/12	47.60541	-122.34414	GPS Start End Average - multiple efforts	Bottom Trawl
31	ELLTBAY_P69	EB	Central Sound	12EB_P69-S1	6/29/12	47.61194	-122.35306	Estimated	Crab Pot
32	ELLTBAY4_P89	EB	Central Sound	12EB4_P89-S1	7/12/12	47.62398	-122.37687	GPS - Single Point	Crab Pot
33	ELLTBAY4_P91SH	EB	Central Sound	12EB4_P91SH-S1	6/29/12	47.62444	-122.38333	GPS - Single Point	Crab Pot
34	4MILEROCK	10	Central Sound	124M-S1A,B,C	5/22/12	47.63703	-122.42081	GPS- Average from multiple efforts	Crab Pots
35	YEOMALT_SH	10	Central Sound	12YEO_SH-S1A,B	5/22/12	47.64000	-122.49717	GPS- Average from multiple efforts	Crab Pots
36	PTMADISN_IND	10	Central Sound	12PM_IND-S1A,B,C	5/23/12	47.73392	-122.49447	GPS- Average from multiple efforts	Crab Pots
37	KINGSTON	10	Central Sound	12KG-S1A,B,C	5/23/12	47.78600	-122.48762	GPS- Average from multiple efforts	Crab Pots
38	EDMONDS	10	Central Sound	12ED-S1A,B,C	5/23/12	47.80297	-122.39833	GPS- Average from multiple efforts	Crab Pots
39	COMMBAY	CB	Central Sound	11CB-H02(A-E)	4/19/11	47.25767	-122.43543	GPS Start End Average - multiple efforts	Bottom Trawl
40	COMMBAY4_DEEP	CB	Central Sound	12CSSU01-H13	5/3/12	47.28175	-122.46606	GPS - Start End Average	Bottom Trawl
41	COMMBAY_P23	CB	Central Sound	12CB_P23-S1	5/25/12	47.28428	-122.41645	GPS - Single Point	Crab Pot
42	QTRMASTR	11	Central Sound	12QM-S1	5/25/12	47.34857	-122.48082	GPS - Single Point	Crab Pot
43	OLALLA	11	Central Sound	12OL-S1A,B,C	5/22/12	47.42058	-122.53609	GPS- Average from multiple efforts	Crab Pots
44	3TREEPOINT	11	Central Sound	12TT-S1A,B,C	5/22/12	47.46066	-122.37141	GPS- Average from multiple efforts	Crab Pots
45	HDCANAL_TA	12	Hood Canal	12HCST02-H22	5/8/12	47.35595	-123.05986	GPS - Start End Average	Bottom Trawl
46	LILLIWAUP	12	Hood Canal	12LW-S1	6/1/12	47.45938	-123.10405	GPS - Single Point	Crab Pot

47	SCENICBEACH	12	Hood Canal	12SC-S1	5/31/12	47.65610	-122.84040	GPS - Single Point	Crab Pot
48	QUILCENE	12	Hood Canal	12QB-S1	6/1/12	47.79040	-122.85520	GPS - Single Point	Crab Pot
49	HDCANAL	12	Hood Canal	11HC-H06	4/26/11	47.83437	-122.64420	GPS Start End Average - multiple efforts	Bottom Trawl
50	SQUAMISHHRBR	12	Hood Canal	12SUH-S1	6/2/12	47.86232	-122.65945	GPS - Single Point	Crab Pot
51	NISQUALY_FLATS_GC	13	South Sound	12NQ_FLGC-S1	7/11/12	47.11448	-122.69442	GPS - Single Point	Crab Pot
52	TREBLEPOINT	13	South Sound	12TRP-S1	7/12/12	47.15338	-122.74805	GPS - Single Point	Crab Pot
53	NISQUALY	13	South Sound	11NQ-H01	4/18/11	47.15453	-122.66850	GPS - Start End Average	Bottom Trawl
54	BRISCOPOINT	13	South Sound	12BRP-S1A,B,C	7/11/12	47.16241	-122.88489	GPS- Average from multiple efforts	Crab Pots

Table C2. Spot prawn station descriptions and locations. Location number refers to Marine Area and the urban embayment is represented by its initials (EB = Elliott Bay).

Map Number	Station ID	Location	Basin	Effort ID	Effort Date	Latitude	Longitude	Station Location Coordinate Calculation Method	Gear Type
1	PROTECTIONISL	6	Strait of Juan de Fuca	12JEET1-H69	5/23/12	48.12535	-122.97075	GPS - Start End Average	Bottom Trawl
2	PARTRIDGEBANK_N	6	Strait of Juan de Fuca	12JEEU1-H71	5/24/12	48.27955	-122.84215	GPS - Start End Average	Bottom Trawl
3	LAWSONREEF_N	7	Strait of Juan de Fuca	12SJSU1-H75	5/29/12	48.42709	-122.72835	GPS - Start End Average	Bottom Trawl
4	POINTCAUTION	7	San Juan Islands	12SJSV1-H53	5/17/12	48.56646	-123.01249	GPS - Start End Average	Bottom Trawl
5	VENDOVI	7	San Juan Islands	11VD-H08	4/28/11	48.64479	-122.64410	GPS Start End Average - multiple efforts	Bottom Trawl
6	POINTDISNEY	7	San Juan Islands	12SJNV2-H52	5/17/12	48.67545	-123.02743	GPS - Start End Average	Bottom Trawl
7	FERNPOINT	7	Strait of Georgia	12GBSU1-H47	5/16/12	48.73699	-122.74786	GPS - Start End Average	Bottom Trawl
8	BABYISLAND	8.1	North Sound	12BBY-S1	6/12/12	48.10930	-122.53403	GPS - Single Point	Prawn Pot
9	NORTHBLUFF	8.1	North Sound	12NBL-S1	5/29/12	48.12418	-122.54700	GPS - Single Point	Prawn Pot
10	NORTHBLUFF_N	8.1	North Sound	12NBL_N-S1	6/12/12	48.13402	-122.55437	GPS - Single Point	Prawn Pot
11	CAMABEACH	8.1	North Sound	12CMB-S1	5/29/12	48.14995	-122.52643	GPS - Single Point	Prawn Pot
12	CAMANOCITY_S	8.1	North Sound	12CCS-S1	6/12/12	48.15932	-122.52988	GPS - Single Point	Prawn Pot
13	ONAMAC	8.1	North Sound	12ON-S1	5/29/12	48.18593	-122.54310	GPS - Single Point	Prawn Pot
14	PTGARDNR	8.2	North Sound	11PG-H05(A-B)	4/25/11	47.98529	-122.24391	GPS Start End Average - multiple efforts	Bottom Trawl
15	CAMANOHEAD	8.2	North Sound	12CH-S1	6/11/12	48.05428	-122.37762	GPS - Single Point	Prawn Pot
16	LANGLEY_N	8.2	North Sound	12LYN-S1	6/12/12	48.07325	-122.45450	GPS - Single Point	Prawn Pot
17	PTSUSAN	8.2	North Sound	12PS-S1	6/14/12	48.08118	-122.32690	GPS - Single Point	Prawn Pot
18	MABANA_N	8.2	North Sound	12WINU1-H31,H32	5/10/12	48.10347	-122.45214	GPS - Start End Average	Bottom Trawl
19	LOWELLPOINT	8.2	North Sound	12WINV1-H29	5/10/12	48.11338	-122.49547	GPS - Start End Average	Bottom Trawl
20	EDMONDS_N	9	Central Sound	12EDN-S01	3/22/12	47.83025	-122.38410	GPS - Single Point	Prawn Pot
21	BROWNBAY	9	Central Sound	12BRB-S01	3/22/12	47.85108	-122.34510	GPS - Single Point	Prawn Pot

Continued.

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Map Number	Station ID	Location	Basin	Effort ID	Effort Date	Latitude	Longitude	Station Location Coordinate Calculation Method	Gear Type
22	POSSEPT	9	North Sound	12PP-S01	3/22/12	47.90123	-122.37453	GPS - Single Point	Prawn Pot
23	BLAKLYRK	10	Central Sound	12BR-S01	3/22/12	47.59152	-122.47678	GPS - Single Point	Prawn Pot
24	ELLTBAY_SW	EB	Central Sound	12EB_SW-S1	6/21/12	47.59157	-122.37298	GPS - Single Point	Prawn Pot
25	ELLTBAY_PSSDA	EB	Central Sound	12EB_PSSDA-S1	6/28/12	47.59740	-122.35782	GPS - Single Point	Prawn Pot
26	DUWAMISHHEAD	EB	Central Sound	12DH-S1	6/21/12	47.59828	-122.38137	GPS - Single Point	Prawn Pot
27	ELLTBAY_P71DEEP	EB	Central Sound	12EB_P71DP-S1	7/12/12	47.61372	-122.36680	GPS - Single Point	Prawn Pot
28	ELLTBAY4_P90DEEP	EB	Central Sound	12EB4_P90DP-S1	6/21/12	47.62022	-122.37953	GPS - Single Point	Prawn Pot
29	ELLTBAY4_P91	EB	Central Sound	12EB4_P91-S1	6/29/12	47.62250	-122.38333	Estimated from map - Single Point	Prawn Pot
30	YEOMALT	10	Central Sound	12YEO-S01	3/22/12	47.63935	-122.48995	GPS - Single Point	Prawn Pot
31	SKIFFPT_N	10	Central Sound	12SKPN-S01	3/22/12	47.67430	-122.49740	GPS - Single Point	Prawn Pot
32	MEADOWPOINT	10	Central Sound	12CSMT1-H15	5/7/12	47.69312	-122.41202	GPS - Start End Average	Bottom Trawl
33	DESMOINES_N	11	Central Sound	12DMN-S01	3/21/12	47.41327	-122.35208	GPS - Single Point	Prawn Pot
34	SEAHURST	11	Central Sound	12SR-S01	3/21/12	47.47953	-122.37227	GPS - Single Point	Prawn Pot
35	BRACEPT_S	11	Central Sound	12BRPS-S01	3/21/12	47.50208	-122.39217	GPS - Single Point	Prawn Pot
36	HDCANAL_MUS	12	Hood Canal	12HCMUS-S01	4/4/12	47.39957	-123.11628	GPS - Single Point	Prawn Pot
37	DEWATTO_S	12	Hood Canal	12DES-S1	6/15/12	47.43840	-123.09124	GPS - Single Point	Prawn Pot
38	HDCANAL_NEL	12	Hood Canal	12HCNEL-S01	4/6/12	47.60265	-122.92460	GPS - Single Point	Prawn Pot
39	PLEASANTHARBOR	12	Hood Canal	12PH-S1	6/15/12	47.62552	-122.90186	GPS - Single Point	Prawn Pot
40	HAZELPOINT_N	12	Hood Canal	12HAZN-S1	6/15/12	47.70389	-122.77889	GPS - Single Point	Prawn Pot
41	HDCANAL_ZEL	12	Hood Canal	12HCZEL-S01	4/5/12	47.71943	-122.82048	GPS - Single Point	Prawn Pot
42	NISQUALY	13	South Sound	11NQ-H01	4/18/11	47.15453	-122.66850	GPS - Start End Average	Bottom Trawl