PERSISTENT ORGANIC POLLUTANTS: A RISK ASSESSMENT OF VANCOUVER ISLAND FIRST NATIONS TRADITIONAL SEAFOODS

By

AMELIA ANNE PORTER

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We accept this thesis proposal as conforming
to the required standard

....
Dr. Peter S. Ross, Thesis Supervisor
Vancouver Aquarium, Vancouver, BC

....
Thesis Coordinator
School of Environment and Sustainability

....
Director
School of Environment and Sustainability

ROYAL ROADS UNIVERSITY

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Abstract

Traditional seafoods are integral to the health and culture of coastal First Nations in British Columbia. However, concerns about ocean pollutants have prompted a need for a human health risk assessment which captures consumption, contaminant exposure, and risk assessment. This study builds on previous contaminant measurements and dietary surveys by assessing risks associated with dioxin-like compounds, PCBs, and PBDEs in traditional seafoods consumed by five Vancouver Island First Nations. Non-cancer risks for respondents fell below levels of concern using Health Canada guidance, but 8% and 7% of respondents were deemed to be at risk of non-cancer risks from dioxin-like compounds and PCBs respectively, using US EPA guidance. Increased risk of cancer using US EPA guidance was associated with estimated exposure to dioxin-like compounds and PCBs. Results suggest that some persistent organic pollutants present risks to traditional seafood consumers, but nutritional and social benefits are expected to outweigh the risks.

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Abbreviations and Acronyms

ATSDR	Agency for Toxic Substances Disease Registry (United States)
COPC	contaminant of potential concern
DL PCBs	dioxin-like polychlorinated biphenyls
EC-SCF	European Commission Scientific Committee on Food
EDI	estimated daily intake
HC	Health Canada
HHRA	human health risk assessment
HQ	hazard quotient
IARC	International Agency for Research on Cancer (WHO)
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System (US EPA)
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LADD	lifetime average daily dose
MRL	minimal risk level (ATSDR)
Non-DL PCBs	non dioxin-like polychlorinated biphenyls
OEHHA	Office of Environmental Health Hazard Assessment (California EPA)
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-*p*-dioxins
PCDFs	polychlorinated dibenzofurans
RfD	reference dose (US EPA)
SF	slope factor

TCDD	tetrachlorodibenzo-*p*-dioxin
TDI	tolerable daily intake
TEF	toxic equivalence factor
TRV	toxicological reference value
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Introduction

People of the Pacific Northwest Coast of North America have relied on subsistence practices in obtaining marine foods for thousands or years (Davis & Twidale, 2011; Garner & Parfitt, 2006; Hopkinson, Stephenson, & Turner, 1995; Matson, Coupland, & Mackie, 2003; Mos et al., 2004; Moss & Cannon, 2011; Muckle, 2006). The Northwest Coast, 1 of 10 North American anthropological cultural areas, ethnographically describes indigenous cultures of the coastal region spanning from Alaska to northern California (Muckle, 2006). The temperate coastal rainforest ecology offering plentiful marine resources have shaped hunting gathering fishing societies common to Northwest Coast cultures including the Haida, Coast Salish, Kwakwaka'wakw, Nisga'a, and Nuu chah nulth. Particularly, fish (e.g., salmon, rockfish, halibut, oolichan, sturgeon, herring, trout, cod), shellfish (e.g., clams, mussles, cockles, crabs, and urchins), and sea mammals (e.g., seals, porpoises, and whales) have long been important nutritional resources to coastal people (Matson et al., 2003; Muckle, 2006).

Archaeological and radiocarbon data have aided the understanding of prehistoric resource use at human settlements along coastal Vancouver Island. McKechnie (2011) found that fish remains represented the majority of vertebrate specimens at a shell midden in Barkley Sound on the west coast of Vancouver Island, with six fish taxa utilized over the duration of 5000 years before present.

Contemporary Importance of Traditional Seafoods

Traditional fishing and harvesting of marine resources continues to be an integral component of First Nation cultures in present day British Columbia (Mos et al., 2004). In essence, the activities involved in procuring traditional foods are regarded as essential to First Nations peoples physical, mental, emotional, and spiritual health (Mos et al., 2004; Van Oostdam et al., 2005). The traditional diet offers nutritional benefits including essential vitamins and minerals, low saturated fat, and high fibre content (Mos et al., 2004). Despite the immense cultural and nutritional benefits, increasing concerns of contaminated fish and aquatic resources have posed questions among First Nations communities concerning the health risks associated with the consumption of traditional marine foods.

Global Contamination by Persistent Organic Pollutants (POPs)

Since the middle of the 20th century, the global environment has become contaminated with chemical contaminants known as Persistent Organic Pollutants (POPs) (e.g., polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-p furans (PCDFs), polybrominated diphenylethers (PBDEs), and organochlorine pesticides (OCPs) such as dichlorodiphenyltrichloroethane (DDT)) (Alava et al., 2012; United States Environmental Protection Agency (US EPA), 2002; Ross & Birnbaum, 2003). POPs are responsible for notorious environmental atrocities including Agent Orange, the chemical utilized during the Vietnam War; the Love Canal; pollution of the Great Lakes; and severe declines of predatory birds due to DDT induced eggshell thinning (US EPA, 2002). These chemicals are anthropocentrically produced as products used in flame retardants, transformers and coolant fluids; or as by-products from thermal and industrial processes, such as incineration of wastes, production of organic chlorinated herbicides, and bleaching of papers at pulp and paper mills (Arisawa, Takeda, & Mikasa, 2005, Ross & Birnbaum, 2003).

Four collective properties characterize POPs: persistence, bioaccumulation, toxicity, and long-range transport (US EPA, 2002). They are redistributed globally via atmospheric, oceanic, and wildlife transport and are commonly found in remote areas far from human activities such as the remote artic and in albatross birds on Midway atoll (Canadian Council of Ministers of the Environment [CCME], 2002; US EPA, 2002).

The Stockholm Convention on POPs is a legally binding international treaty ratified on May 23, 2001 aimed to protect human health and the environment from POPs (Stockholm Convention, 2008). The production and/or use a number of POPs including PCBs, PCDD/Fs, OCPs, and some PBDEs are restricted under the Stockholm Convention. Although most (but not all) POPs were banned from use and/or production in the late 1970s in many parts of the world, their persistent nature has lead to profound long lasting global effects for environmental, wildlife, and human health. Lipophilic properties and resistance to chemical and biological degradation allow POPs to persist in nature as well as biomagnify through the food web resulting in the greatest contaminant concentrations within the tissues of higher trophic level species (Ross & Birnbaum, 2003; Weisglas-Kuperus et al., 2004).

Toxicological Health Risks

Prolonged exposure to certain POPs mixtures can have devastating health consequences. Humans and wildlife are exposed through food, air, and water intake and skin absorption (CCME, 2002). Consumption of dairy products, meat, and fish is the primary vector for human exposure (Koopman-Esseboom et al., 1996). POPs accumulate in organs of wildlife and humans including the liver and adipose tissue (Arisawa et al., 2005). Adverse health effects involving endocrine, immune, reproductive, developmental, and neurological dysfunction and carcinogen effects resulting from POP exposure have been detected in high trophic level wildlife and humans (Krahn et al., 2007; Mos et al., 2004; Ross, 2006; Ross & Birnbaum, 2003; Weisglas-Kuperus, Van Oostdam et al., 2005; Vreugdenh, & Mulder, 2004). The CHE Toxicant and

Disease Database has linked environmental contaminants to 200 different human diseases (Van Oostdam et al., 2005).

Dioxin-like toxic equivalency (TEQ).

Dioxin-like compounds (PCBs, dioxins and furans, etc.) have a common mechanism of action in humans and wildlife involving a cytosolic protein known as the aryl hydrocarbon receptor (A*h*R) (Arisawa et al., 2005; Ross & Birnbaum, 2003). Throughout evolution, the A*h*R and its translocator protein (ARNT) have remained conserved and are common across mammals, birds, and fish (CCME, 2002; Simms, 2000). Dioxin-like compounds bind A*h*R with high affinity. This promotes the formation of the A*h*R nuclear translocator (ARNT) which subsequently moves into the nucleus where it binds specific DNA sequences to alter the induction of specific enzymes, many of which are responsible for detoxification of the xenobiotic itself (Arisawa et al., 2005; Simms, 2000).

Given that *Ah*R is found in all vertebrates, this has enabled extrapolation from rat laboratory studies to other vertebrates (Ross & Birnbaum, 2003). This is the basis for the Toxic Equivalency Factor (TEF) approach developed by the World health Organization as a method to quantify the relative toxicity of a complex mixture of dioxin-like chemicals that bind the A*h*R receptor (Van den Berg et al., 1998). Chemical units have been assigned a Toxic Equivalency Factor (TEF) relative to the most toxic dioxin compound, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), a contaminant of the chemical herbicide Agent Orange utilized in the Vietnam War, with a TEF equal to 1.0 (Van den Berg et al., 1998).

Contaminants in the Coastal Food Web

British Columbia's watersheds, inland seas including the Strait of Georgia and Juan de Fuca Strait, and outer marine coast have become contaminated from point source pollution originating from pulp and paper mills, agricultural activities, municipal wastewater effluent and urban runoff, and industrial activities (Johannessen et al., 2008). In the late 1980s, the Canadian Department of Fisheries and Oceans Canada began implementing fisheries closures and consumption advisories due to elevated dioxin and furan levels sourced from nearby pulp and paper mills (Wiseman & Gobas, 2002). First, shellfish fishery areas in Howe Sound and Prince Rupert were closed in 1988, followed by areas in Kitimat Arm, Gold River, Crofton, Nanaimo, Powell River, Campbell River, and Cowichan Bay in 1989. By 1992, British Columbia closures totalled an area of 900 km^2 (Wiseman & Gobas, 2002). Pulp and paper mill closures as well as a shift to chlorine free bleaching processes have resulted in re-opening of fisheries gradually since 1995 (M. Dodd, personal communication, October 22, 2014). In addition to locally sourced pollution, global contaminants are deposited to the coastal food web and tributaries via atmospheric transport and biotransport by migratory species such as pacific salmon (Morrissey, Pollet, Ormerod, & Elliott, 2012).

Contaminants present throughout the coastal food web in British Columbia are well documented. British Columbia's killer whales (*Orcinus orca)* are some of the most PCB contaminated marine mammals in the world (Ross, 2006). High levels of POPs (e.g., PCBs, PCDD/Fs, PBDEs, OCPs, and DDTs) have been measured in killer whales, harbour seals (*Phoca vitulina*) (Ross et al., 2000; Ross et al., 2004; Ross, 2006), Steller sea lions (*Eumetopias jubatus*) (Alava et al., 2012), and Pacific salmon (Kelly et al., 2011) among other species.

The biomagnification of POPs in coastal food webs has also been characterized; for example, PCBs in a harbour seal food web of the Strait of Georgia (Cullon et al., 2012). Contaminant measurements in sediments, both a contaminant sink and source for marine food webs, in the Strait of Georgia revealed urban harbours and municipal outfalls are hotspots for

PCBs and PBDEs and physiochemical properties and environmental processes determine chemical fate in nonurban waters (Grant et al., 2011; Johannessen et al., 2008). Addison, Ikonomou, and Smith (2004) found higher concentrations of PCDD/Fs and PCBs in harbour seal blubber samples from Strait of Georgia than samples from Quatsino Sound on the west coast of Vancouver Island reflecting the impact of pulp and paper mill and industrial activities on the east coast of Vancouver Island.

Adverse health effects in British Columbia wildlife attributed to POPs have been reported in the literature for harbour seals, great blue herons (*Ardea Herodias*), osprey (*Pandion haliaetus*), and bald eagles (*Haliaeetus leucocephalus*) (Krahn et al., 2007; Ross, 2006; Mos et al., 2004). Captive studies have shown that harbour seals fed POP contaminated fish exhibited reproductive impairment, immunotoxicity, and reduced circulating vitamin A and thyroid hormone concentrations (Ross, 2006). Blood samples collected from harbour seals inhabiting remote and near urban areas of the Salish Sea suggested chemical associated immunotoxicity (Mos et al., 2006). PCB-associated alterations in mRNA expression were observed in killer whales providing evidence for adverse physiological effects (Buckman et. al., 2011).

Killer whales occupy a similar trophic level as humans, and like coastal First Nation communities, salmon is a highly important part of their diet. Observed contaminants and adverse health effects evident in high trophic level wildlife such as killer whales and seals provide indication of food web contamination and potential health risks to humans associated with the consumption of marine foods.

Vancouver Island First Nations as Important Consumers of Seafoods

Canadian human health advice for safe seafood consumption is based on consumption patterns of average Canadians, and do not accurately represent British Columbia First Nation consumer groups. The Chemical Health Hazard Division of Health Canada indicated that Total Diet Studies (TDS) for the general population focus only on retail fish and not on subsistence fishing (J. Lalonde, personal communication, May 10, 2013). Therefore, current Health Canada consumption guidelines may not be protective of coastal First Nations, given the strong interest in traditional seafood harvesting in many communities. Furthermore, human health effects have been documented in Inuit populations in the Canadian Arctic exposed to high levels of POPs through a traditional diet (Chan, 2009; Dewailly et al., 1993; Van Oostdam et al., 2005).

Little knowledge and documentation regarding the consumption patterns and dietary preferences of coastal Vancouver Island First Nation’s communities has made it essentially impossible to carry out a risk-benefit analysis from exposure to chemicals through seafoods. Discussions on Canadian aboriginal seafood consumption health risk have cited the need for investigations in coastal British Columbia (Chan, 2009; Chan et al., 2011). This gap in information emphasizes the need for a risk assessment specific to Vancouver Island First Nation peoples’ consumption patterns and subsistence-oriented fishing and harvesting.

First Nations Human Health Risk Assessment

In this study, we conducted a human health risk assessment in partnership with Vancouver Island coastal First Nation communities in an effort to answer the question: “Is it safe to consume traditional seafoods?” Health risks attributed to the ingestion of POPs (i.e., PCDD/Fs, PCBs, and PBDEs) via seafood were assessed for five communities (i.e., Ahousaht, Pacheedaht, Quatsino, Snuneymuxw and Weweikum). The five communities represent Vancouver Island First Nations People (Kwakwaka’wakw, Coast Salish, and Nuu-chah-nulth) with a total on-reserve resident population of approximately 2,500 people (see Appendix A for community descriptions). These communities capture two differing biogeographical features: Marine (west coast of Vancouver Island) and Inland Sea (Strait of Georgia). Each community differs in proximity to point sources of environmental contamination (e.g., pulp and paper mills, urban centres).

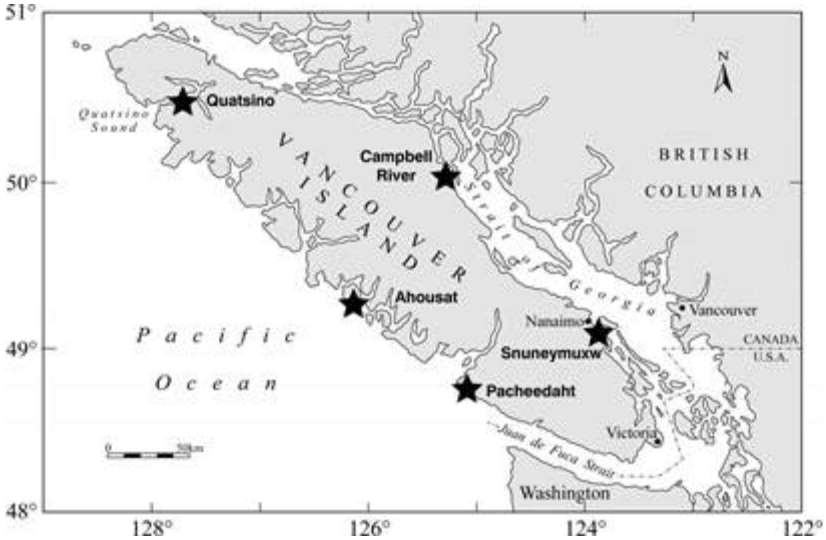

Figure 1. Location of the five First Nation communities on coastal Vancouver Island, British Columbia, Canada. The two east coast communities, Weweikum and Snuneymuxw, are located in semi-urban settings within Campbell River and Nanaimo municipalities respectively. The three west coast communities, Quatsino, Ahoushat, and Pacheedhat, are located within the remote communities of Coal Harbour, Tofino, and Port Renfrew. (P.S. Ross & N.J. Dangerfield, copyright granted, April 25, 2013).

Companion Studies

This risk assessment was contingent upon two information-generating companion studies: Dietary Surveys and Contaminant Analysis. The Dietary Analysis and Contaminant Analysis have previously been completed as part of a three-component project. The study herein (Risk Analysis) marks the third component and builds on findings of the first two components. The objective of the Dietary Analysis was to determine the importance of traditional seafoods to five Vancouver Island First Nation Communities. The objective of the Contaminant Analysis was to determine pollution levels in four sentinel seafood species.

Dietary analysis.

A team of partners from Fisheries and Oceans Canada, University of Victoria, and the five first nations communities carried out the dietary study in 2008 (Child, Ross, & Turner, 2008). Consumption levels of traditional marine foods were estimated via dietary surveys. Dietary surveys were carried out in an interview process with ~60 respondents in each of the five communities for a total of ~300 participants.

Results illustrated that the diet of coastal First Nation people is defined by a diverse mix of marine foods collected from traditional harvesting sites. Seafood consumption is very high at a mean consumption rate of 60.3 kg/person/year or 165 grams/person/day, which is equivalent to two servings per day (P.S. Ross, personal communication, April 25, 2013). The average Canadian seafood consumption is 4.4 kg/year (Conacher, Graham, Newsome, & Graham, 1989; Conacher & Mes, 1993). This signifies that coastal First Nations of Vancouver Island consume almost 14 times more seafood than the average Canadian. Sixty-three percent of the seafood diet consists of salmon (38 kg/year) (i.e., Sockeye, Chinook, Coho, and Pink), with sockeye salmon being the most important food source accounting for 51% of the total average seafood consumption. Other important seafoods contributing to coastal diets include halibut, Dungeness crab, prawns, lingcod, and butter clams. Approximately 90% of seafoods are sourced from traditional harvesting methods and not restaurants or supermarkets.

Fears and concerns related to traditional seafood resources were expressed by elders and food gathering specialists (hunters and fishers). Decreasing availability and abundance as well as pollution concerns are leading to a shift away from the traditional diet to less nutritious market foods (P.S. Ross, personal communication, April 25, 2013).

Figure 2 demonstrates relative seafood consumption levels of the average Canadian and Canadian Aboriginal groups.

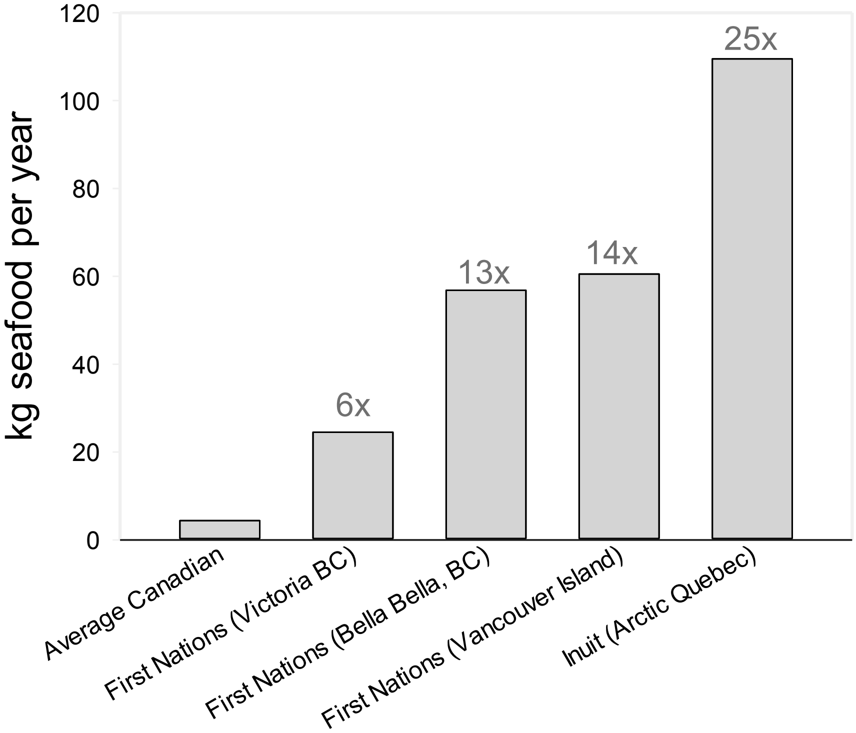

Figure 2. Variations in mean seafood consumption of different groups in Canada. P. S. Ross, personal communication, April 25, 2013. Adapted with permission.

Contaminant analysis.

Four sentinel species were chosen for the contaminant analysis: Butter clams (*Saxidomus gigantean)*, Dungeness crabs (*Cancer magister*), sockeye salmon (*Oncorhynchus nerka*), and harbour seals (*Phoca vitulina*). These four particular species were selected in an effort to capture a spectrum of trophic levels, feeding and life history features; to incorporate species that are either consumed by the First Nation communities or are important; and to incorporate species that are found at harvesting sites of all five First Nation communities. Table 1 illustrates the rationale for selection of each species.

Table 1

Rationale for the selection of four sentinel seafood species.

Species	Rationale
Dungeness crab	Non-migratory scavenger; mill monitoring species of choice in BC.
Butter clams	Sedentary filter feeder; preferred shellfish species of coastal First Nations.
Sockeye salmon	Migratory; preferred item of coastal First Nations.
Harbour seals	Non-migratory; top of the food chain.

Eighty-eight samples (clam n = 11, crab muscle n = 10, harbour seal n = 27, and sockeye salmon n = 30) were collected and analyzed for PCDD/Fs, PCBs, and PBDEs using high-resolution gas chromatography/mass spectrometry in 2006 (P.S. Ross & N.J. Dangerfield, personal communication, April 25, 2013). Analysis took place at the Regional Contaminant Laboratory at the Institute of Ocean Sciences (Fisheries and Oceans Canada) in Sidney, British Columbia. Figure 3 demonstrates that PCBs are much higher in harbour seals, which occupy the top of the food chain. Figure 4 shows that PCB concentrations in Dungeness crab muscle tissue are lower on the west coast of Vancouver Island.

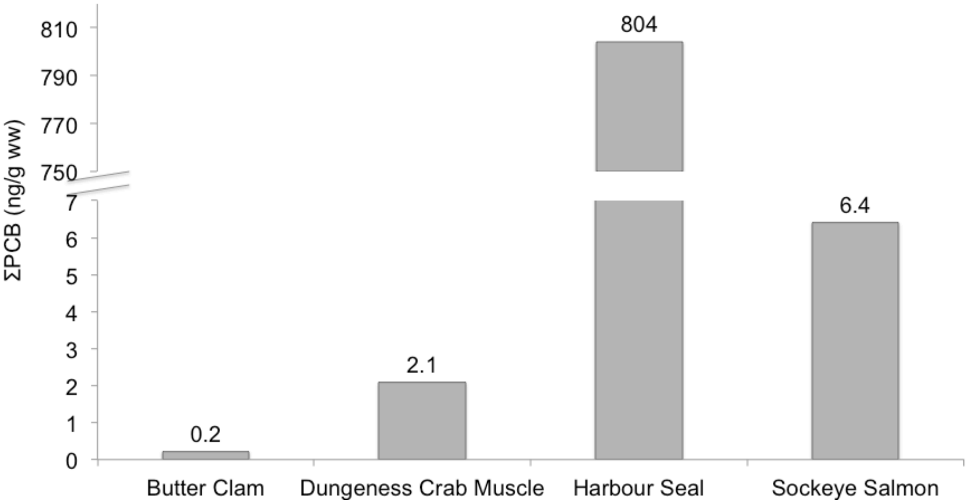

Figure 3. PCB concentrations present in traditional foods from five First Nations communities around Vancouver Island (P.S. Ross & N.J. Dangerfield, personal communication, April 25, 2013).

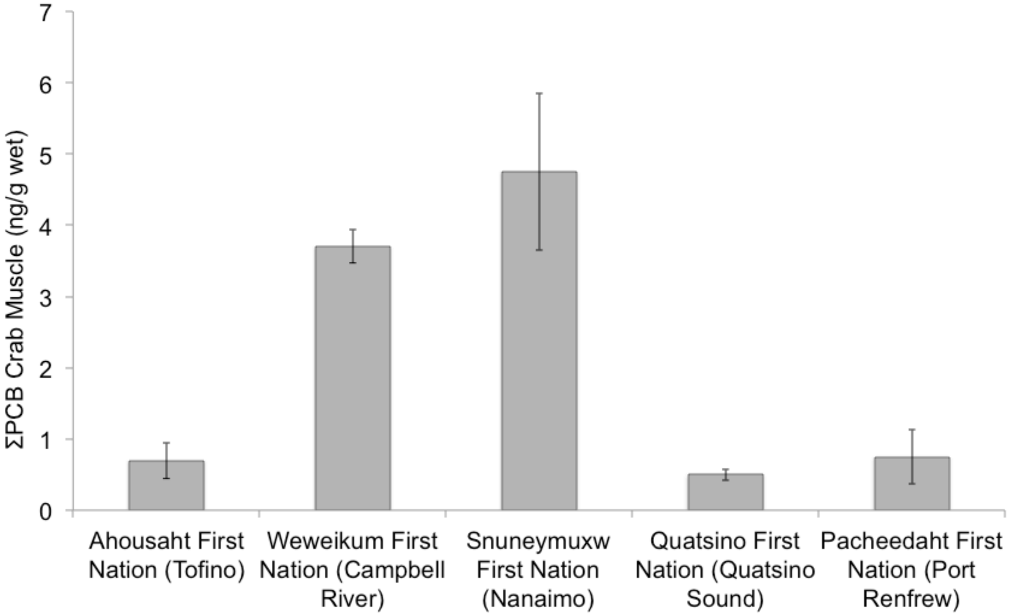

Figure 4. PCB concentrations in Dungeness crab muscle at each of the five First Nations communities around Vancouver Island (P.S. Ross & N.J. Dangerfield, personal communication, April 25, 2013).

Research Question & Objectives

The research question and objectives have been developed in collaboration with coastal First Nations Communities and research scientists from Fisheries and Oceans Canada.

Research Question

First Nations communities have asked "Is it safe to eat traditional seafoods?"

Research Objectives

The goal of this research was to evaluate the risk of adverse human health effects posed to Vancouver Island First Nation communities associated with exposure to contaminants in traditional seafoods. Research objectives are to:

- Select the most suitable and effective human health risk assessment (HHRA) framework(s);
- Assimilate data collected from two companion studies (Dietary Analysis and Contaminant Analysis) to characterize exposure dose for each individual;
- Characterize toxicity of assessed chemicals using information from various regulatory authorities;
- Carry out a HHRA to assess the risk of (a) non-cancer deleterious human health effects and (b) cancer effects;
- Describe risks as they relate to seafood type (species), contaminant class, and consumer attributes (i.e., consumption rates, age, gender, community);
- Consider risks in light of benefits of seafood consumption (nutritional, social, and cultural) as well as countervailing risks associated with alternative foods (e.g., supermarket, fast food etc.).

Methodology

Risk Assessment Framework

The methods utilized in this study follow the framework set out by Health Canada for human health risk assessment (HHRA) (Health Canada [HC], 2010). Health Canada's HHRA guidelines, originally outlined by BC Environment in 1993, are consistent with approaches that have been practiced internationally since the 1980s and are modelled after the framework established by the United States Environmental Protection Agency (US EPA) (HC, 2010). Illustrated in Figure 5, the HHRA framework is comprised of four principal stages: problem formulation, exposure assessment, toxicity assessment, and risk characterization. HHRA guidelines are divided into two categories, which are decided based on the level of effort and complexity of the risk analysis process: 1) Preliminary Quantitative Risk Assessment (PQRA); and 2) Detailed Quantitative Risk Assessment (DQRA) (HC, 2010). The study herein is characteristic of a DQRA in light of the vast quantity of data collection involved in proceeding companion studies (dietary and contaminant analysis).

To supplement the risk assessment, Toxicological Reference Values (TRVs) set forth by Health Canada and several international authorities were employed in risk characterization. Each risk assessment agency derives TRVs based on research and laboratory animal dose-response studies. As a result of differing research, laboratory methods, and assumptions, chemical TRVs and rational for their derivation vary between jurisdictions, with some being more conservative than others. Commonly, assumptions involving chemical characteristics and behaviour are different. Whether a chemical demonstrates a threshold or non-threshold response is a common area of disagreement. This means that some agencies deem a chemical to be a genotoxic carcinogen while others have determined the same chemical is not a carcinogen but perhaps elicits non-cancer health effects. As such, calculations are completed utilizing varying regulatory agency TRVs, in order to complement, compare, contrast, and provide further confidence in the overall assessment. Prominent international agencies include: United States Environmental Protection Agency (US EPA), World Health Organization (WHO), Joint FAO/WHO Expert Committee on Food Additives (JECFA), Agency for Toxic Substances Disease Registry (United States) (ATSDR), European Commission Scientific Committee on Food (EC-SCF), and the Office of Environmental Health Hazard Assessment (OEHHA) (California EPA).

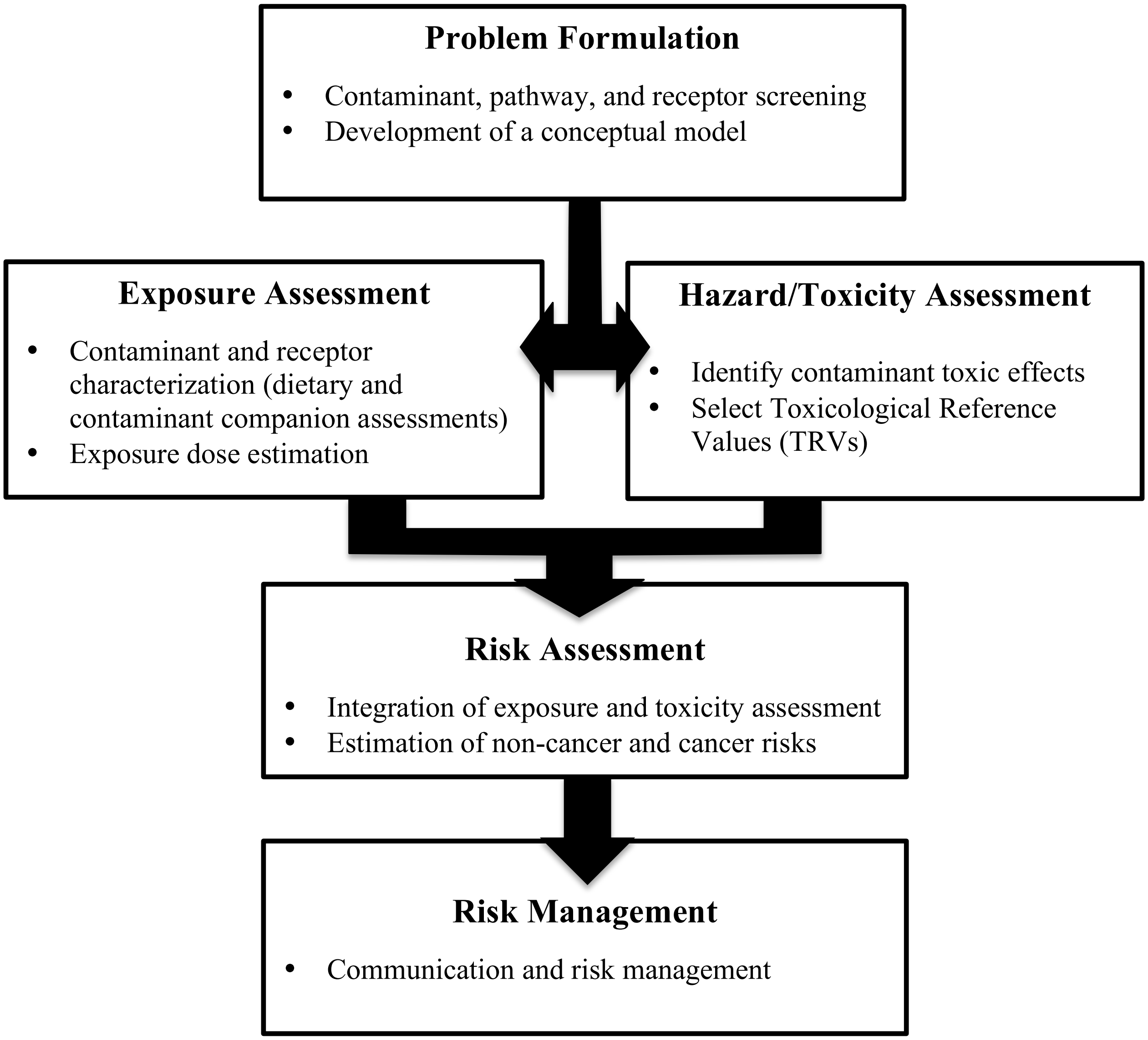

Figure 5. Human Health Risk Assessment (HHRA) framework illustrating components of the four primary stages: problem formulation, exposure assessment, toxicity assessment, and risk characterization (HC, 2010).

Problem Formulation

The first HHRA stage, problem formulation, entails contaminant, receptor, and pathway screening. Contaminant screening reviews a wide range of compounds that have been identified as contaminants of potential concern present in the marine environment and foodweb of coastal Vancouver Island. In consideration of resource and financial limitations, the scope of this risk assessment study has identified the following high priority POPs: PCBs, PCDDs, PCDFs, and PBDEs. These four POPs are priority contaminants as they demonstrate a known presence at traditional harvesting sites, high persistence in the environment, high bioaccumulation potential, and high potential toxicity to humans.

Vancouver Island Coastal First Nation people are regarded sensitive receptor groups considering their high rate of seafood consumption relative to the general population (up to 14 times). The primary pathway of exposure to POPs is through consumption of foods, of which seafoods represent an important component. Subsistence-oriented First Nations marine food harvest sites located both remotely and in proximity to industrialized regions are vulnerable to POP exposure. Figures 6 and 7 provide a conceptual model of the POP exposure pathway to humans via the consumption of marine foods. While other exposure pathways are discussed, assessment of all other pathways is outside the scope of this study.

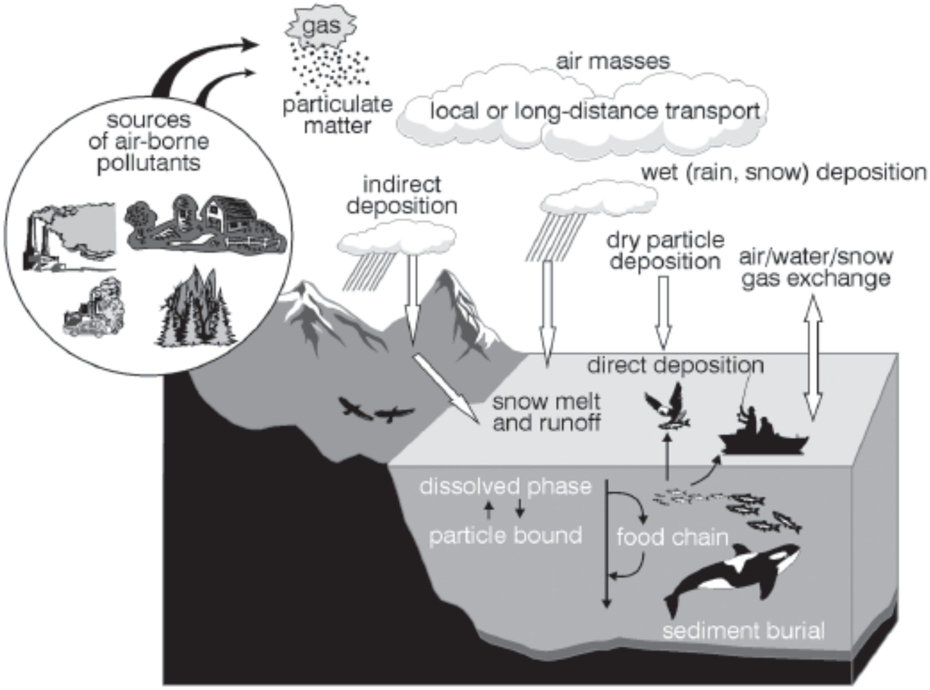

Figure 6. POPs enter the marine food web from direct effluent discharges in addition to

atmospheric deposition depicted above. Long-range atmospheric transport results in uptake and exposure to even remote human and wildlife populations. Adapted from Ross & Birnbaum (2003) with permission.

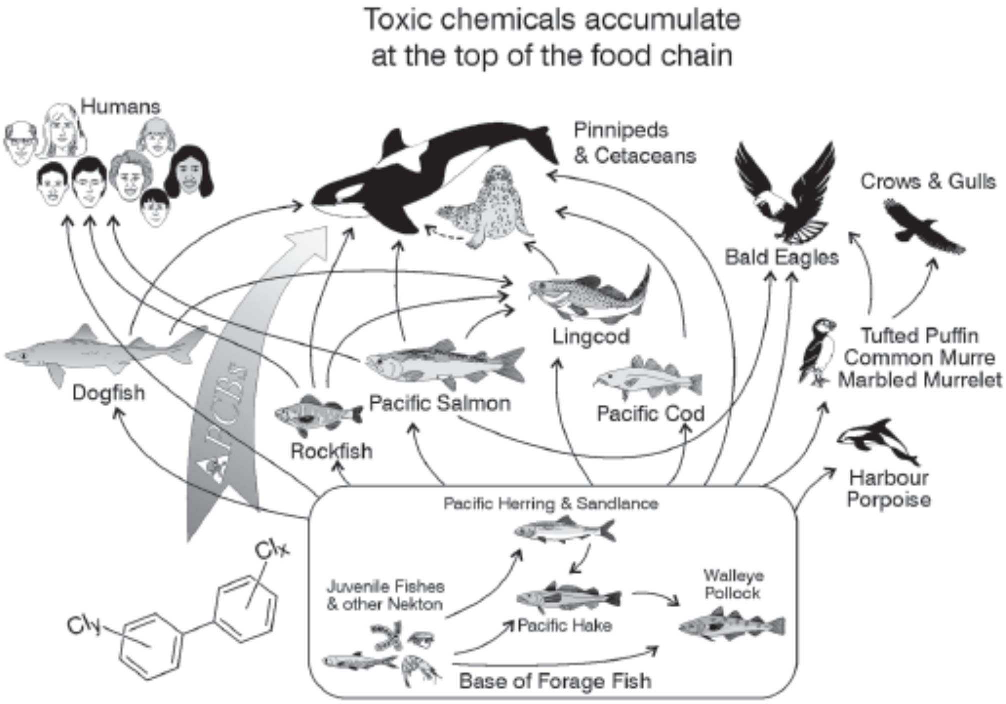

Figure 7. Lipophilic properties and resistance to breakdown make marine foodwebs susceptible to POP contamination. Higher trophic level organisms are often exposed to high POP concentrations due to bioaccumulation. Adapted from Ross & Birnbaum (2003) with permission.

Toxicity Assessment

The purpose of the toxicity assessment is to identify potential toxic effects and select established TRVs (Toxicological Reference Values), associated with each chemical (POP). Toxicological endpoints and derived TRVs have been determined by regulatory agencies through a weight-of-evidence approach in evaluating dose-response animal laboratory studies and human epidemiological studies including occupational exposure studies. Animal studies for POP effects are commonly performed on Rhesus monkeys, mice, rats, mink, and rabbits. Results of toxicity testing inform determinations of non-cancer health effects and likelihood that a substance is a human carcinogen.

TRVs are in the form of either a tolerable exposure dose or a toxic potency/slope factor, depending on whether or not chemicals are classified to have an exposure threshold below which adverse health effects are not anticipated.

Threshold-effect chemical (non-cancer) TRVs are described by Health Canada in the form of a Tolerable Daily Intake (TDI) (mg/kg bw/d). The TDI is defined by Health Canada as 'the maximum dose of a threshold substance to which an individual could be exposed daily over a lifetime without any expected deleterious effects' (HC, 2010). The US EPA and ATSDR refer to non-cancer TRVs as an Oral Reference Dose (RfD) and Minimal Risk Level (MRL), respectively.

Non-threshold-effect substances (carcinogenic) TRVs are expressed by Health Canada and most regulatory agencies in the form of a slope factor (SF) $(\text{mg/kg bw/d})^{-1}$. A SF is defined as the relationship between the exposure dose and the expected probability of developing cancer (HC, 2010). Some regulatory agencies may also refer to a SF as a cancer slope factor or cancer potency factor. Where genotoxic carcinogens are also considered to have threshold effects associated with them, both types of TRVs are utilized to determine both types of risk. This is the case for the US EPA non-cancer and cancer TRVs for both dioxin-like compounds and PCBs.

Concentrations of dioxin-like congeners within a mixture are expressed as toxic equivalents (TEQ) of 2378-TCDD. Toxic equivalency was calculated for 17 PCDD and PCDF congeners and 12 dioxin-like PCB (DL PCB) congeners. Mathematically, Equation 1 is used to determine toxic equivalency where C_i is the concentration of congener i and TEF_i is the toxic equivalency factor for the congener i.

$$\text{Total TEQ} = \Sigma(C_i \times TEF_i) \quad (1)$$

WHO (2005) congener-specific Toxic Equivalency Factors (TEF) shown in Table 2 were multiplied by the corresponding mean concentration of each dioxin-like congener and summed to determine a toxic equivalent concentration (TEC). The TEC was then inputted into the exposure dose calculation and interpreted as a 2,3,7,8-TCDD dosage.

Table 2

Summary of WHO 2005 TEF Values (HC, 2010; Van den Berg et al., 2006).

Compound	WHO 2005 TEF
chlorinated dibenzo-p-dioxins	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0003
chlorinated dibenzofurans	
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.03
2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0003
non-ortho substituted PCBs	
PCB 77	0.0001
PCB 81	0.0003
PCB 126	0.1
PCB 169	0.03
mono-ortho substituted PCBs	
105	0.00003
114	0.00003
118	0.00003

123	0.00003
156	0.00003
157	0.00003
167	0.00003
189	0.00003

Exposure Assessment

The objective of the exposure assessment is to estimate the exposure dose. The quantity of each chemical received by human receptors was estimated as a daily intake (mg/kg bw/d). Exposure to POPs via seafood consumption was determined utilizing the daily intake rate of seafood and the mean chemical concentration within the consumed seafood tissue. An exposure dose value was calculated for each person surveyed (N = 284) utilizing Equation 2 adopted from Health Canada (HC, 2010).

$$\text{Dose (mg/kg/d)} = \frac{C_{\text{Foodi}} \text{ x } IR_{\text{Foodi}} \text{ x } RAF_{\text{GITi}} \text{ x } ET_{\text{i}}}{BW} \tag{2}$$

Where:

BW = body weight (kg)

C_{Foodi} = concentration of contaminant in food type "i"' (mg/kg)

ET = exposure term (unitless)

IR_{Foodi} = ingestion rate of food type "i" (kg/d)

RAF_{GITi} = relative absorption factor from the gastrointestinal tract (unitless)

Contaminant concentration and ingestion rate data were obtained from the two companion analyses and utilized for input parameters in exposure dose calculations.

The exposure assessment does not evaluate all potential exposure routes through which chemical contact can occur including non-seafood consumption; air, and water intake; and dermal contact with environmental media. Moreover, a bioavailability assessment was not conducted as the relative absorption factor in the gastrointestinal track is considered to be 1. The Canadian general population adult body weight of 70.7kg was utilized (HC, 2010).

The companion dietary analysis study found that the four sentinel species represent 58% of the total seafood diet. In this risk assessment study, further calculations were carried out to extrapolate POP dose to represent 100% of the seafood diet as a best estimate.

Risk Characterization

Risk characterization is the process of quantifying and evaluating risks/hazards associated with chemical exposure. Risks were quantified by integrating the exposure and toxicity assessments where the estimated exposure is compared with the TRV. Non-cancer risks were expressed as the hazard quotient (HQ) and cancer risks were expressed as the incremental lifetime cancer risk (ILCR). Subsequently, whether or not the risks were acceptable was delineated. Uncertainties were then evaluated qualitatively for risk characterizations.

Risk analysis was divided into three contaminant classes: Dioxin-like compounds (PCDD/Fs + DL PCBs), ∑PCBs, and PBDEs. Risk values were determined for all 284 individuals surveyed and described as they relate to consumer attributes including gender, age, or community. Risk was based on the consumption of four sentinel species: harbour seals, sockeye salmon, Dungeness crab and butter clams. Risk of adverse health effects (both cancer and non-cancer) from POP exposure through the consumption of traditional seafoods was determined.

Non-carcinogen Risk Quantification

Non-cancer risks are expressed as the hazard quotient (HQ) for threshold-response chemicals. The HQ demonstrates whether or not the estimated exposure exceeds the TRV, where the TRV represents the established dose that is free of human health effects for the majority of the population. A HQ less than 1.0 is considered acceptable risk since the total exposure is less than the TRV. However, this must be interpreted with caution, as only the exposure via seafood consumption is being assessed and not total exposure via all pathways. Equation 3 illustrates the derivation of the HQ.

$$\text{Hazard Quotient} = \frac{\text{Estimated Exposure Dose } (\frac{\frac{\text{mg}}{\text{kg}}}{\text{d}})}{\text{Tolerable Daily Intake } (\frac{\frac{\text{mg}}{\text{kg}}}{\text{d}})} \tag{3}$$

Carcinogen Risk Quantification

Cancer risks are expressed as the incremental lifetime cancer risk (ILCR) for chronic exposure to non-threshold-response chemicals. Estimated exposures were multiplied by the inverse of the established cancer slope factor (SF) or unit risk (UR). ILCR less than or equal to 1 in 100,000 ($\leq 1.0 \times 10^{-5}$) are considered negligible by Health Canada. Equation 4 illustrated the derivation of the ILCR.

$$\text{ILCR} = \text{Exposure} \left(\frac{\frac{\text{mg}}{\text{kg}}}{\text{d}}\right) \times \text{Cancer Slope Factor } (\frac{\frac{\text{mg}}{\text{kg}}}{\text{d}})^{-1} \tag{4}$$

Data Analysis

For all risk values, descriptive statistics including the mean, 95th percentile, standard deviation, minimum, and maximum were computed utilizing SPSS Statistics statistical software program. Risk values are displayed as a frequency distribution for all 284 individuals. Two-tailed independent t-tests were completed to determine whether or not there was a significant difference in risk between (a) gender (b) teens and adults (i.e., 13-19 and 20+) and (c) communities on the east and west coasts of Vancouver Island (i.e., Ahousaht (Tofino), Quatsino (Quatsino Sound), and Pacheedaht (Port Renfrew) First Nations versus Weweikum (Campbell River), and Snuneymuxw (Nanaimo) First Nations). One-way analysis of variance (ANOVA) tests were carried out to determine if there was a significant difference in means between (a) age groups (i.e., 13-19, 20-40, 41-54, 55-64, and 65+) and (b) the five communities. Where ANOVA tests established that a significant difference does exist, a TUKEY's post-hoc test was employed to determine which group(s) differs significantly.

Table 3

Summary of First Nation Vancouver Island Traditional Seafood Consumption Human Health Risk Assessment Plan illustrating input parameters for risk equations.

Endpoint	Non-Carcinogenic		Carcinogenic	
Risk Point Estimate	Hazard Quotient (HQ)		Incremental Lifetime Cancer Risk (ILCR)	
	Mean	95th Percentile	Mean	95th Percentile
Seafood Diet Evaluated	Four Sentinel Species Four Sentinel Species + All Salmon Total Seafood Diet		Four Sentinel Species Four Sentinel Species + All Salmon Total Seafood Diet	
Chemical Groups Evaluated	PCDD/Fs DL PCBs *∑TEQ (PCDD/Fs + DL PCBs)* *Σ PCBs* PBDEs		PCDD/Fs DL PCBs *∑TEQ (PCDD/Fs + DL PCBs)* *Σ PCBs* PBDEs	
DL Toxic Equivalency	WHO 2005 TEFs		WHO 2005 TEFs	
TRV Authorities	HC, US EPA, WHO, JECFA, ATSDR, EC-SCF		US EPA, OEHHA	
Concentration (C)	Mean		Mean	
Body Weight (BW)	70.7 Kg		70.7 Kg	
Exposure Term (ET)	n/a		80 years	
Ingestion Rate (IR)	Individual		Individual	
Relative Absorption Factor (RAF)	1.0		1.0	
Gender Differences	t-test		t-test	
Age Differences	t-test (Teens and Adults) ANOVA (5 Age Categories)		t-test (Teens and Adults) ANOVA (5 Age Categories)	
Community Differences	t-test (East and West Coast) ANOVA (Five Communities)		t-test (East and West Coast) ANOVA (Five Communities)	

Benefits and Countervailing Risks

In order to take a balanced approach, benefits of consuming seafood as well as countervailing risks (e.g., consumption of supermarket or fast foods) are deliberated. Given the difficulty in determining benefits and countervailing risks quantitatively, risks of consuming traditional seafoods are considered in light of qualitative benefits and countervailing risks determined via a literature review.

Results

Toxicity Assessment

A comparative analysis of critical toxicological endpoints and carcinogenicity classification between HC and the US EPA, is displayed in Table 4. The weight of evidence collected by the EPA generally illustrates more non-cancer effects in addition to more stringent cancer risk classifications. Thus, derived TRVs by the US EPA are more conservative.

While this section is focused on critical endpoints considered by regulatory agencies in the derivation of TRVs, scientific evidence for a broad spectrum of endpoints are described in the literature and are deliberated in the introduction section of this paper.

Table 4

Critical Toxicological Endpoints for PCDD/Fs, PCBs, and PBDEs utilized in derivation of TRVs.

	Toxicological Endpoints			
	Non-Cancer Critical Health Effects		Carcinogenicity Classification	
Chemical Class	HC	US EPA	HC (IARC system)	US EPA
TCDD (PCDD/Fs and DL PCBs)	Developmental Immune Reproductive	Hepatic Neurological Immunological Reproductive Endocrine Developmental	Group 2B: possibly carcinogenic to humans	Draft: Group A: Carcinogenic to humans
PCBs	Not published (although a TDI is established).	Neurological Endocrine Dermal Ocular Immunological (Aroclor 1254 mixture)	Inadequate data for evaluation of carcinogenicity to humans	B2: probable human carcinogen
PBDEs	Not published	Neurobehavioral (BDE-99)	Not published	“Inadequate information to assess the carcinogenic potential"

Reference. (HC, 2010; US EPA, 2012)

As seen in Table 5, HC has not established TRVs for PBDEs. The *State of Science Report for a Screening Health Assessment* published by HC in 2004 references critical endpoints comprising adverse developmental, neurobehavioural, and liver effects. The screening health assessment suggested a critical effect level of 0.8 mg/kg/day, accompanied by a list of uncertainties and data gaps for PBDEs and the requirement for a more in-depth evaluation (HC, 2004). Despite this, further review of PBDEs was considered low priority since they meet Canadian Environmental Protection Act, 1999 (CEPA 1999) environmental criteria. In regards to cancer effects, HC deemed the critical effect level to be protective of liver tumours and neoplastic nodules observed in mice and rats respectively since the weight of evidence does not support PBDE genotoxicity (HC, 2004). Comparably, the US EPA is the only regulatory agency of the six agencies considered in this study that has established a TRV (RfD) for PBDEs.

Non-cancer TRVs obtained from Health Canada, the US EPA, WHO, JECFA, ATSDR, and EC-SCF are outlined in Table 5. Carcinogenic TRVs obtained from the US EPA and the OEHHA are summarized in Table 6.

Table 5

Non-cancer Toxicological Reference Values (mg/kd-day) associated with the ingestion of TCDD, PCBs, and PBDEs. Published TRVs were obtained from several regulatory authorities including: Health Canada (HC) tolerable daily intake (TDI), United States Environmental Protection Agency (US EPA) oral reference dose (RfD), World Health Organization (WHO) TDI, Joint FAO/WHO Expert Committee on Food Additives (JECFA) TDI, Agency for Toxic Substances Disease Registry (United States) (ATSDR) minimal risk level (MRL), and the European Commission Scientific Committee on Food (EC-SCF) TDI.

	Non-cancer Toxicological Reference Values (mg/kd-day)					
Chemical Class	HC TDI (HC, 2010)	US EPA RfD (IRIS, 2012)	WHO TDI (2000)	JECFA TDI (WHO, 2002)	ATSDR MRL (2013)	EC-SCF TDI (2001)
TCDD	2.3E-9	7E-10	1.0E-9	2.3E-9	1.0E-9	2.0E-9
PCBs	1.3E-4	2.0E-5	2.0E-4		2.0E-4	
PBDEs		0.0001				

Note. The US EPA RfD values for PCBs and PBDEs are based on the congener mixture Aroclor 1254 (CASRN 11079-69-1) and BDE-99 (CAS No. 60348-60-9) respectively.

Table 6

Carcinogenic Toxicological Reference Values (mg/kd-day)$^{-1}$ associated with the ingestion of TCDD and PCBs. Slope Factors were obtained from United States Environmental Protection Agency (US EPA) and the OEHHA (California EPA).

	Cancer Toxicological Reference Values (mg/kg/day)$^{-1}$	
Chemical Class	US EPA (2010)	Cal EPA (OEHHA) (2011)
TCDD	1.0E6	1.3E5
PCBs	2.0	2.0

Note. The US EPA slope factor for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is a draft value as the cancer assessment for TCDD is currently underway (US EPA draft, 2010).

Exposure Assessment

The quantity of each chemical ingested by people of the five coastal Vancouver Island First Nation Communities via the consumption of four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals) is estimated as a mean daily dose. The exposure dose (Tables 7 and 8) is utilized for non-cancer and cancer risk calculations. PCDD/F and DL PCB exposure dose concentrations are illustrated in Table 7 to facilitate comparison to non-dioxin-like chemicals. However, TEC exposure dose values (Table 8) for dioxin-like congeners (17 PCDD/Fs and 12 PCBs) are utilized in risk calculations. Since carcinogenic exposure was calculated under the assumption that exposure lasts a lifetime (i.e., 80 year exposure term in an 80 year average life expectancy), the lifetime carcinogenic exposure daily dose is the same as the exposure dose utilized for non-cancer risk calculations.

Table 7

Daily exposure dose of for contaminant categories used in our risk assessment based on consumption of four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals).

	Exposure Dose (ng/kg/day) Mean ± SD (min, max)				
Chemical Class	Butter Clam	Dungeness Crab Muscle	Harbour Seal	Sockeye Salmon	Total (Four Species)
PCDD/Fs	6E-5 ± .0002 (0, .002)	.0006 ± .0016 (0, .0141)	3E-6 ± 1E-5 (0, .0001)	.0009 ± .001 (0, .006)	.002 ± .002 (0, .01)
DL PCBs	.0002 ± .0006 (0, .005)	.03 ± .06 (0, .59)	.03 ± .17 (0, 1.45)	.50 ± .48 (0, 2.93)	.56 ± .53 (0, 2.94)
Non-DL PCBs	.01 ± .03 (0, .36)	.23 ± .57 (0, 6.04)	.79 ± 4.13 (0, 36.26)	6.10 ± 5.99 (0, 35.73)	7.13 ± 7.58 (0, 51.17)
Σ PCBs	.01 ± .03 (0, .36)	.26 ± .63 (0, 6.63)	.83 ± 4.38 (0, 38.58)	6.59 ± 6.47 (0, 38.61)	7.69 ± 8.14 (0, 54.68)
PBDEs	.01 ± .03 (0, .21)	.05 ± .14 (0, 1.58)	.21 ± 1.13 (0, 9.93)	.11 ± .14 (0, 1.16)	0.39 ± 1.15 (0, 10.26)

For all assessed chemicals, mean exposure dose concentrations in increasing order are from butter clams, Dungeness crab muscle, harbour seal, and sockeye salmon (Table 7). PBDEs are an exception to this, with a greater mean exposure dose received from harbour seal. Dungeness crab muscle is also a significant source of PCDD/Fs in the same order of magnitude as sockeye salmon. The mean exposure dose of DL PCBs received from Dungeness crab muscle and harbour seal are equal. As seen in Table 7 and demonstrated clearly in Figure 8, ∑PCBs (209 congeners) contribute a significantly greater percentage of the mean total exposure dose ingested through all four species (95.15%), mainly from sockeye salmon (81.54%). Of the ∑PCBs, DL PCBs and non-DL PCBs represent 6.93% and 88.22% (1:13) of the mean total exposure dose respectively. PCDD/Fs contribute significantly less than other POPs assessed to the mean exposure dose concentration, with ∑PCBs being almost 4000 times greater. However, only 17 (7 PCDDs and 10 PCDFs) of the existing 210 PCDD/Fs congeners (75 PCDDs and 135

PCDFs) are included as they are the only ones determined to be significantly toxic based on the number and position of chlorine atoms. Specifically, only those PCDD/Fs with chlorine at the 2, 3, 7, and 8 positions (dioxin-like properties) have been determined as significantly toxic, hence the TEQ scheme.

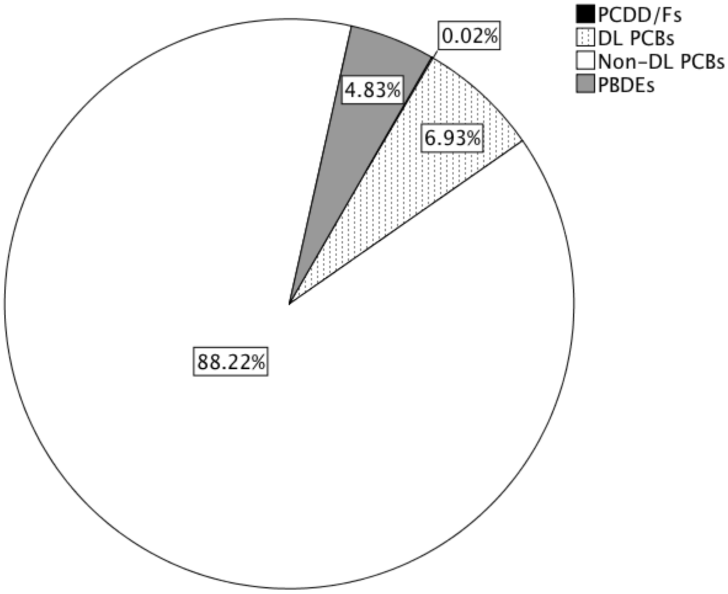

Figure 8. Exposure dose percentage attributed to each chemical class (PCDD/Fs, ∑PCBs (non-DL PCBs and DL PCBs), and PBDEs.

Table 8

Daily exposure dose of dioxin-like congeners (17 PCDD/Fs and 12 PCBs) expressed as toxic equivalent concentrations (TEQ) to 2,3,7,8-TCDD from the four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals).

	Exposure Dose (TEC-ng/kg/day) Mean ± SD (min, max)				
Chemical Class	Butter Clam	Dungeness Crab Muscle	Harbour Seal	Sockeye Salmon	Total (Four Species)
PCDD/Fs	5E-7 ± 2E-6 (0, 2E-5)	4E-5 ± .0001 (0, .0007)	1E-6 ± 5E-6 (0, 5E-5)	8E-5 ± 9E-5 (0, .0006)	.0001 ± .0002 (0, 0.0008)
DL PCBs	6E-8 ± 2E-7 (0, 2E-6)	1E-6 ± 3E-6 (0, .4E-5)	1E-6 ± 5E-6 (0, 4E-5)	.0002 ± .0002 (0, .0015)	.0002 ± .0002 (0, 0.0015)
PCDD/Fs + DL PCBs	5E-7 ± 2E-6 (0, 2E-5)	4E-5 ± .0001 (0, .0008)	2E-6 ± 1E-5 (0, 9E-5)	.0002 ± .0002 (0, .0018)	.0003 ± .0003 (0, .0018)

Non-carcinogen Risk Assessment

Four sentinel seafood species.

Non-cancer health risks to people of the five coastal Vancouver Island First Nation Communities that can be attributed to the consumption of four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals) are expressed in Table 9 as the hazard quotient (HQ). HQ values are calculated based on toxicological reference (TRVs) values adopted by differing international regulatory agencies.

Table 9

Non-cancer health risks associated with the consumption of POPs via the four species represented as the Hazard Quotient (HQ). HQ values are quantified for several regulatory authorities based on differing toxicological reference (TRV) values for each chemical. TRV values include: Health Canada (HC) tolerable daily intake (TDI), United States Environmental Protection Agency (US EPA) oral reference dose (RfD), World Health Organization (WHO) TDI, Joint FAO/WHO Expert Committee on Food Additives (JECFA) TDI, Agency for Toxic Substances Disease Registry (United States) (ATSDR) minimal risk level (MRL), and the European Commission Scientific Committee on Food (EC-SCF) TDI.

	Hazard Quotient Mean ± SD (min, max)					
Chemical Class	HC	US EPA	WHO	JECFA	ATSDR	EC-SCF
PCDD/Fs (TEQ)	.05 ± .06 (0, .37)	.18 ± .21 (0, **1.2**)	.12 ± .14 (0, .84)	.05 ± .06 (0, 0.37)	.12 ± .14 (0, .84)	.06 ± .07 (0, .42)
DL PCBs (TEQ)	.07 ± .07 (0, .65)	.23 ± .23 (0, **2.12**)	.16 ± .16 (0, **1.49**)	.07 ± .07 (0, .65)	.16 ± .16 (0, **1.49**)	.08 ± .08 (0, .74)
Σ TEQ (PCDD/Fs + DL PCBs)	.12 ± .12 (0, .77)	.41 ± .39 (0, **2.54**)	.28 ± .27 (0, **1.78**)	.12 ± .12 (0, .77)	.28 ± .27 (0, **1.78**)	.14 ± .13 (0, .89)
Non-DL PCBs	.05 ± .06 (0, .39)	.35 ± .38 (0, **2.56**)	.03 ± .04 (0, .26)		.03 ± .04 (0, .26)	
Σ PCBs	.06 ± .06 (0, .42)	.38 ± .45 (0, **2.73**)	.04 ± .04 (0, .27)		.04 ± .04 (0, .27)	
PBDEs		.0004 ± .001 (0, .01)				

Note: HQ values greater than Health Canada's acceptable level of 1.0 are in boldface.

Mean non-cancer health risks from ∑TEQ (PCDD/Fs + DL PCBs), ∑PCBs, and PBDEs associated with the consumption of only the four sentinel seafood species are found to be below the acceptable risk level of 1.0. This was consistent among all TRVs employed from different regulatory agencies. However, US EPA, WHO, and ATSDR maximum HQ values for DL PCBs (TEQ) and ∑TEQ (PCDD/Fs + DL PCBs) are above the acceptable risk level of 1.0.

Additionally, US EPA maximum HQ values for PCDD/Fs (TEQ) and ∑PCBs are above the acceptable risk level of 1.0. In fact, the maximum US EPA non-cancer risk for ∑PCBs was almost three times the acceptable limit. While mean estimates indicate current chemical concentrations in conjunction with consumption patterns of the four sentinel seafood species are unlikely to pose non-cancer health risks, mean estimates are not indicative of the entire population, specifically maximally exposed individuals. The US EPA, WHO, and ATSDR HQ distributions demonstrate that some individuals are at risk of non-cancer health effects attributed to dioxin-like compounds (TEQ (PCDD/Fs + DL PCBs)) (Figure 9). The US EPA HQ distribution demonstrates that some individuals are at risk of non-cancer health effects attributed to ∑PCBs (Figure 9).

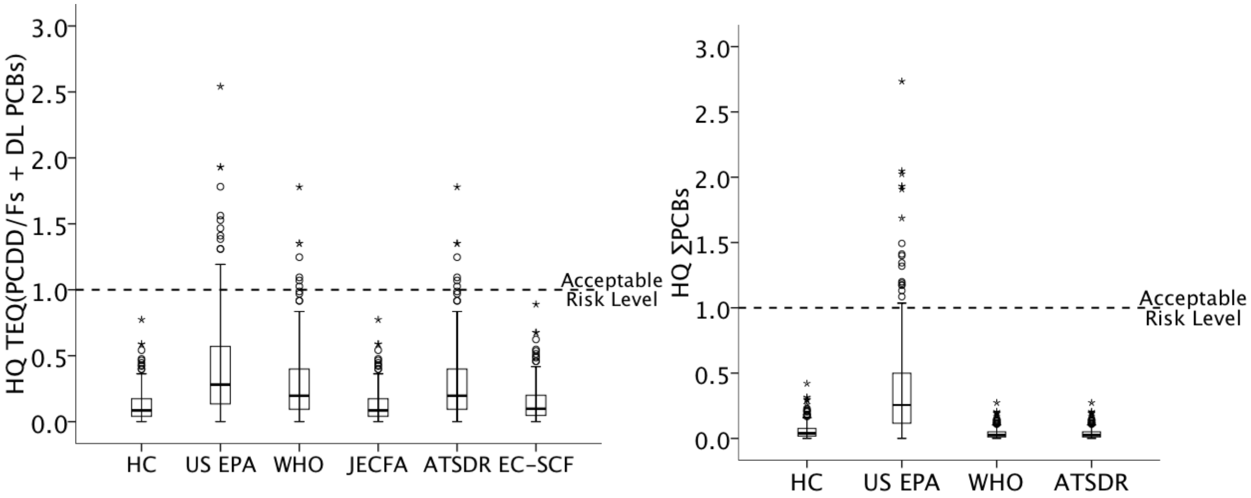

Figure 9. Non-cancer hazard quotient distribution for TEQ (PCDD/Fs + DL PCBs) and ∑PCBs among 284 individuals for each applicable regulatory authority. PBDEs are not illustrated given their relatively low mean and maximum risk (HQ).

In order of increasing magnitude of risk, international authorities are: HC and JECFA; EC-SCF; WHO and ATSDR; US EPA. Considering that HC represents the lowest- and the US EPA represents the most conservative- estimates of non-cancer risk, further calculations will focus on these two authorities in order to represent the greatest range and confidence in risk estimates.

Among the 284 people surveyed, risk distributions are skewed to the right, indicating that most individuals have lower HQ values (Figure 10 and 11). Based on HC toxicity values for dioxin like compounds (TEQ (PCDD/Fs + DL PCBs)) and ∑PCBs, all 284 respondents are below the level of concern for non-cancer health effects related to each. The mean and upper 95th percentile of the risk distribution for non-carcinogenic HC human health risk is 0.12 and 0.36 respectively. For ∑PCBs, the mean and upper 95th percentile of the risk distribution for non-carcinogenic HC human health risk is 0.06 and 0.18 respectively. While all 284 individuals fall below the accepted hazard level of 1.0 for ∑TEQ and ∑PCBs based on HC's TDIs (10), they do not based on the US EPA RfDs (Figure 11).

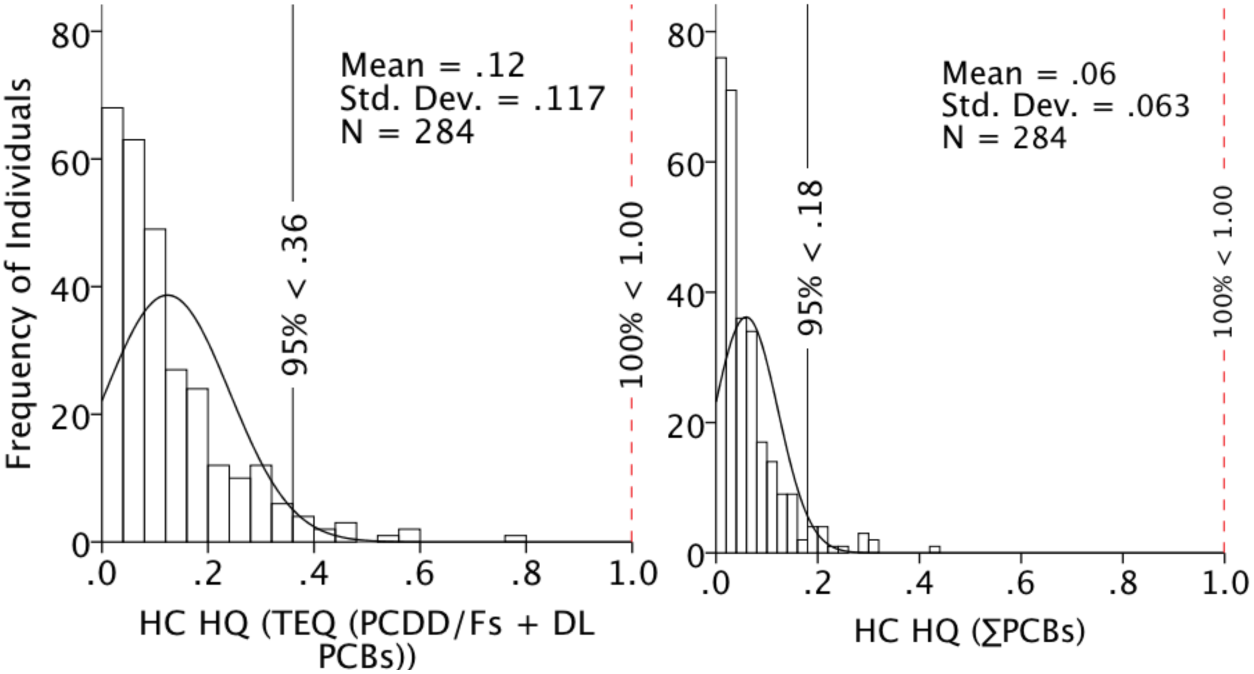

Figure 10. Frequency distribution for 284 people representing Health Canada non-carcinogen risk as the hazard quotient (HQ) for ∑TEQ (PCDD/Fs and DL PCBs) and ∑PCBs. The 95th percentile estimate of risk is shown, specifically the risk level of which 95% of the population is below. PBDEs are not illustrated given there relatively low mean and maximum risk (HQ).

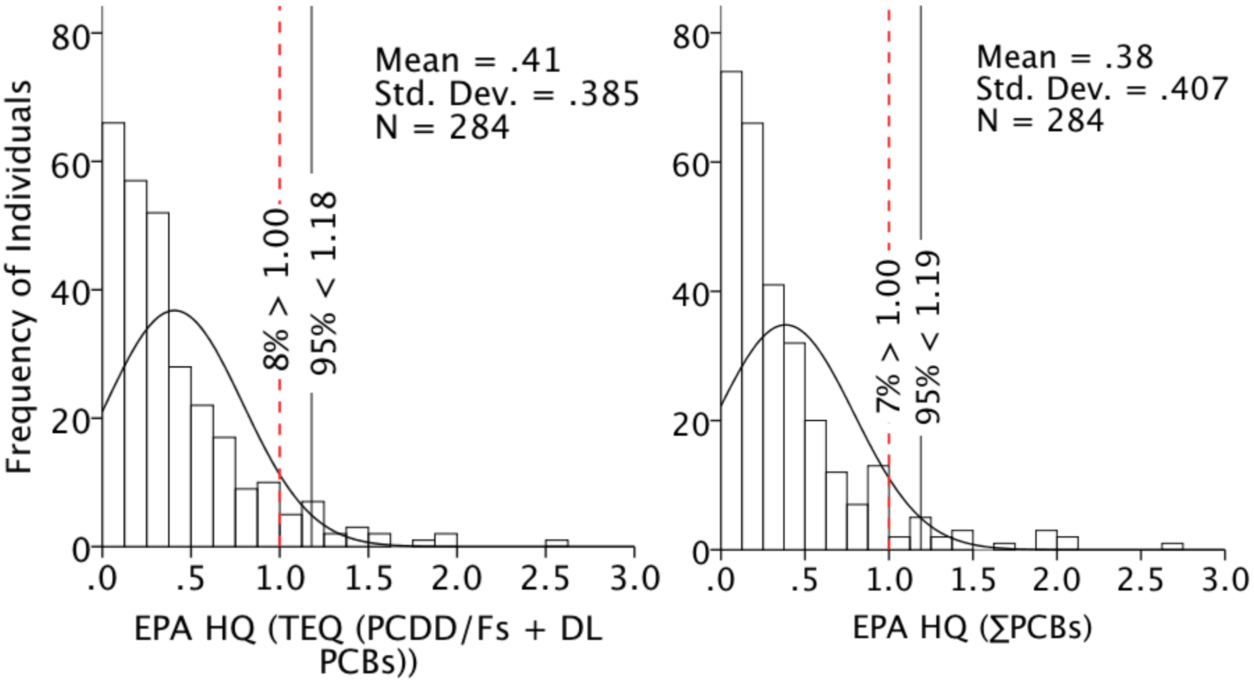

Figure 11. Frequency distribution for 284 people representing US EPA non-carcinogen risk as the hazard quotient (HQ) for ∑TEQ (PCDD/Fs and DL PCBs) and ∑PCBs. The 95th percentile estimate of risk is shown, specifically the risk level of which 95% of the population is below. PBDEs are not illustrated given their relatively low mean and maximum risk (HQ).

∑PCBs are illustrated to be in exceedance of the acceptable risk level based on the US EPA 95th percentile. In addition, PCDD/Fs and DL PCBs that are collectively evaluated as the toxic equivalency of 2,3,7,8-TCDD are in exceednace of the acceptable risk level based on the US EPA 95th percentile. Therefore, based on the US EPA RfD for both 2, 3, 7, 8-TCDD and PCBs, current chemical concentrations and consumption rates of the four sentinel species are not protective of all 95 percent of the population from health effects related to dioxin-like compounds or PCBs.

DL PCBs contribute to the majority of the ∑TEQ non-cancer risk (Figure 12). Non-cancer health risk from ∑PCBs and ∑TEQ (Figure 10) are relatively similar, although they each have differing mechanisms of action. This is despite PCDD/F and DL PCB concentrations representing only a small portion of the exposure dose (Figure 8), emphasizing the significantly higher toxicity of dioxin-like compounds.

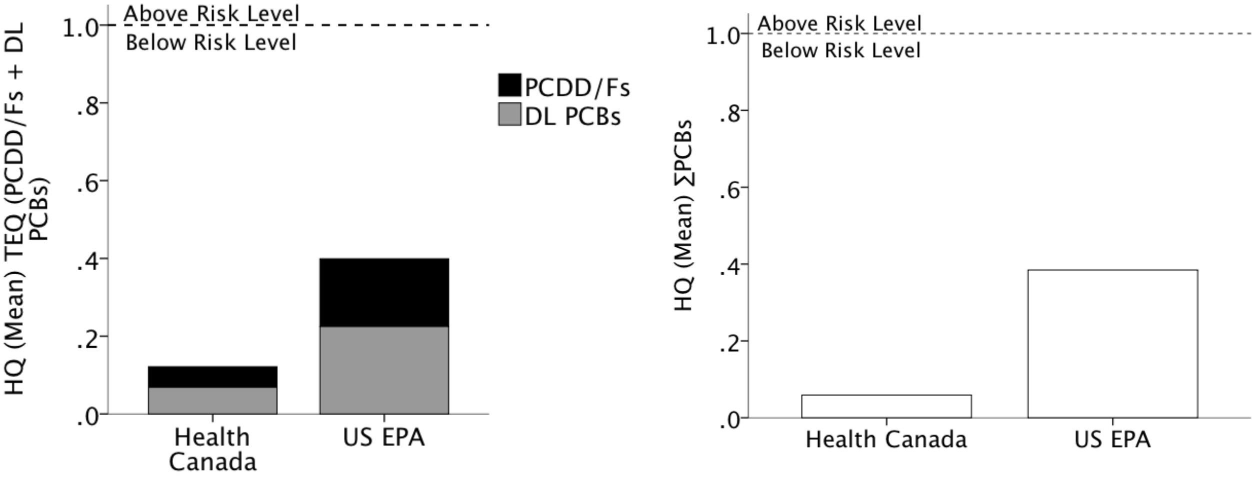

Figure 12. Mean non-cancer risk (HQ) from ∑TEQ and ∑PCBs based on Health Canada and the US EPA TRVs.

Differences in risk amoung the four species are depicted in Figure 13. Of the four sentinel species, the majority of non-cancer risk is attributed to sockeye salmon for both ∑PCBs and ∑TEQ. This is likely primarily due to the very high consumption rate for salmon. Noteably, the majority of the ∑TEQ risk is due to DL PCBs in sockeye salmon. Comparing risk from ∑TEQ and ∑PCBs among species, a higher proportion of ∑TEQ risk is from Dungeness crab while a higher proportion of ∑PCB risk is from harbour seal.

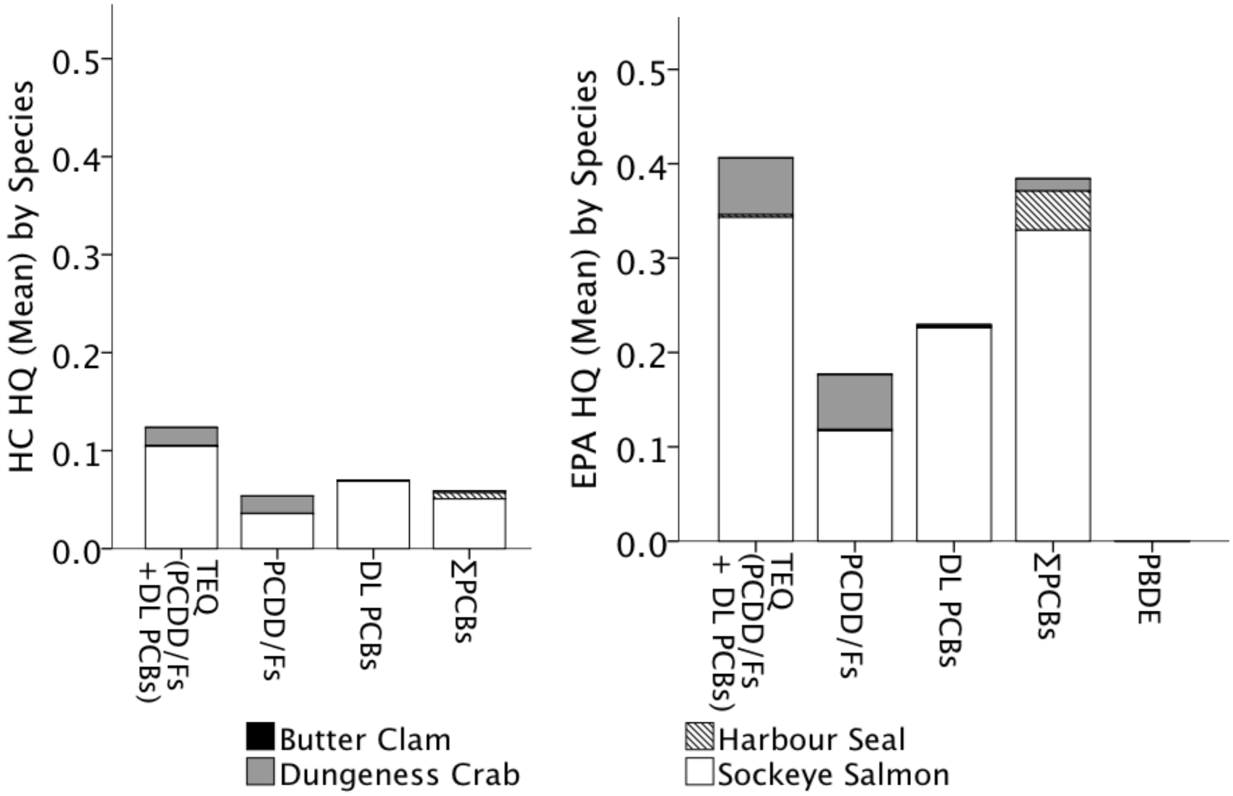

Figure 13. Cumulative non-cancer risk attributed to each of the four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals). Estimates are based on both Health Canada's TDI and the US EPAs RfD.

Species concentration, and exposure/risk comparisons.

The four species are ranked for contaminant concentration measurements as well as contribution to human exposure dose and associated toxicity risk (Table 10). For each chemical, species comparisons can be made between concentration and exposure/risk relative to consumption rates among the 284 people. Although PCDD/F and ΣPCB concentration levels were the greatest in harbor seals, the greatest human exposure dose and associated risk is attributed to sockeye salmon due to high consumption levels of this fish.

Table 10

Species comparisons from greatest to lowest for concentration, exposure, and risk for each chemical class. Greatest to lowest species consumption rates among the 284 people is Salmon>Crab>Clam>Seal.

Chemical Class	Rankings for concentration, exposure, and risk compared to: Consumption:	Salmon>Crab>Clam>Seal
PCDD/Fs (TEQ)	Concentration:	Seal>Crab>Salmon>Clam
	Exposure/Risk:	Salmon>Crab>Seal>Clam
DL PCBs (TEQ)	Concentration:	Seal>Salmon>Crab>Clam
	Exposure/Risk:	Salmon>Crab>Seal>Clam
Σ TEQ (PCDD/Fs + DL PCBs)	Concentration:	Seal>Crab>Salmon>Clam
	Exposure/Risk:	Salmon>Crab>Seal>Clam
Σ PCBs	Concentration:	Seal>Salmon>Crab>Clam
	Exposure/Risk:	Salmon>Seal>Crab>Clam
PBDEs	Concentration:	Seal>Crab>Clam>Salmon
	Exposure/Risk:	Seal>Salmon>Crab>Clam

Estimating non-cancer risk for a larger portion of the seafood diet.

The four sentinel seafood species comprise 58% of the total seafood diet (and not attributed to any supermarket/other foods). Thus, the analysis to this point only accounts for risk that is anticipated from 58% of the total seafood diet. While contaminant concentrations were not directly measured in other species consumed, risk attributed to the consumption of other salmon species are estimated in an effort to determine risk for a larger percentage of the seafood diet. Mean concentrations for Sockeye salmon are utilized in risk calculations pertaining to known ingestion rates of Chum, Pink, Chinook, and Coho salmon. Supporting evidence of similar concentrations of chemicals between salmon species allows for extrapolation from sockeye salmon to the other salmon species. Subsequently, we account for 70% of the seafood diet (Table 11).

To provide a basic estimate of non-cancer human health risks from all seafood dietary components (compared to the ~ 70% of the diet for which we had contaminant data), risk values were multiplied by 1.43 (Table 12). However, the results must be interpreted with caution as this assumes that the remaining 30% of the seafood intake represents similar contaminant concentrations as the four species. Risks estimated in this manner for non-cancer effects are still below the acceptable risk level of 1.0 for all regulatory agencies. However, based on Health Canada's TDI for ∑TEQ, 0.4% of individuals are now in exceedance. Based on the US EPA's RfD for ∑TEQ, 15% and 24% of respondents are above HQ = 1 for 'four species plus other salmon' and 'total seafoods consumed' respectively. For ∑PCBs, 13% and 23% of respondents are above the concern level for 'four species plus other salmon' and 'total seafoods consumed' respectively based on the US EPA.

Table 11

Non-cancer health risks associated with the consumption of POPs via the four species plus Chum, Pink, Chinook, and Coho salmon represented as the Hazard Quotient (HQ). HQ values are quantified for several regulatory authorities based on differing toxicological reference (TRV) values for each chemical. TRV values include: Health Canada (HC) tolerable daily intake (TDI), United States Environmental Protection Agency (US EPA) oral reference dose (RfD), World Health Organization (WHO) TDI, Joint FAO/WHO Expert Committee on Food Additives (JECFA) TDI, Agency for Toxic Substances Disease Registry (United States) (ATSDR) minimal risk level (MRL), and the European Commission Scientific Committee on Food (EC-SCF) TDI.

	Hazard Quotient Mean ± SD (min, max)					
Chemical Class	HC	US EPA	WHO	JECFA	ATSDR	EC-SCF
PCDD/Fs (TEQ)	.06 ± .07 (0, .40)	.21 ± .24 (0, **1.3**)	.15 ± .17 (0, .91)	.06 ± .07 (0, .40)	.15 ± .17 (0, .91)	.07 ± .08 (0, .46)
DL PCBs (TEQ)	.09 ± .08 (0, .65)	.28 ± .28 (0, **2.12**)	.20 ± .19 (0, **1.49**)	.09 ± .08 (0, .65)	.20 ± .19 (0, **1.49**)	.10 ± .10 (0, .74)
Σ TEQ (PCDD/Fs + DL PCBs)	.15 ± .14 (0, .77)	.49 ± .47 (0, **2.54**)	.34 ± .32 (0, **1.78**)	.15 ± .14 (0, .77)	.34 ± .32 (0, **1.78**)	.17 ± .16 (0, .89)
Non-DL PCBs	.07 ± .07 (0, .45)	.43 ± .46 (0, **2.94**)	.04 ± .05 (0, .29)		.04 ± .05 (0, .29)	
Σ PCBs	.07 ± .08 (0, .49)	.47 ± .50 (0, **3.16**)	.05 ± .05 (0, .32)		.05 ± .05 (0, .32)	
PBDEs		.0004 ± .001 (0, .01)				

Note: HQ values greater than Health Canada's acceptable level of 1.0 are in boldface.

Table 12

Estimated non-cancer health risks associated with the consumption of POPs via the total seafood diet represented as the Hazard Quotient (HQ). HQ values are quantified for several regulatory authorities based on differing toxicological reference (TRV) values for each chemical. TRV values include: Health Canada (HC) tolerable daily intake (TDI), United States Environmental Protection Agency (US EPA) oral reference dose (RfD), World Health Organization (WHO) TDI, Joint FAO/WHO Expert Committee on Food Additives (JECFA) TDI, Agency for Toxic Substances Disease Registry (United States) (ATSDR) minimal risk level (MRL), and the European Commission Scientific Committee on Food (EC-SCF) TDI.

	Hazard Quotient Mean ± SD (min, max)					
Chemical Class	HC	US EPA	WHO	JECFA	ATSDR	EC-SCF
PCDD/Fs (TEQ)	.09 ± .10 (0, .57)	.30 ± .34 (0, **1.86)**	.21 ± .24 (0, **1.30**)	.09 ± .10 (0, .57)	.21 ± .24 (0, **1.30**)	.10 ± .12 (0, .65)
DL PCBs (TEQ)	.12 ± .12 (0, .92)	.40 ± .40 (0, **3.03)**	.28 ± .28 (0, **2.13**)	.12 ± .12 (0, .92)	.28 ± .28 (0, **2.13**)	.14 ± .14 (0, **1.06**)
Σ TEQ (PCDD/Fs + DL PCBs)	.21 ± .20 (0, **1.11)**	.70 ± .67 (0, **3.63)**	.49 ± .47 (0, **2.54**	.21 ± .20 (0, **1.11**)	.49 ± .47 (0, **2.54**)	.25 ± .23 (0, .**1.27**)
Non-DL PCBs	.10 ± .10 (0, .65)	.62 ± .66 (0, **4.21)**	.06 ± .07 (0, .42)		.06 ± .07 (0, .42)	
Σ PCBs	.10 ± .11 (0, .70)	.67 ± .71 (0, **4.52)**	.07 ± .07 (0, .45)		.07 ± .07 (0, .45)	
PBDEs		.0006 ± .002 (0, .01)				

Note: HQ values greater than Health Canada's acceptable level of 1.0 are in boldface

Carcinogen Risk Quantification

Four sentinel species.

Carcinogenic risks to people of the five coastal Vancouver Island First Nation Communities that can be attributed to the consumption of four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals) are expressed in Table 13 as the Incremental Lifetime Cancer Risk (ILCR). ILCR values are calculated based on slope factors adopted by the US EPA and OEHHA (division of the California EPA).

The mean risk of developing cancer from each genotoxic chemical class associated with the consumption of only the four sentinel seafood species are in exceedance of the Health Canada's acceptable risk level of 1 in 100,000 cancers (1.0E-5). This is true for both the US EPA and the OEHHA, although the US EPA cancer risk values for dioxin-like compounds are significantly higher than the OEHHA due to slope factor that is almost eight times higher than the OEHHA.

Table 13

Cancer risk associated with the consumption of POPs via the four species, represented as the Incremental Lifetime Cancer Risk (ILCR). ILCR values are quantified for each chemical based on toxicological reference (TRV) values (slope factors) adopted by the United States Environmental Protection Agency (US EPA) and the Office of Environmental Health Hazard Assessment (OEHHA) (California EPA). Cancer risk is presented as the number of human receptors estimated to develop cancer per 100,000 people.

	Incremental Lifetime Cancer Risk (ILCR) Mean ± SD (min, max)	
Chemical Class	US EPA	California OEHHA
PCDD/Fs (TEQ)	**12.4 ± 14.5**	**1.6 ± .1.9**
	(0, **84.1)**	(0, **10.9)**
DL PCBs (TEQ)	**16.1 ± 16.1**	**2.1 ± 2.1**
	(0, **148.6)**	(0, **19.3)**
Σ TEQ (PCDD/Fs + DL PCBs)	**28.5 ± 27.0**	**3.7 ± 3.5**
	(0, **177.9)**	(0, **23.1)**
Non-DL PCBs	**1.4 ± 1.5**	**1.4 ± 1.5**
	(0, **10.2)**	(0, **10.2)**
Σ PCBs	**1.5 ± 1.6**	**1.5 ± 1.6**
	(0, **10.9)**	(0, **10.9)**

Note. ILCR values greater than Health Canada's acceptable level of 1 in 100,000 (1.0E-5) are in boldface.

Figure 14 illustrates that even the minimally exposed individuals on the lower end of the US EPA risk distribution for dioxin-like compounds are in exceedance of Health Canada's acceptable level of 1 in 100,000. In fact, 96% of the population exceeds the acceptable cancer risk level of 1 in 100,000 from only the four sentinel species. The upper 5% of the population have a greater than 80 in 100,000 cancer risk from TEQ, with the maximum risk reaching 178 in 100,000 based on the US EPA cancer slope factor (Figure 14).

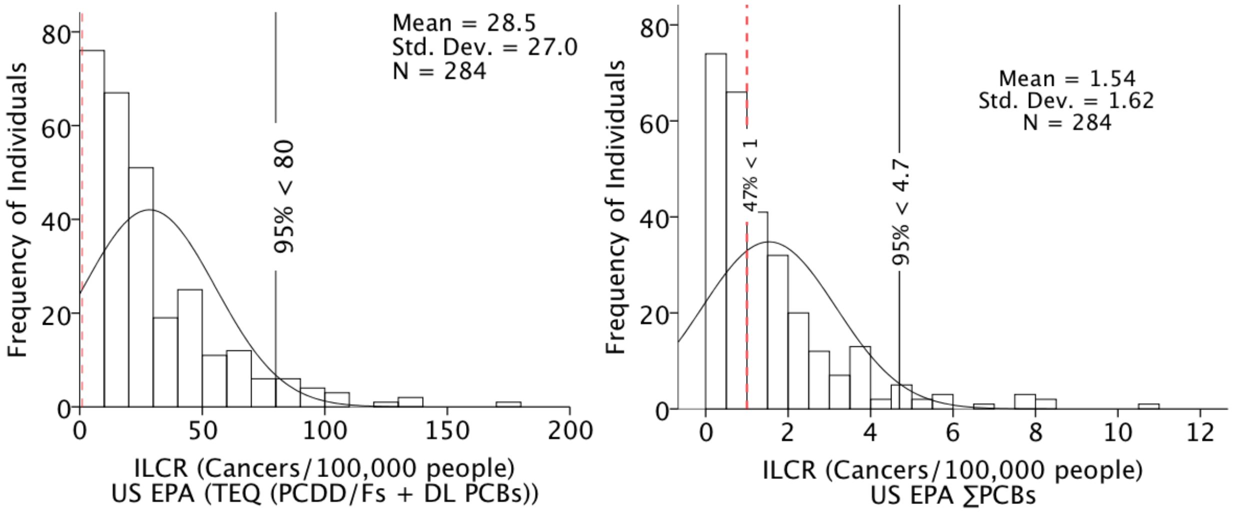

Figure 14. Incremental Lifetime Cancer Risk distribution for dioxin-like compounds (PCDD/Fs and DL PCBs) and ∑PCBs among 284 individuals for the US EPA. The dashed red line represents Health Canada's acceptable cancer risk level of 1 in 100,000.

Dioxin-like compounds contribute to a significantly greater cancer risk than ∑PCBs (Figure 15) with DL PCBs representing slightly more of the TEQ risk. DL PCBs and PCDD/Fs contribute to 56% and 44% of the dioxin-like risk respectively. Similar to non-cancer risk, sockeye salmon represent a significant majority of the ∑TEQ and ∑PCB carcinogenic risk (Figure 16). However, in contrast with non-cancer risk, both ∑TEQ and ∑PCB cancer risk attributed to sockeye salmon alone are in exceedance of Health Canada's risk limit of 1 in 100,000. Furthermore, ∑TEQ cancer risk, specifically from PCDD/Fs attributed to Dungeness crab is in exceedance of Health Canada's risk limit of 1 in 100,000.

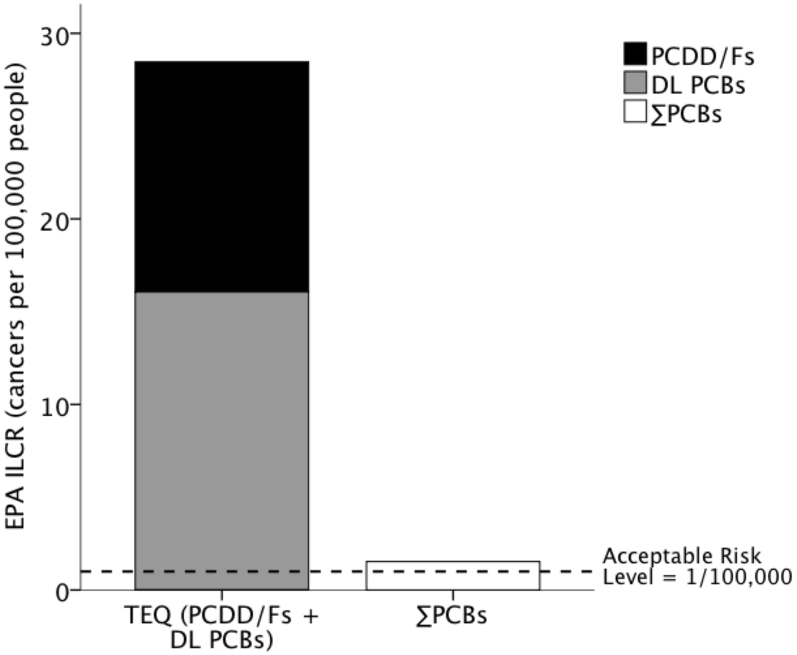

Figure 15. Risk of genotoxic chemicals: TEQ (PCDD/Fs + DL PCBs) and ∑PCBs. Risk is represented as both the mean for 284 people. Estimates are based on the US EPA slope factor of 1,000,000 and 2.0 $(mg/kg/day)^{-1}$ for 2,3,7,8-TCDD and PCBs respectively.

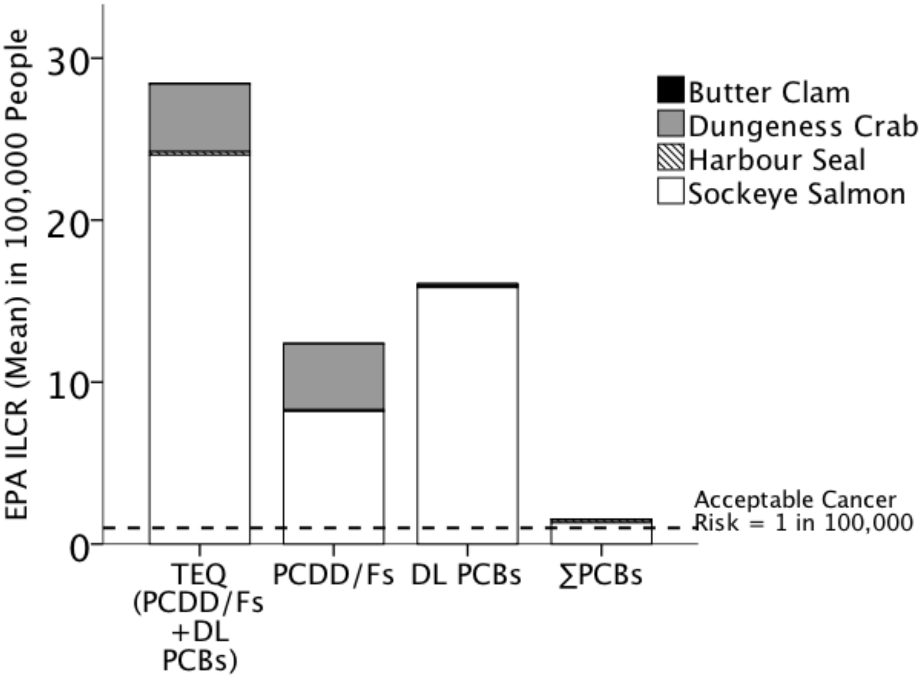

Figure 16. Risk of genotoxic chemicals: TEQ (PCDD/Fs + DL PCBs) and ∑PCBs attributed to each of the four sentinel seafood species (Butter clams; Dungeness crab; Sockeye salmon; and Harbour seals). Risk is represented as the mean for 284 people. Estimates are based on the US EPA slope factor of 1,000,000 and 2.0 $mg/kg/day^{-1}$ for 2,3,7,8-TCDD and PCBs respectively.

Estimating cancer risk for a larger portion of the seafood diet.

Cancer risks are estimated in a similar manner as the estimation of non-cancer risks for 70% and 100% of the seafood diet. When Sockeye salmon risk is extrapolated to Chum, Pink, Chinook, and Coho salmon, risk attributed to 70% of the seafood diet is accounted for (Table 14). 100% of the seafood diet is accounted for when these values are then multiplied by 1.43 (Table 15). As previously discussed, the results must be interpreted with caution as this assumes that the remaining 30% of the seafood intake represents a similar contaminant concentration as the four species and other salmon. Accounting for 100% of the seafood diet, ∑TEQ cancer risks are above Health Canada's acceptable risk level of 1 cancer per 100,000 for both the US EPA (ILCR = 49.2 cancers per 100,000 people) and OEHHA (6.4 cancers per 100,000 people). Similarly, ∑PCB cancer risk for both the US EPA and OEHHA are above the acceptable risk at 2.7 in 100,000.

Table 14

Cancer risk associated with the consumption of POPs via the four species plus Chum, Pink, Chinook, and Coho salmon, represented as the Incremental Lifetime Cancer Risk (ILCR). ILCR values are quantified for each chemical based on toxicological reference (TRV) values (slope factors) adopted by the United States Environmental Protection Agency (US EPA) and the Office of Environmental Health Hazard Assessment (OEHHA) (California EPA). Cancer risk is presented as the number of human receptors estimated to develop cancer per 100,000 people.

	Incremental Lifetime Cancer Risk (ILCR) Mean ± SD (min, max)	
Chemical Class	US EPA	California OEHHA
PCDD/Fs (TEQ)	**14.7 ± 16.6** (0, **91.2)**	**1.9 ± 2.2** (0, **11.9)**
DL PCBs (TEQ)	**19.7 ± 19.5** (0, **148.6)**	**2.6 ± 2.5** (0, **19.3)**
Σ TEQ (PCDD/Fs + DL PCBs)	**34.4 ± 32.6** (0, **177.9)**	**4.5 ± 4.2** (0, **23.1)**
Non-DL PCBs	**1.7± 1.9** (0, **11.8)**	**1.7 ± 1.9** (0, **11.8)**
Σ PCBs	**1.9 ± 2.0** (0, **12.7)**	**1.9 ± 2.0** (0, **12.7)**

Note. ILCR values greater than Health Canada's acceptable level of 1 in 100,000 (1.0x-5) are in boldface.

Table 15

Estimated cancer risk associated with the consumption of COPCs via the total seafood diet, represented as the Incremental Lifetime Cancer Risk (ILCR). ILCR values are quantified for each chemical based on toxicological reference (TRV) values (slope factors) adopted by the United States Environmental Protection Agency (US EPA) and the Office of Environmental Health Hazard Assessment (OEHHA) (California EPA). Cancer risk is presented as the number of human receptors estimated to develop cancer per 100,000 people.

	Incremental Lifetime Cancer Risk (ILCR) Mean ± SD (min, max)	
Chemical Class	US EPA	California OEHHA
PCDD/Fs (TEQ)	**21.0 ± 23.8** (0, **130.4)**	**2.7 ± 3.1** (0, **16.9)**
DL PCBs (TEQ)	**28.2 ± 27.9** (0, **212.5)**	**3.7 ± 3.6** (0, **27.6)**
TEQ (PCDD/Fs + DL PCBs)	**49.2 ± 46.7** (0, **254.4)**	**6.4 ± 6.1** (0, **33.1)**
Non-DL PCBs	**2.5 ± 2.6** (0, **16.8)**	**2.5 ± 2.6** (0, **16.8)**
∑PCBs	**2.7 ± 2.8** (0, **18.1)**	**2.7± 2.8** (0, **18.1)**

Note. ILCR values greater than Health Canada's acceptable level of 1.0x-5 (1 in 100,000) are in boldface.

Risks Compared Between Receptor Groups

Differences in risk (non-cancer or cancer) due to the consumption of the four sentinel species is compared between males and females, age categories, and communities. While the magnitude of mean risk for non-cancer versus cancer are inherently different, the significance of differences are the same due to identical distributions.

Gender.

Non-cancer risk HQ and cancer risk ILCR values for all 284 people for each chemical group was subjected to a *t* test dependent on gender. The difference in risk between males and females for all chemical classes were not significant.

Age.

Risk values for all 284 people for each chemical group was subjected to a one-way analysis of variance (ANOVA) dependent on age class. Five age categories were defined as ages 13-19, 20-40, 41-54, 55-64, and 65+. Differences between all age categories were determined to be not significant.

Furthermore, a two-tailed independent t-test was completed to determine whether or not there is a significant difference in risk between teens (ages 13-19) and adults (ages 20+) for each chemical class. Results of the t-test illustrated no significant difference at the .05 significance level between teens and adults for all chemical classes, with the exception of PBDEs. Since a preliminary Levene's test for equality of variances revealed that the variances of the two age groups for risk related to PBDEs were significantly different, a two-sample t-test was performed that does not assume equal variances. Risk related to PBDEs was significantly higher in adults ($M_{HQ} = 4.0E\text{-}4$, $SD_{HQ} = 1.2E\text{-}4$, $N = 247$) compared to teens ($M_{HQ} = 2.0E\text{-}4$, $SD_{HQ} = 1.6E\text{-}4$, $N = 37$), $t(280) = -3.24$, $p = .001$.

Community.

Differences in risk between the five coastal Vancouver Island First Nation communities (Ahousaht (Tofino), Weweikum (Campbell River), Snuneymuxw (Nanaimo), Quatsino First Nation (Quatsino Sound), and Pacheedaht First Nation (Port Renfrew)) were examined with a one-way analysis of variance (ANOVA) for each chemical class. An analysis of variance showed statistically significant differences in risk (non-cancer and cancer) exists for all chemical classes among communities. The following statistics highlight these differences.

Toxic equivalents PCDD/Fs and DL PCBs (TEQ) risk differed among the five communities ($F(4, 279) = 3.25$, $p = .01$). Specifically, post hoc analysis using the TUKEY test indicated that the mean risk for Weweikum First Nation (Campbell River) ($M_{HQ} = .16$, $SD_{HQ} = .12$) was higher than Quatsino First Nation (Quatsino Sound) ($M_{HQ} = .10$, $SD_{HQ} = .12$). This is illustrated in Figure 17.

PCDD/Fs risk differed among the five communities ($F(4, 279) = 13.65$, $p < .001$). Specifically, a TUKEY post hoc test indicated that the mean risk for the Ahousaht First Nation (Tofino) ($M = .06$, $SD = .06$), Weweikum First Nation (Campbell River) ($M = .08$, $SD = .08$), and Snuneymuxw First Nation (Nanaimo) ($M = .06$, $SD = .06$) were each higher than both Quatsino First Nation (Quatsino Sound) ($M = .02$, $SD = .02$) and Pacheedaht First Nation (Port Renfrew) (M = .02, SD = .02). This is illustrated in Figure 17.

DL PCBs risk differed among the five communities ($F(4, 279) = 2.81$, $p = .03$). Specifically, a TUKEY post hoc comparison indicated that the mean HQ and ILCR for the Snuneymuxw First Nation (Nanaimo) ($M = .04$, $SD = .04$) was lower than the Quatsino First Nation (Quatsino Sound) ($M = .08$, $SD = .10$). This is illustrated in Figure 17.

∑PCBs risk differed among the five communities (*F*(4, 279) = 9.50, *p* < .001). Specifically, a TUKEY post hoc test indicated that the mean HQ and ILCR for the Ahousaht First Nation (Tofino) (*M* = .10, *SD* = .10) was higher than each of the Weweikum First Nation (Campbell River) (*M* = .06, *SD* = .04), Snuneymuxw First Nation (Nanaimo) (*M* = .04, *SD* = .03), Quatsino First Nation (Quatsino Sound) (*M* = .04, *SD* = .05), and Pacheedaht First Nation (Port Renfrew) (*M* = .06, *SD* = .05). This is illustrated in Figure 15. The higher risk from ∑PCBs to Ahousaht First Nation compared to the other four communities is likely due to the significantly greater consumption levels of harbor seal which have the greatest concentration of PCBs among the four species.

PBDEs risk, based on the US EPA RfD value, differed among the five communities (*F*(4, 279) = 9.46, *p* < .001). Specifically, a TUKEY post hoc test indicated that the mean cancer and non-cancer risk for the Ahousaht First Nation (Tofino) (*M* = .001, *SD* = .002) was higher than each of the Weweikum First Nation (Campbell River) (*M* = .0002, *SD* = .0001), Snuneymuxw First Nation (Nanaimo) (*M* = .0002, *SD* = .0002), Quatsino First Nation (Quatsino Sound) (*M* = .0002, *SD* = .0004), and Pacheedaht First Nation (Port Renfrew) (*M* = .0002, *SD* = .0001).

In addition, a two-tailed independent *t*-tests was completed to determine whether or not there is a significant difference in risk between communities on the east and west coast of Vancouver Island (i.e., Ahousaht (Tofino), Quatsino (Quatsino Sound), and Pacheedaht (Port Renfrew) First Nations versus Weweikum (Campbell River), and Snuneymuxw (Nanaimo) First Nations) for each chemical class. Results of the *t*-tests illustrated a difference at the .05 significance level between communities on the east and west coast for chemical classes including PCDD/Fs (*p* < .001), DL PCBs (*p* < .001), and ∑PCBs (*p* < .001). However, dioxin-like compound (∑TEQ(PCDD/Fs + PCBs)) risk did not show a significant difference between east and west coast communities (*p* = .68).

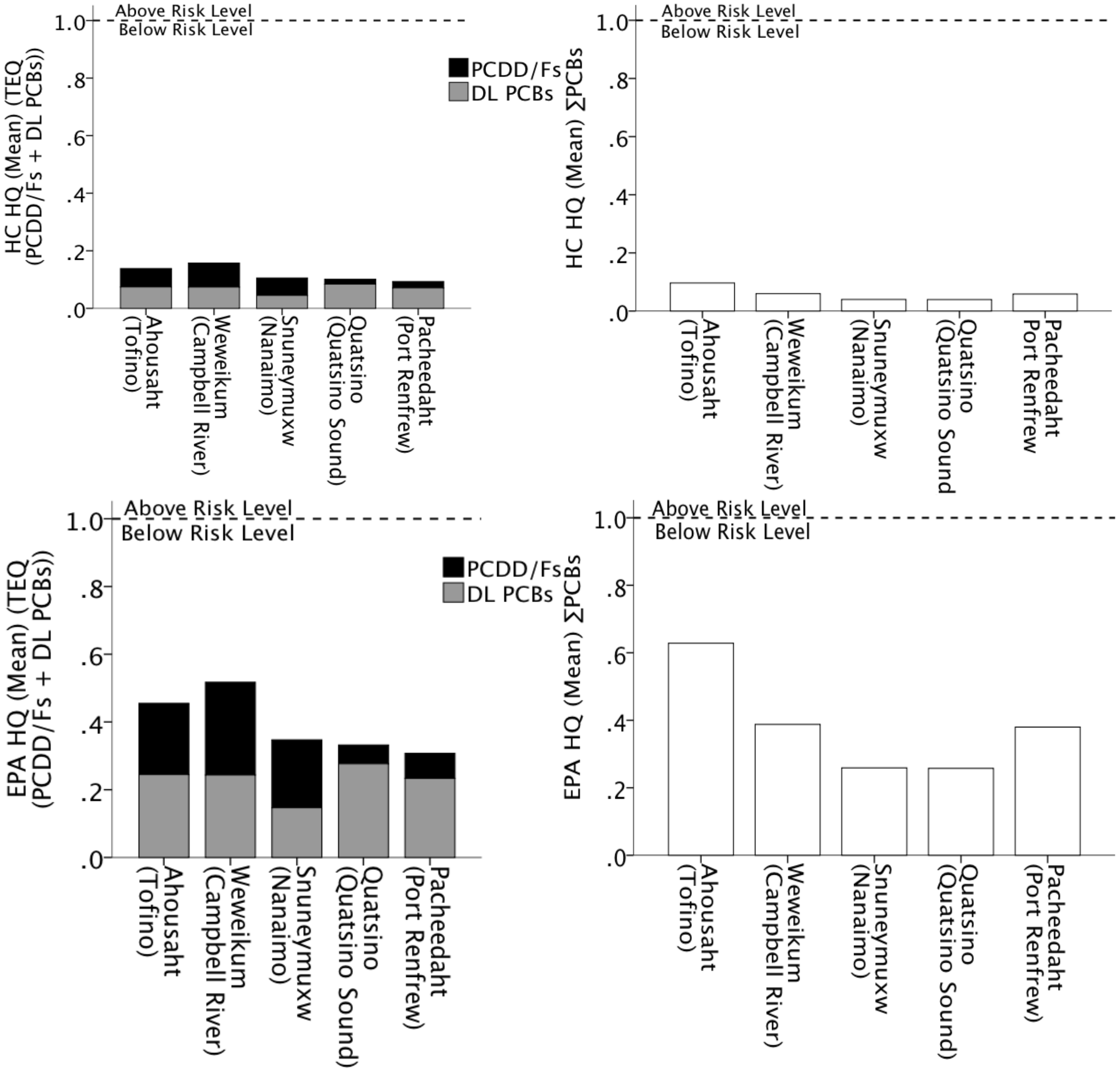

Figure 17. Mean non-cancer risk (HQ) from ∑TEQ and ∑PCBs among the five communities based on Health Canada as well as US EPA TRVs.

While the mean estimates of risk are all below HQ = 1 for ∑TEQ and ∑PCBs in all five communities based on Health Canada and the US EPA (Figure 17), it is once again highlighted that the upper distribution of risk and outliers are at risk in accordance with the US EPA estimates (Figure 18). Ahoushat and Weweikum First Nations particularly appear to have an upper risk distribution and outliers above the acceptable risk level (Figure 18).

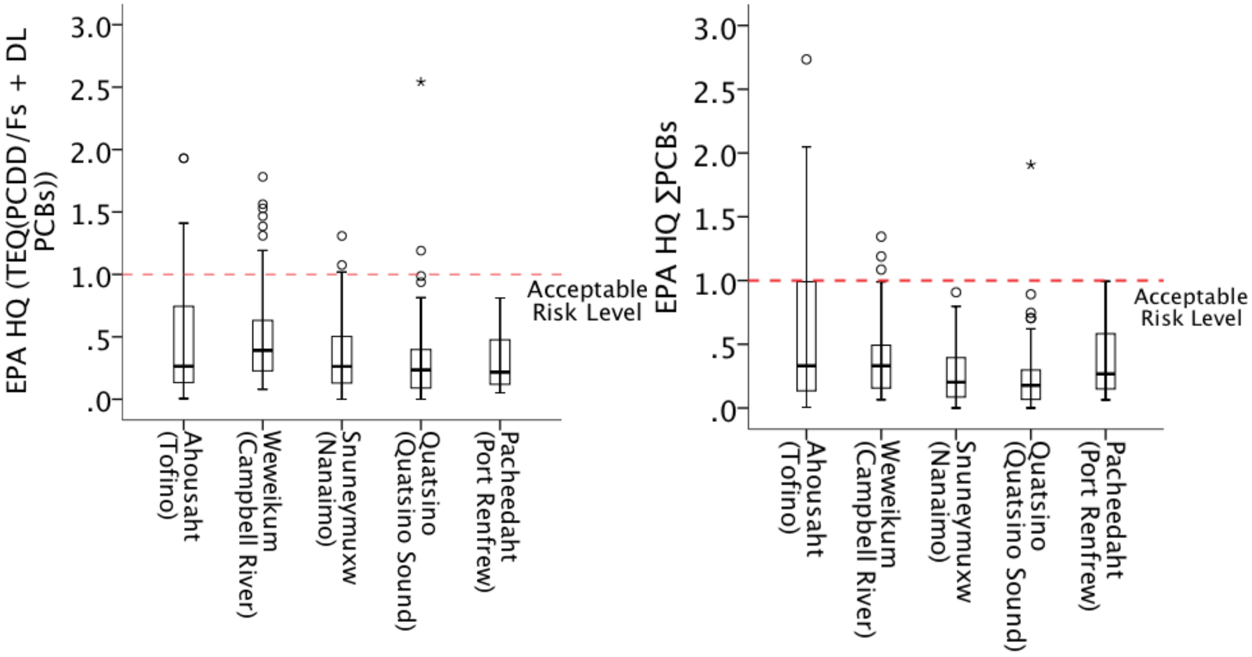

Figure 18. Non-cancer health risk distribution for each community among 284 people for ∑TEQ (PCDD/Fs + DL PCBs) and ∑PCBs. Estimates are based on the US EPA RfD values. The importance of recognizing the upper risk distribution and outliers is demonstrated.

Regarding cancer risk, the US EPA mean ILCR attributed each ∑TEQ (and also PCDD/Fs and DL PCBs separately) are all beyond the limit of 1 in 100,000 cancers for all five First Nation communities (Figure 19). The US EPA cancer risk attributed to ∑PCBs is beyond Health Canada's acceptable level of 1 in 100,000 for Ahousaht, Weweikum, and Pacheedaht First Nations, while the risk is equal to 1 in 100,000 for both Quatsino and Sunueymuxw First Nations.

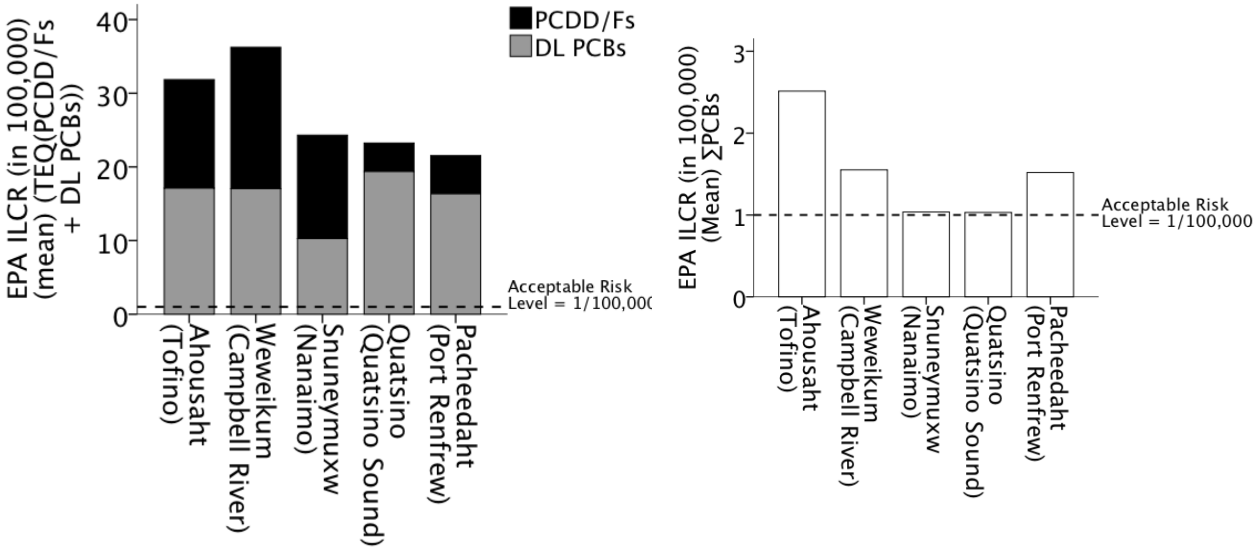

Figure 19. Mean carcinogenic risk (ILCR) from ∑TEQ and ∑PCBs among the five communities based on US EPA RfD values.

Qualitative Sensitivity Analysis

Uncertainty and variability are inherent in risk assessment. Uncertainty can arise from model input parameters in the data or assumptions. The risk models used are also a source of uncertainty as they are not perfect models due to the need for simplicity in modeling very complex and dynamic processes.

Potential uncertainty in this risk assessment may arise from the estimate selected for contaminant concentrations. The mean estimate of concentration of contaminants in seafood species was used in exposure calculations. Because average contaminant concentrations may underestimate risk, reasonable maximum exposure (RME) values such as the 95th percentile are often utilized. The consequence of utilizing the mean seafood contaminant concentration might be that the daily exposure dose calculation is lower than reality. This being said, using reasonable maximum values for all model input values may lead to overly conservative estimates. In this assessment, the 95th percentile HQ and ILCR estimates to represent maximally exposed individuals are encompassed in order to gain some understanding of the worst-case scenario. However, maximally exposed individuals are vulnerable to being exposed to even higher contaminant concentrations as a result of the mean contaminant concentration values used in this assessment.

Dietary surveys did not differentiate between crab muscle or hepatopancreas body part consumed. Thus, it was necessary to utilize only contaminant concentrations from crab muscle in order to prevent over estimating risk. However, this may lead to underestimates in risk calculations. A similar scenario was true for seal; the assumption was made that blubber was the consumed body part. Notwithstanding this, considering that Dungeness crab and Harbour seal only contributed to 4.7 and 0.04% of the total seafood diet respectively, the described assumptions are not expected to significantly influence a change in risk estimates. As such, they are unlikely to be a great source of uncertainty.

The overall uncertainty in calculations based on the four species is regarded as low and with a high degree of confidence in light of the large amount of data. However, calculations to represent a larger portion of the seafood diet are best estimates and may hold a higher degree of uncertainty.

Benefits and Countervailing Risks

Benefits of a diet comprising traditional seafoods are immense. The importance of traditional seafoods to coastal Vancouver Island First Nations has been highlighted in the Dietary Survey companion study. A review of the literature further underscores the physical, mental, social, cultural, spiritual, and economic benefits associated with a traditional diet.

Nutrition and physical health benefits.

Seafoods are a healthy source of nourishment and have been shown to prevent health problems including diabetes, cardiovascular and coronary heart disease, cardiac arrhythmias, stroke, obesity, rheumatoid arthritis, depression, hypertension, and cancers (Domingo, Bocio, Marti-Cid, & Llobet, 2006; Sidhu, 2003). In addition, a diet rich in seafood promotes development of the nervous (brain), photoreception (vision) and reproductive systems (Sidhu, 2003). Fish and seafoods are a rich source of essential dietary nutrients including vitamins, minerals, proteins, and fatty acids (Sidhu, 2003; Van Oostdam et al., 2005) and have been suggested to reduce or prevent effects of contaminants (Van Oostdam et al., 2005). Omega-3 fatty acids, namely eicosapentaenoic acid (EPA) and docosohexaenoic acid (DHA), deliver many of the health benefits associated with a seafood diet, although the optimal intake and mechanism of action is not fully understood (Domingo et al., 2006; Sidhu, 2003; Van Oostdam et al., 2005).

Social, cultural, spiritual, traditional, and economic benefits.

Family and community social and cultural ties and tradition are strengthened by the activities involved in fishing and gathering, sharing, preparing, and consuming of traditional foods (Chan, 2009; Van Oostdam et al., 2005). Celebrations and festivities are often centered around traditional foods (Van Oostdam et al., 2005). Traditional foods define, preserve, and enhance cultural, social, and spiritual identity and well-being among individuals and communities (Van Oostdam et al., 2005). Furthermore, economic relationships and value are sustained through traditional foods (Van Oostdam et al., 2005).

Kuhnlein, Receveur, Chan, and Loring (2000) found that Inuit of the Canadian Arctic believe that harvesting country foods not only contributes to good health and fitness, and provides healthy foods, it also fosters community sharing, is an essential part of culture, demonstrates parental responsibility, and provides environmental education, survival and food preparation skills.

Countervailing risks.

Shifting away from the traditional diet due to pollution concerns and/or consumption advisories is likely to result in the adoption of a nutritionally inferior western market based diet (Chan, 2009; Chan et al, 2011; Wiseman & Gobas, 2002). Recently, the *First Nations Food, Nutrition and Environment Study (FNFNES): Results from British Columbia (2008/2009)* found that dietary quality was higher on days that a traditional diet was consumed (Chan et al., 2011). Similar findings have been found in several studies across the Arctic (Van Oostdam et al., 2005). Traditional foods contain less fat, saturated fat, sucrose, and carbohydrates and more protein than non-traditional market foods, lower vitamins A, D, E, riboflavin, and B6 and minerals iron, zinc, copper, magnesium, phosphorous, potassium, and selenium (Van Oostdam et al., 2005). For example, ground beef and Dungeness crab contain 18 and 1 grams of fat respectively per 90 g serving (Wiseman & Gobas, 2002).

Increased diabetes, cardiovascular disease, coronary heart disease, and obesity in addition to a less active lifestyle and mental health effects are linked to loss of traditional diet and transition to store bought foods (Van Oostdam et al., 2005; Wiseman and Gobas, 2002). High sucrose and saturated fat are linked to increased colorectal cancers (Van Oostdam et al., 2005).

Discussion

Interpretation of Study Findings

The goal of this study was to carry out a human health risk assessment to determine the safety of seafoods consumed. The risk of developing cancer and non-cancer health effects attributed to the ingestion of POPs (i.e., PCDD/Fs, PCBs, and PBDEs) via four sentinel seafood species (i.e., Butter clams, Dungeness crabs, sockeye salmon, and harbor seals) was assessed for five coastal Vancouver Island First Nation communities (i.e., Ahousaht, Pacheedaht, Quatsino, Snuneymuxw and Weweikum). Results were subsequently extrapolated to estimate risks for (a) all other salmon species consumed, and finally, (b) all seafoods consumed.

The results of this study suggest that based on Health Canada's HHRA framework, coastal Vancouver Island First Nation communities are not at risk of non-cancer health effects associated with PCDD/F and PCB exposure via the consumption of the consumption of the four sentinel species or via the four species plus all other salmon. However, the highest consumers are at risk of non-cancer health effects related to dioxin-like compounds (∑TEQ) based on all traditional seafoods consumed.

Health Canada has not published a TDI for PBDEs for the assessment of non-cancer risks. Likewise, a cancer slope factor has not been established for any of the assessed chemicals. This is despite Health Canada's classification of dioxin-like compounds as 'group 2B: possibly carcinogenic to humans'. Moreover, 'Inadequate data for evaluation of carcinogenicity to humans' has limited the implementation of a slope factor for PCBs. Cancer effects related to PBDEs are believed to be protected by the critical effect level.

Based on the most conservative risk assessment authority considered here (US EPA), results suggest that heavy seafood consumers are at risk of developing non-cancer health effects related to PCDD/Fs, and PCBs, but not from PBDEs. Specifically, 8%, 15%, and 24% of respondents are estimated to be in exceedance of ∑TEQ risk for the 'four species', 'four species + other salmon', and 'total seafood' diet respectively. Correspondingly, 7%, 13%, and 23% of respondents exceeded ∑PCB values. While Health Canada has not established a cancer slope factor for PCDD/Fs, PCBs or PBDEs, the US EPA has done so for PCDD/Fs and PCBs. Based on US EPA cancer slope factors, results suggest that the average consumer has a risk of developing cancer that is greater than Health Canada's acceptable level (1 in 100,000 people) caused by exposure to both PCDD/Fs and PCBs through the seafood diet. We estimate that 96% and 53% of respondents are at increased risk of developing cancer from ∑TEQ and ∑PCBs respectively based on the consumption of the four species, using US EPA guidance.

Based on WHO and the ATSDR, results suggest that heavy consumers are at risk of developing non-cancer health effects related to ∑TEQ. WHO and ATSDR TRVs do not exist for PBDEs, hence associated risks were not assessed for these agencies.

One of the research objectives was to establish whether unacceptable health risks might exist as a screening step in identifying or refuting the need for further action. Considering the results based on WHO, ATSDR and particularly the US EPA TRVs, which are in turn based on sound scientific research, potential adverse human health effects are possible and further investigation is warranted.

Seafood Safety in Context

Coastal Vancouver Island First Nation communities asked: "Is it safe to consume traditional seafoods?" This question, queried in the context of pollution has been explored, with noted associated HHRA limitations and uncertainties. However, to provide a definitive answer to this question is very difficult as the safety of traditional seafoods is dependent on a complex system of multidisciplinary factors, some which cannot be measured quantitatively. The main goal of this study was to quantitatively estimate the risks attributed to exposure to four POPs of concern through the traditional seafood diet. One objective of this goal was to qualitatively describe benefits and countervailing risks in light of pollution risks in an effort to advance a balanced approach. Despite the fact that qualitative descriptions do not easily permit direct comparison on a mathematical scale, qualitative benefits and countervailing risks cannot be discounted as they may in reality have more weight. For example, the cultural benefits of procuring, cooking, gathering, and sharing traditional seafoods, although not measurable, may in actuality outweigh potential contamination risks. In addition, the nutritional benefits associated with a wild-caught diet are widely thought to outweigh the risks associated with exposure to the POPs found in those foods. Much of the literature concerning aboriginal dietary and risk assessment advise that in most cases, the immeasurable benefits surrounding a traditional diet outweigh the direct risks of consuming contaminated traditional foods and that changes in the diet may be far more detrimental to subsistence communities (Chan, 2009; Hellberg, Mireles DeWitt, & Morrrissey, 2012; Van Oostdam et al., 2005; Wiseman & Gobas, 2002).

Turner et al. (2008) speak of the ‘invisible losses’ that Fist Nations in western Canada have experienced; those indirect or cumulative losses that are often not accounted for in management and decision-making. Types of losses identified encompassed cultural, identity, health, self-determination and influence, emotional and psychological, order in the world, knowledge, and indirect economic and opportunity losses (Turner et al., 2008). This study underlines the need for culture and traditional knowledge to play key roles in environmental decision-making.

There has been some effort to quantify benefits and/or countervailing risks. Wiseman and Gobas (2002) conducted a study involving coastal First Nations in Gold River and Powell River BC that quantitatively estimated both (a) the cancer risks of consuming dioxin contaminated shellfish in 1990 and (b) the countervailing risk of mortality due to coronary heart disease. Results showed that health risks from altering the diet may be as significant as the contamination risks. This study suggested the fisheries closures may have resulted in replacing one risk with another and risk management and decision-making must encompass a broad spectrum of countervailing risks and benefits. In another study, Domingo et al. (2006) designed a computer program, RIBEPEIX, as a tool for professionals and the general population to balance the risk of seafood contaminants versus the benefits of omega-3 fatty acids in order to choose optimal species, consumption frequency, and meal size. However, the website link to the program was not functioning.

While there have been attempts in seafood consumption risk-benefit analyses to weigh environmental contamination risk against nutritional benefits as well as nutritional countervailing risks, health authorities have not yet established a formal framework to quantitatively balance nutritional benefits, risks, and nutritional and contaminant countervailing risks. Even still, all of these pertain to measurable direct physical health outcomes and not mental health outcomes or indirect health outcomes in terms of cultural, social, and economic changes in the way of life.

Factors Not Considered In This Study

Sensitive consumers.

This study did not determine risk for three important sensitive receptor groups: infants, toddlers, and children. Considering the potential risks determined for youth and adults in conjunction with the vulnerability of these infants, toddlers, and children, future assessments should be implemented for these sensitive groups. Likewise, studies involving *in utero* and lactational exposure and risk should be carried out.

Cooking loss.

Bayen, Barlow, Lee, & Obbard (2005) showed that after cooking salmon, mean POP concentrations decreased by 25% and that skin removal contributed to an additional 9%. Furthermore, there was no significant difference in POP levels between cooking methods (i.e., baking, boiling, frying, microwaving) (Bayen at al., 2005). Finally, a strong linear correlation between POP loss and lipid loss during cooking indicates that cooking raw fish and thereby removing lipids is likely to reduce POP exposure risk (Bayen at al., 2005). In another study, Moses, Whiting, Muir, Wang, and O'Hara (2009) determined that preparation methods significantly alter both contaminant and nutrient levels.

Additional exposure routes.

All exposure routes were not assessed in this study. Multiple exposure routes may exist in addition to ingestion of seafoods. Ingestion of other foods encompassing the remainder of the diet also likely presents an important exposure route, particularly via meat and dairy consumption. Drinking water, dermal exposure, and inhalation are other routes of exposure that were not necessary to evaluate given that more than 95% of POPs are ingested through animal fat in food (meat, dairy, fish and shellfish) (US EPA, 2002). Finally, background levels were not considered given the scope of this study. Specifically, this study essentially assessed background exposure as global contamination in the foodweb. This study was not meant to determine risk from a contaminated site or point source of pollution per say and thus background estimates were not necessary.

Additional chemicals.

There are approximately 78,000 chemicals in current commercial use, with 5 billion tons produced every year globally in addition to 1,000 new chemicals created per year (Chan et al., 2011). As a result of historical, current, and new substances, there are a plethora of chemicals that present a human health risk, many of which regulatory authorities regard as priority chemicals. Chemicals including other POPs such as organophosphate and organochlorine pesticides (OPPs/OCPs) (e.g., DDT, chlordane, toxaphene), perfluorinated compounds (PFCs), polycyclic aromatic hydrocarbons (PAHs), heavy metals (e.g., arsenic, mercury and methyl mercury, lead, and cadmium), pharmaceuticals and personal care products (PPCPs), biological, radionuclides, and micro-plastics are all primary and/or emerging contaminant concerns in traditional seafoods (Chan, 2009; Chan et al., 2011; Van Oostdam et al., 2005). This HHRA was limited to the assessment of risks from PCBs, PCDDs, PCDFs, and PBDEs; all high priority POPs. Consequently, health risks estimates do not account for the total pollution in seafoods and risks could be greater than determined in this study. For comparison, Cullon, Jeffries, and Ross (2005) measured POPs in the diet of harbor seals of the Strait of Georgia (Table 16). Our study did not measure organochlorine pesticides (OCPs): DDT, HCH, Heptachlor, Chlorodane, Nonachlor, and Mirex. Based on the proportion of PCBs, PBDEs, PCDDs, and PCDFs to OCPs in Cullon et al. (2005), it is estimated that we measured nearly 70% of total POPs.

Table 16

Relative POP intakes by harbor seals in the Strait of Georgia on a wet weight basis. Measurements were conducted by Cullon et al (2005) in 2001.

Chemical	Estimated daily intake (μg/d)
Flame retardants and industrial byproducts	
PCB	42.28
PBDE	13.82
PCDD	3.5
PCDF	2.15
Organochlorine pesticides	
DDT	18.02
HCH	2.5
Heptachlor	0.12
Chlorodane	2.05
Nonachlor	3.00
Mirex	0.05

(Cullon et al., 2005)

Risk Assessment Deficiencies and Research Gaps

Variation among HHRA authorities.

Whether or not chronic low-dose exposures present health concerns is a controversial topic of debate that arises from inconsistent findings among toxicological studies (Chan, 2009). Considerable disagreement exists between scientists and HHRA authorities whether a threshold or non-threshold effect exists for individual POPs. For example, Health Canada has deemed dioxin-like compounds as chemicals with a threshold-response. That is, below the threshold concentration, effects are considered to be acceptable or insignificant. In contrast, other international agencies including the US EPA believe a non-threshold model is more appropriate and that even low levels of dioxins and furans (i.e., Canadian air) can cause cancer (CCME, 2002). Therefore, they have established a non-threshold-response for dioxin-like compounds assuming there is a linear relationship between dose and response to zero dose. This differing assumption has resulted in a more conservative risk assessment approach employed by the US EPA.

Uncertainty of uncertainty factors.

Of particular challenge in risk assessment is dealing with uncertainty. Uncertainty in risk assessment arises from lack of available data on a variety of variables including effect level, exposure duration, taxonomic group response, contaminant mixture interactions and differences between field and laboratory studies (Duke & Taggart, 2000). Uncertainty factors (or safety factors) have been developed to account for variability when extrapolating known toxicity data within a species, across species, from acute to chronic or subchronic to chronic exposure durations, from the lowest observed adverse effect level (LOAEL) to the no observable adverse effect level (NOAEL) (Duke & Taggart, 2000). Uncertainty factors are used in risk assessment to reduce the probability of underestimating risk due to deficient knowledge of the dose-response relationship and exposure estimates for the contaminant and receptor in addition to accounting for sensitive receptor groups, lifestage and human variability) (Duke & Taggart, 2000).

Duke and Taggart (2000) determined that uncertainty factor methodology is widely used but is not consistent across studies, especially between regulatory guidelines and academic literature. Disagreements among the scientific community regarding magnitudes, types, and theories reduces the reliability of the uncertainty factor method and results in further uncertainty in risk assessment models (Chan, 2009; Duke & Taggart, 2000).

Toxic effects of mixture interactions.

Most chemicals are not present as one single chemical, but as a mixture with other chemicals. The toxic effect of a chemical can be influenced by interactions with other chemicals in a mixture. Interactions may be additive (i.e., sum of combined chemical effects), synergistic/potentiative (i.e., greater than additive) or antagonistic (i.e., less than additive) (HC, 2010; Simms, 2000). The combined toxic effect of multiple chemicals is an area of toxicological research that is very limited, largely due to the excessive number of possible combinations. Resultantly HHRA authorities generally recommend assessing toxicity and risk on a chemical-by-chemical basis unless mixture specific TRVs have been developed (HC, 2010). This is the case with dioxin like compounds (TCDD, PCDDs, PCDFs, DL PCBs) sharing the A*h*R mediated mode of action that has allowed for the development of the WHO-TEF approach.

However, the TEF approach must be used with caution as non-dioxin-like contaminants may unknowingly elicit the A*h*R mode of action contributing to adverse effects. Similarly, dioxin-like compounds have many other modes of action (P.S. Ross, personal communication, April 25, 2013). Further, organisms are affected by the cumulative exposure of A*h*R mediated compounds and not a single dioxin-like compound (CCME, 2002). Thus, TEQs may not be a true reflection of total toxicity.

While additive toxic effects of PCDD/Fs and DL PCBs are widely accepted among regulatory agencies, less is known about interactions that may exist between the other chemical classes evaluated in this study. However, there is evidence in the literature to suggest not only that PCBs and PBDEs do in fact exhibit additive interactions, but they might even act in a synergistic manner (i.e., greater than additive) effects (Miller, Sanchez-Morrissey, Brosch, & Seegal, 2012; Pellacani et al., 2012). The risk assessment framework available precludes the analysis of interactions that may be greater than additive. Furthermore, given the lack of adequate research on the study of complex mixtures in the real world, we suggest that this subject remains a high priority for future research.

Computational capabilities.

An amalgamated and routinely updated source for all differing TRVs across regulatory agencies and the literature would greatly assist in the toxicity assessment stage of risk assessment. From this study, experience in gathering TRVs for each chemical from various agencies proved to be time consuming. The International Toxicity Estimates for Risk (ITER) is the only integrated source for TRVs for several organizations, including Health Canada (Toxicology Excellence for Risk Assessment, 2010). This database is very useful, however some oral TRVs are missing.

Chan (2009) suggests that a meta-database would be very useful for different organizations (e.g., government departments, private firms, and non-profits) to share collected data such as fish contaminant data or health indicator data. This would prevent duplication, aid in literature review, and help to identify data gaps. Further to this, an online database graphically displaying all aboriginal environmental health, risk assessment, exposure, epidemiological, and contaminant studies across Canada would be a valuable tool. This would include studies from the various aboriginal contaminant and health programs and research in addition to numerous studies throughout the literature. This central location for the abundance of contamination and risk related information would significantly aid in an efficient and more effective literature review.

Lastly, the development of a computer program specifically designed for risk assessment would aid in the process. Ideally such a program would have several simulation options to adjust for varying approaches and assumptions, and would generate results, outputs, and graphs.

Future of Risk Assessment

The *U.S. Environmental Protection Agency's Strategic Plan for Evaluating the Toxicity of Chemicals* (2009) is a vision of a new paradigm of toxicity testing and risk assessment. The strategy focuses on toxicity 'pathways' of chemicals at the molecular, genomic, and cellular levels in order to determine tissue, organ, and organism toxic endpoints. Specifically, focusing on the toxicity pathway will advance our understandings of how chemical triggers perturb cellular functions (e.g., genes, proteins, and molecules) and cause cascading events that produce deliterious health outcomes.

The implementation of frameworks surrounding this new paradigm is intended to respond to inadequacies of the existing risk assessment framework and fufill changing and higher demands. The goal is to shift away from animal laboratory testing that is outdated, inefficient, expensive, time consuming, and laden with deficiencies and uncertanties associated with species extrapolation (e.g., animal to human) and dose extrapolation (i.e., high laboratory animal doses to determine risks of lower environmental exposures). New scientific tools (i.e., computational, informtational, and molecular sciences) offer greater capabilities in the realm of toxicity testing and risk assessment. Specificially, greater database capabilities, genomic data, in vitro assays (especially human cells), in silico (computer based) algorithms and simulation, and new models will address knowledge and data gaps. Parallel approaches in medicine and genetics are responsible for accelerating significant discoveries and advancements. Information gaps to be filled pertain to upwards of 100,000 chemicals humans may be exposed to, cumulative exposure risk, mixtures, lifestage differences, exposure scenarios, dose-response relationships, meghanisms of toxicity, and the uncertainty and inconsistancy in application of uncertanity factors (US EPA, 2009). Lastly, a greater focus on integrated HHRA and ecological risk assessment (ERA) toxicity testing and risk assessment will be put forward.

Conclusions and Recommendations

The identity and way of life for First Nation peoples in British Columbia continues to be defined by a harmonious reciprocal relationship with the land and environment. Interfering with this in terms of restrictions on subsistence food gathering has been demonstrated to have a number of succeeding negative impacts involving loss of benefits and introduction of unwanted countervailing risks. This study was intended as a screening step and has shown that there may potentially be adverse pollution related health risks associated with the consumption of traditional seafoods. It is necessary that these potential risks are explored further.

Considering the large number and breadth of benefits received from the traditional diet and the expected repercussions associated with changing the traditional diet in conjunction with the exploratory nature of this study, the traditional diet should continue to be embraced with perhaps taking small actions that will significantly reduce risk. Moreover, in conjunction with further exploration of risks, focus should be placed on sustaining healthy seafood resources and ecosystems. This involves local, provincial, national, and international responsibility in regulating to prevent further contamination of our local and global food systems. International conventions with this very purpose such as the Stockholm Convention need to become more stringent if we wish for their true effectiveness. Where such governments are negligent, it is necessary they are held accountable, as pollution of the global environment, sources of food nourishment, and people is a fundamental food security issue in violation of human rights.

Finally, regulations that have targeted persistent organic pollutants have led to progress, which is mirrored in food webs of coastal Vancouver Island and other parts of the world (Ross et al., 2013; US EPA, 2012). While this will take a long time to reach negligible levels, the knowledge we have today learned from lessons of the past should lead to the development of preventative measures that diminish widespread contamination in the future if we take action.

This HHRA should help to inform other coastal Vancouver Island First Nations and other coastal subsistence-oriented peoples. Furthermore, this study highlights the high social cost of pollution of aquatic organisms. These costs can be avoided in the future with broader environmental protection, prevention of chemical release to the environment, and use of non-toxic alternatives. The following recommendations are made:

- Continued sequestration of benefits received from a traditional seafood diet;
- Preferential selection of cooked seafoods over raw seafoods;
- Preferential selection of lower trophic levels and avoidance of e.g., marine mammals;
- Further exploration of potential health risks that may be associated with traditional seafoods involving:

  - HHRAs as conformational, focused, and detailed re-assessments of risks in coastal Vancouver Island communities;
  - HHRA specific to sensitive receptor groups: infants, toddlers, and children;
  - HHRA pertaining to other contaminants of concern in the traditional seafood diet;
  - HHRA that comprehensively evaluates of all exposure routes including the remainder of the diet (meat and dairy);
  - Epidemiological studies and evaluations of in utero and lactational exposure;
- Further research on First Nation perspectives on risks and benefits and food choices;
- Promotion and implementation of education and research programs;
- Application of traditional aboriginal knowledge and traditional ecological knowledge (TEK) in sustainability and protection of food sources.

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Appendices

Appendix A. Descriptions of the Five First Nation Communities

Quatsino First Nation

Approximately 250 people, the Quatsino First Nation is a subgroup of the Kwakwaka'wakw peoples. The community is located on the west coast of northern Vancouver Island in the Quatsino Sound region, approximately 18 km northwest of Port Hardy near the town of Cole Harbour.

Ahoushat First Nation

Approximately 900 people, the Ahoushat First Nation is the largest Nuu-chah-nulth Nation. The community is located in the central region of the west coast of Vancouver Island in Clayoquot Sound.

Pacheedaht First Nation

Approximately 100 people, the Pacheedaht First Nation culturally identify with the Nuu-chah-nulth-aht people but are not a member of the Nuu-chah-nulth Tribal Council. The Pacheedaht First Nation is based on the west coast of Southern Vancouver Island within the community of Port Renfrew.

Snuneymuxw First Nation

Approximately 750 people, the Snuneymuxw First Nation is one of the largest First Nations in British Columbia. Snuneymuxw Fisrt Nation is located on the east coast of Vancouver Island, and the Gulf Islands, in Coast Salish territory. Four reserves are located on the harbour shores of the City of Nanaimo and two on Gabriola Island.

Weweikum First Nation

Approximately 500 members, the Weweikum First Nation is a subgroup of the Kwakwaka'wakw peoples. The Weweikum First Nation is located on the east coast of Vancouver Island in the City of Campbell River.

Appendix B. First Nation Consumption and Demographic Data

(Data credit: T. Child, P.S. Ross, & N.J. Turner)

First Nation Community
1 - Ahousaht First Nation
2 - Weweikum First Nation
3 - Snuneymuxw First Nation
4 - Quatsino First Nation
5 - Pacheedaht First Nation

Age Category
1 - 13-19
2 - 20-40
3 - 41-54
4 - 55-64
5 - 65+

First Nation Community	Survey #	Gender	On Reserve	Age Category	Sockeye Salmon (kg/year)	Butter Clams (kg/year)	Dungeness Crab (kg/year)	Harbour Seal (kg/year)	Individual Seafood Total (kg/year)
1	1	f	y	4	18	0	1.08	0	19.08
1	2	m	y	4	18	0	0	0	18.00
1	3	m	y	3	9	0	0	0	9.00
1	4	f	y	4	12.96	0.9	0.36	0	14.22
1	5	f	y	6	0.36	0.36	0	0	0.72
1	6	f	y	5	0.54	0	0.18	0	0.72
1	7	f	y	4	27	1.08	2.16	0	30.24
1	8	f	y	5	2.7	0.36	0.9	0	3.96
1	9	m	y	6	14.4	1.44	0.72	0.27	16.83
1	10	f	y	6	14.4	0.72	0.72	0.18	16.02
1	11	f	y	3	0.9	0	0.18	0	1.08
1	12	m	y	2	5.04	0	0.36	0	5.40
1	13	m	y	3	6.3	0.72	1.08	0.72	8.82
1	14	f	y	1	5.4	2.16	1.08	0	8.64
1	15	f	y	2	129.6	0	0	0	129.60
1	16	f	y	2	129.6	0	0	0	129.60
1	17	f	y	2	3.6	4.5	0	0	8.10
1	18	f	y	2	67.5	9.45	0.9	0.18	78.03
1	19	f	y	4	18	0.54	0.54	0.18	19.26
1	20	f	y	2	15.975	0	0.36	0	16.34
1	21	m	y	3	48.6	0	1.8	0	50.40
1	22	m	y	1	14.58	0	0.72	0	15.30
1	23	f	y	1	23.94	0	1.35	0	25.29
1	24	f	y	2	66.15	0	3.6	0	69.75

1	25	m	y	2	43.56	0	2.7	0	46.26
1	26	m	y	1	66.15	0	3.6	0	69.75
1	27	m	y	3	47.7	18.72	2.7	0.36	69.48
1	28	f	y	1	26.1	0	0.9	0	27.00
1	29	f	y	3	56.16	0	0	0.18	56.34
1	30	m	y	3	56.16	3.96	2.7	0.45	63.27
1	31	f	y	3	7.56	5.4	1.8	0	14.76
1	32	f	y	1	6.48	0.36	0.36	0	7.20
1	34	m	y	1	10.8	3.6	0.18	0	14.58
1	35	m	y	1	54	1.44	0	0	55.44
1	36	m	y	1	18.9	0	1.08	0	19.98
1	37	m	y	1	37.44	0.54	1.8	0	39.78
1	39	f	y	1	10.8	0	0	0	10.80
1	40	f	y	3	47.7	14.04	1.08	0.18	63.00
1	41	f	y	2	1.08	0	0	0	1.08
1	42	f	y	2	56.16	1.08	0.36	0	57.60
1	43	m	y	1	23.4	0.63	2.88	0	26.91
1	44	m	y	2	4.32	2.52	4.32	0.36	11.52
1	46	m	y	3	12.96	0	0.27	0.45	13.68
1	48	f	y	3	9	1.08	0	0	10.08
1	49	m	y	2	94.68	0	1.35	0	96.03
1	50	f	y	1	11.52	0	1.08	0	12.60
1	51	f	y	2	5.04	0	0	0	5.04
1	52	m	y	2	11.34	0	0	0	11.34
1	53	m	y	3	78.75	2.16	1.08	0	81.99
1	54	m	y	3	21.6	4.32	2.7	0	28.62
1	55	m	y	1	23.4	13.5	0	0	36.90
1	56	f	y	4	54	0.18	0.54	0.72	55.44
1	57	f	y	2	9.36	0	0	0	9.36
1	58	f	y	2	15.12	0	0.18	0	15.30
1	59	f	y	1	15.12	0.18	2.88	0	18.18
1	60	m	y	1	4.32	10.8	2.7	0	17.82
1	61	f	y	3	7.2	0	0.18	0	7.38
1	62	f	y	3	16.56	0	1.44	0	18.00
1	63	m	y	1	63.9	5.76	1.08	0	70.74
1	64	f	y	3	16.2	0.72	1.08	0	18.00
1	65	m	y	2	6.48	0	0	0	6.48
1	66	m	y	1	51.84	1.08	37.8	0	90.72
2	1	f	y	2	72	0	7.2	0	79.20
2	2	f	y	5	9.36	0	0	0	9.36
2	3	m	y	4	43.56	0.36	2.16	0	46.08

2	4	f	y	3	13.68	7.2	3.6	0	24.48
2	5	m	y	2	11.52	0.72	3.6	0	15.84
2	6	f	y	3	57.6	1.44	3.6	0	62.64
2	7	f	y	2	11.16	0	0	0	11.16
2	8	m	y	6	32.76	0	3.6	0	36.36
2	9	f	y	3	14.4	0	0	0	14.40
2	10	f	y	3	9	0	0.18	0	9.18
2	11	f	y	2	43.2	1.8	7.2	0	52.20
2	13	m	y	5	90	1.44	7.2	0	98.64
2	15	f	y	3	33.12	1.08	5.4	0	39.60
2	16	f	y	4	7.56	0.72	1.8	0	10.08
2	17	f	y	3	65.52	0	3.6	0	69.12
2	18	f	y	5	12.6	7.2	3.6	0	23.40
2	19	f	y	2	31.86	0.54	9.36	0	41.76
2	20	m	y	3	72	7.2	7.2	0	86.40
2	21	f	y	2	9.9	0.54	0.9	0	11.34
2	22	f	y	4	19.8	2.16	2.16	0	24.12
2	23	f		3	34.56	0	5.4	0	39.96
2	24	m	y	3	74.88	3.6	18	0	96.48
2	25	m	n	3	11.25	0.9	3.6	0	15.75
2	26	m	y	3	11.88	1.08	2.16	0	15.12
2	27	m	y	3	37.8	7.2	3.6	0	48.60
2	28	f	y	2	32.4	0	0.18	0	32.58
2	29	f	y	2	8.64	1.44	2.16	0	12.24
2	30	f	y	2	21.6	0	1.8	0	23.40
2	31	f	y	2	18.99	0	3.6	0	22.59
2	32	f	y	2	11.7	3.6	0	0	15.30
2	33	f	y	5	27.54	1.8	1.8	0	31.14
2	34	m	y	2	51.03	1.08	6.75	0	58.86
2	35	m	y	5	36	1.8	4.5	0	42.30
2	36	f	y	2	25.56	0	2.16	0	27.72
2	37	m	y	3	10.8	1.44	1.44	0	13.68
2	38	f	y	3	10.08	0.72	4.32	0	15.12
2	39	f	y	3	17.64	0	0	0	17.64
2	40	f	n	2	56.16	0	17.28	0	73.44
2	41	f	y	2	36.9	0	0.72	0	37.62
2	42	f	y	3	8.28	0	0	0	8.28
2	43	f	y	3	25.2	0	6.12	0	31.32
2	44	m	y	1	18.72	0	0	0	18.72
2	45	f	y	3	35.28	1.44	0	0	36.72
2	46	m	y	4	75.24	6.84	3.24	0	85.32

2	47	f	y	4	25.92	0	0	0	25.92
2	48	f	y	1	5.22	0	0.9	0	6.12
2	49	f	y	3	43.2	0	1.8	0	45.00
2	50	f	y	6	117	0	0	0	117.00
2	51	f	y	3	103.5	0	0	0	103.50
2	52	f	y	3	27	0	4.5	0	31.50
2	53	f	y	1	18.9	0	0	0	18.90
2	54	f	y	2	31.5	0.36	0.9	0	32.76
2	55	m	y	2	31.5	0.36	0.63	0	32.49
2	56	m	y	4	33.66	0.18	0	0	33.84
2	57	f	y	6	10.98	0.18	0.36	0	11.52
2	58	m	y	2	41.4	0	0	0	41.40
2	59	m	y	3	12.96	0	0.36	0	13.32
2	60	m	y	2	32.4	0	3.6	0	36.00
2	61	f	y	6	26.91	0.9	0	0	27.81
2	62	f	y	3	48.15	15.12	0	0	63.27
2	63	m	y	2	5.4	0	0.36	0	5.76
2	64	f	y	3	44.46	0	1.8	0	46.26
2	65	f	y	7	36.72	0.36	0	0	37.08
2	66	f	y	5	36.72	0	0.9	0	37.62
2	67	m	y	2	18	2.52	0.72	0	21.24
2	68	f	y	3	47.25	0	18	0	65.25
2	69	m	y	5	19.26	2.16	2.16	0	23.58
2	70	m	y	2	8.28	1.8	1.08	0	11.16
2	71	f	y	2	14.4	0	0.9	0	15.30
2	72	f	n	2	9.36	0	0.54	0	9.90
2	73	f	y	4	59.04	1.08	17.28	0	77.40
2	74	f	y	2	16.56	0	1.8	0	18.36
3	1	f	y	4	13.68	0.18	0	0	13.86
3	2	m	n	2	2.16	2.16	4.32	0	8.64
3	3	m	y	2	50.4	5.4	2.16	0	57.96
3	4	f	y	3	32.4	0	6.3	0	38.70
3	5	f	y	4	5.22	0	3.15	0	8.37
3	6	m	y	2	13.68	0	2.16	0	15.84
3	7	m	y	3	13.68	0	10.8	0	24.48
3	8	f	y	2	13.86	0.72	4.41	0	18.99
3	9	m	n	2	38.88	0	17.28	0	56.16
3	10	f	y	3	16.2	0	1.8	0	18.00
3	11	f	y	3	15.48	0	2.7	0	18.18
3	12	m	n	3	13.14	0	2.16	0	15.30
3	13	f	y	3	24.66	0.18	0.72	0	25.56

3	14	f	y	2	10.8	0.72	1.08	0	12.60
3	15	m	y	3	3.6	0.72	1.08	0	5.40
3	16	f	y	3	3.6	0	0	0	3.60
3	17	f	y	2	6.48	0	0.72	0	7.20
3	18	m	y	4	22.32	0	1.08	0	23.40
3	19	f	y	1	5.76	0	0	0	5.76
3	20	f	y	3	18	0	0.72	0	18.72
3	21	f	y	3	0	0	1.08	0	1.08
3	22	f	y	2	11.88	0	3.78	0	15.66
3	23	f	y	1	1.08	0	0.18	0	1.26
3	24	m	y	3	11.52	2.16	3.6	0	17.28
3	25	f	y	3	31.32	2.16	3.6	0	37.08
3	26	f	y	1	22.68	0.18	0.72	0	23.58
3	27	f	y	1	26.1	0	0	0	26.10
3	28	m	y	4	31.5	21.6	5.4	0	58.50
3	30	m	y	4	35.28	0.72	2.16	0	38.16
3	31	m	y	4	25.92	0	0	0	25.92
3	32	m	y	1	66.24	0.36	0.54	0	67.14
3	33	f	y	5	35.1	0.54	2.16	0	37.80
3	34	f	y	5	4.32	0	0	0	4.32
3	35	m	y	4	25.92	0	1.44	0	27.36
3	36	f	n	2	6.48	0	1.08	0	7.56
3	37	m	y	3	0	0	0	0	0.00
3	38	m	y	1	56.88	0.18	2.16	0	59.22
3	39	m	n	1	28.8	0	0.18	0	28.98
3	40	f	n	2	22.68	0	0	0	22.68
3	41	f	y	4	18.36	0	0.9	0	19.26
3	42	m	y	3	18	2.16	36	0	56.16
3	43	m	y	4	6.3	1.8	0	0	8.10
3	44	m	n	2	3.6	0	6.75	0	10.35
3	45	f	n	2	33.66	0	21.6	0	55.26
3	46	f	y	3	26.64	0	1.44	0	28.08
3	47	m	y	3	53.28	0.36	0.18	0	53.82
3	48	m	y	2	5.76	0	2.7	0	8.46
3	49	m	n	3	18.99	0	0.36	0	19.35
3	50	m	y	2	5.76	0	10.8	0	16.56
3	51	f	y	6	4.68	0.36	0	0	5.04
3	52	f	y	4	6.48	3.6	1.08	0	11.16
3	53	f	y	3	3.06	0	0.18	0	3.24
3	54	m	y	4	47.7	0.72	1.44	0	49.86
3	55	m	n	3	26.1	0.36	0.72	0	27.18

3	56	m	y	4	4.68	0	1.08	0	5.76
3	57	m	y	2	8.64	0	1.08	0	9.72
3	58	m	y	5	12.6	1.8	1.44	0	15.84
3	59	f	y	6	0.54	0.81	0.36	0	1.71
3	60	f	y	3	44.28	1.8	1.8	0	47.88
3	61	f	y	5	48.96	0	0.72	0	49.68
4	1	m	y	4	74.88	0	6.48	0	81.36
4	2	f	y	4	48.96	0	6.48	0	55.44
4	3	f	y	5	8.64	0	1.08	0	9.72
4	4	f	y	2	0	0	0	0	0.00
4	5	f	y	2	11.88	0.18	0.18	0	12.24
4	6	m	y	2	38.88	0	5.4	0	44.28
4	7	f	y	4	26.1	0.18	0.18	0	26.46
4	8	f	n	2	22.68	2.7	0.72	0	26.10
4	9	f	n	3	4.14	0	0.72	0	4.86
4	10	f	y	3	0.36	0	0	0	0.36
4	12	m	y	3	13.32	0	1.08	0	14.40
4	13	f	y	2	0.18	0	0	0	0.18
4	14	f	y	2	21.24	0	0	0	21.24
4	15	m	y	2	29.16	0	0	0	29.16
4	16	f	y	3	30.24	0	0.54	0	30.78
4	17	m	y	6	5.76	0	0.72	0	6.48
4	18	f	n	3	20.52	0	0.72	0	21.24
4	19	m	y	5	71.28	3.24	1.62	0	76.14
4	20	m	y	4	17.46	0	1.08	0	18.54
4	21	m	y	3	61.56	1.08	10.08	0	72.72
4	22	m	y	2	2.52	0	0	0	2.52
4	23	f	n	1	43.2	0	1.8	0	45.00
4	24	m	y	1	0	0	0	0	0.00
4	25	m	y	1	4.68	0	0	0	4.68
4	26	m	y	1	6.66	0	0.36	0	7.02
4	27	f	y	3	21.96	0	0	0	21.96
4	28	f	y	1	0.9	0	0.18	0	1.08
4	29	m	y	1	5.76	0	0	0	5.76
4	30	f	y	2	4.32	0	0	0	4.32
4	31	f	y	2	17.82	0	1.44	0	19.26
4	32	m	y	2	2.52	0	0.36	0	2.88
4	33	f	y	4	28.08	3.6	4.32	0	36.00
4	34	f	y	3	39.96	0	2.88	0	42.84
4	35	f	y	5	193.32	0	2.88	0	196.20
4	36	f	y	2	7.2	0	1.08	0	8.28

4	37	f	n	2	20.34	1.8	1.8	0	23.94
4	38	m	y	1	2.52	0	0.72	0	3.24
4	39	f	y	3	24.12	0	1.44	0	25.56
4	40	m	y	3	18	0	1.44	0	19.44
4	41	f	y	2	4.86	0.36	2.16	0	7.38
4	42	f	n	3	24.84	0.36	8.1	0	33.30
4	43	m	y	2	15.48	0	1.08	0	16.56
4	44	m	y	4	14.4	2.16	4.32	0	20.88
4	45	f	y	1	36.72	0	0	0	36.72
4	46	f	y	2	90.54	0	0	0	90.54
4	47	f	y	2	46.62	0.72	0	0	47.34
4	48	m	y	2	44.64	0	34.56	0	79.20
4	49	m	y	2	51.84	6.48	1.62	0	59.94
4	50	m	n	2	56.88	0	0	0	56.88
4	51	f	y	2	26.64	0	1.44	0	28.08
4	52	m	y	2	7.2	0	0.72	0	7.92
4	53	f	y	2	30.24	0	0	0	30.24
4	54	f	y	3	8.28	0	1.44	0	9.72
4	55	m	y	2	0	0	0	0	0.00
4	56	m	y	3	17.64	0	2.16	0	19.80
4	57	m	y	1	11.16	0	2.16	0	13.32
4	58	m	y	4	25.2	1.08	4.32	0	30.60
4	59	f	y	2	4.32	0	0.36	0	4.68
4	60	m	y	2	9	0	0.72	0	9.72
4	61	f	y	2	7.2	0	0	0	7.20
4	62	m	y	2	28.44	0	1.62	0.54	30.60
5	1	m	n	4	81	0	0.315	0	81.32
5	2	f	n	3	12.96	0	0	0	12.96
5	3	m	y	3	18	0	0	0	18.00
5	4	f	y	3	8.235	0	0.945	0	9.18
5	5	m	y	5	81	0	0.315	0	81.32
5	6	f	y	3	30.24	2.7	2.88	0	35.82
5	7	m	y	2	47.52	0	0	0	47.52
5	8	m	y	5	59.04	0	4.5	0	63.54
5	9	m	y	5	13.41	0.9	4.32	0	18.63
5	10	f	y	2	48.6	0.72	1.8	0	51.12
5	11	f	y	2	70.2	0	0	0	70.20
5	12	f	y	2	26.1	0	10.8	0	36.90
5	13	m	y	4	74.52	0	7.2	0	81.72
5	14	f	y	2	16.74	0.54	1.44	0	18.72
5	15	f	y	2	5.4	0	1.8	0	7.20

5	16	m	y	3	43.56	1.44	8.64	0	53.64
5	17	m	y	2	11.88	0.9	4.32	0	17.10
5	18	m	y	3	6.84	1.44	25.92	0	34.20
5	19	m	y	3	56.88	0.9	1.8	0	59.58
5	20	m	y	2	21.6	0	1.8	0	23.40
5	21	f	y	2	34.56	0.72	4.32	0	39.60
5	22	f	y	2	8.28	4.32	3.24	0	15.84
5	23	f	y	5	21.6	0	7.2	0	28.80
5	24	m	y	3	5.04	0	2.16	0	7.20
5	25	f	y	2	5.04	0	2.16	0	7.20
5	28	m	y	3	28.08	3.6	0.72	0	32.40
5	29	m	y	6	21.42	1.08	4.32	0	26.82
5	30	f	y	7	10.71	0	2.16	0	12.87
5	31	f	y	2	19.8	0	2.7	0	22.50

Appendix B. Butter Clam Concentration Data (pg/g)

(Data credit: P.S. Ross)

	Sample ID	Total PCBs	Non-DL PCBs	PCDD/Fs [TEQ-2005]	DL PCBs [TEQ-2005]	PBDEs
	AH06 BC2	213.95	206.42	0.00092	0.00020	338
	AH06 BC1	221.15	214.94	0.00371	0.00024	90
	CR06 BC2	31.58	27.47	0.02101	0.00425	154
	CR06 BC1	14.34	11.91	0.02800	0.00293	453
	SN06-BC2	632.77	624.56	0.02400	0.00009	223
	SN06-BC1	230.87	227.89	0.01100	0.00025	277
	PR06 BC1	211.87	203.25	0.00021	0.00221	1072
	QS06 BC2	182.01	180.06	0.00001	0.00006	49
	QS06 BC1	128.45	126.56	0.00000	0.00006	92
Mean		207.44	202.56	0.00001	0.00114	305
SD		179.16	177.55	0.00001	0.00146	316

Appendix C. Dungeness Crab Muscle Concentration Data (pg/g)

(Data credit: P.S. Ross)

Sample ID	Total PCBs	Non-DL PCBs	PCDD/Fs [TEQ-2005]	DL PCBs [TEQ-2005]	PBDEs
AH06 DC M1	519	466	0.00000	0.00163	287
AH06 DC M2	879	830	0.00000	0.00151	39
CR06DC-M1	3539	3232	0.40820	0.00933	727
CR06DC-M2	3864	3382	1.44648	0.01702	477
SN06DC-M1	3974	3596	0.57738	0.01151	1616
SN06DC-M2	5534	5059	0.43989	0.05225	648
PR06 DC Ma	445	394	0.00101	0.00174	20
PR06 DC Mb	558	489	0.00120	0.00218	431
QS06 DC M1	1014	912	0.01100	0.00313	280
QS06 DC M2	480	428	0.00000	0.00157	6
Mean	2080	1879	0.28852	0.01019	453
SD	1926	1746	0.50188	0.01573	481

Appendix D. Harbour Seal Concentration Data (pg/g)

(Data credit: P.S. Ross)

Sample ID	Total PCBs (ww)	Non-DL PCBs (ww)	PCDD/F (ww [TEQ-2005])	DL PCB (ww [TEQ-2005])	PBDEs (ww)	
PV06-013	1145884	1063034	10.0	3.0	528176	
PV06-014	1221478	1162852	18.2	2.3	446734	
PV06-015	846405	812760	0.6	1.4	269014	
PV06-016	1687773	1610053	0	3.0	557573	
PV06-017	357415	320391	6.8	1.6	151119	
PV06-018	1085629	1026025	3.0	2.3	502436	
PV06-023	551867	510914	11.0	2.1	166421	
PV06-024	627451	591099	0	1.3	151280	
PV06-025	859801	806126	0	1.9	218998	
PV06-026	2174921	2053910	0	4.3	504424	
PV06-027	680455	631592	3.7	1.7	182138	
PV06-001	808766	761486	0	1.9	196623	
PV06-002	199226	186531	1.6	0.5	120970	
PV06-003	393504	367421	0.03	1.0	98382	
PV06-004	385015	362422	0.7	0.8	115423	
PV06-005	16957	15627	0	0.2	13033	
PV06-006	619800	592121	0	1.0	123753	
Mean		803668	757315	0.3	0.9	255676
SD		542478	515395	0.7	0.6	177433

Appendix E. Sockeye Salmon Concentration Data (pg/g)

(Data credit: P.S. Ross)

Sample ID	Total PCBs	Non-DL PCBs	PCDD/Fs [TEQ-2005]	DL PCBs [TEQ-2005]	PBDEs
Sock06-07	4495	4197	0.041	0.038	117
Sock06-08	3701	3461	0.038	0.045	83
Sock06-09	14200	13063	0.293	0.420	303
Sock06-10	11785	10857	0.261	0.237	296
Sock06-11	5346	4977	0.049	0.048	37
Sock06-12 - Male	6594	6136	0.061	0.081	96
Sock06-01	10986	10136	0.169	0.370	135
Sock06-02	4175	3916	0.035	0.068	29
Sock06-03	5554	5138	0.030	0.162	57
Sock06-04	4028	3792	0.035	0.046	34
Sock06-05	7544	6956	0.108	0.143	55
Sock06-06 - Male	3284	3050	0.017	0.031	80
Sock06-28 - Male	5507	5135	0.065	0.062	954
Sock06-29 - Male	3020	2805	0.011	0.013	53
Sock06-30 - Male	7341	6775	0.077	0.109	83
Sock06-25 - Female	10179	9366	0.206	0.264	176
Sock06-26 - Female	3157	2991	0.016	0.017	281
Sock06-27 - Male	12821	11783	0.241	0.300	297
Sock06-13	8132	7504	0.098	0.216	144
Sock06-14	5071	4694	0.051	0.112	41
Sock06-15	5051	4755	0.026	0.082	138
Sock06-16	8848	8169	0.039	0.191	94
Sock06-17	6072	5630	0.026	0.144	66
Sock06-18 - Male	4829	4479	0.020	0.079	106
Sock06-19	7985	7308	0.033	0.235	131
Sock06-20	5136	4730	0.049	0.670	48
Sock06-21	3756	3502	0.017	0.061	71
Sock06-22 - Male	6098	5629	0.077	0.113	372
Sock06-23 - Female	3729	3461	0.017	0.051	200
Sock06-24avg	3796	3518	0.042	0.059	104
Mean	6407	5930	0.075	0.149	156

SD	3021	2761	0.084	0.144	177