Preliminary Assessment of Contaminant Exposure Risk to Developing Cultus Lake Sockeye Embryos

Summary report *Prepared for:*

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ABSTRACT

Anadromous Pacific sockeye salmon (*Oncorhynchus nerka*) are an important fish species of Canada's west coast. Cultus Lake sockeye have recently been designated as an endangered species by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). This study reports on concentrations of several environmental contaminants of concern in water and sediments collected from locations on Cultus Lake, representing spawning habitat of this endangered sockeye population. In addition, samples of water and sediments were collected from a nearby reference lake, Chilliwack Lake. The chemicals investigated include Hg and other trace elements, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polycyclic aromatic hydrocarbons (PAHs), polybrominated diphenyl ethers (PBDEs), pesticides and pharmaceuticals and personal care products (PPCPs).

The results show that contaminant concentrations in water and sediments from Cultus Lake were generally comparable, or in some cases lower than concentrations of those contaminants in nearby Chilliwack Lake, as well as other British Columbia freshwater systems. However, some site specific concentration differences were observed. For example, Spring Bay and Mallard sampling sites (on Cultus Lake) and Chilliwack 2 (on Chilliwack Lake) consistently exhibited the highest concentrations of organic contaminants such as PCDD/Fs, PCBs, PAHs and PBDEs and organochlorine pesticides. These reflect differences in organic carbon content, historical anthropogenic loadings, proximity to local source inputs and/or topography/drainage. An evaluation of observed sediment concentrations showed that, in a number of samples, concentrations of ∑PCDD/F TEQs, nine metals (Cr, Ni, Fe, Ba, Cd, Mn, Se, Cu and Zn) and several PAHs (acenaphthene, fluorene and low molecular weight PAHs) exceeded sediment quality guidelines (SQGs) used by the British Columbia Ministry of Environment (BC-MOE) for the protection of aquatic life. Concentrations of several other metals (Hg, Ag, Al, Pb) and the PAH, 2-Methylnaphthalene, which were slightly below SQGs, exhibited upper 95 % confidence limits (CLs) that exceeded corresponding guidelines. Current levels of Cr, Ni and Fe in Cultus Lake sediments are particularly alarming. Cr, Ni and Fe levels in Cultus Lake sediments exceeded severe effects levels (SELs) previously established for those metals. For example, ambient Cr concentrations in Cultus Lake sediment (range = 33.6-303 μg/g dry wt) exceeded the SEL for Cr (110 μg/g dry wt).

Similarly, levels of Ni (range = 24.2-133 μg/g dry wt) and Fe (range = 23,000-52,900 μg/g dry wt) in Cultus Lake sediments exceeded SELs established for those metals. No evaluation of observed PBDE levels in Cultus Lake sediments was possible due to the unavailability of SQGs of those brominated flame retardants. Also, SQGs of many current-use pesticides (CUPs) and pharmaceuticals and personal care products (PPCPs), which were below detection limits in Cultus Lake sediments, have also not yet been established by regulatory agencies. Furthermore, predicting biological effects of a given contaminant based on laboratory derived SQGs or SELs for a given contaminant is difficult due to variability in environmental and biological factors, including lake pH, sediment characteristics, species sensitivity, lifestage sensitivity and toxicological endpoints. In particular, laboratory derived SQGs and SELs may not necessarily include all toxicological endpoints and may underestimate effects in relatively more sensitive species such as salmon. The consequences of relatively high ambient levels of Cr, Ni and Fe and several other identified chemicals of concern on developing Cultus Lake sockeye embryos are not clear from results of the present study. Further investigation into the toxicological effects of those and other contaminants of concern on developing Pacific sockeye embryos is warranted and should include laboratory-based assays using field collected spawning substrate, as well as studies investigating the effects of complex contaminant mixtures on fish health and reproduction.

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1. Introduction

Anadromous Pacific sockeye salmon (*Oncorhynchus nerka*) are important components of both marine and freshwater ecosystems on Canada's west coast. British Columbia's Fraser River, flowing over 1,400 km through agricultural, industrial and urbanized lands, is a major migration route and spawning grounds for several Pacific sockeye stocks. After hatching, juvenile sockeye tend to remain in fresh water for 1 to 2 years before a 2-3 year open-ocean feeding migration. During spring/summer adults return to their natal streams to spawn. This upstream migration can span several hundred kilometers (Groot and Margolis, 1991; Ewald et al., 1998). For example, Cultus Lake sockeye travel approximately 112 km upstream from the Strait of Georgia (SoG) to their spawning grounds (Cultus Lake).

In recent years there have been concerns regarding the health of several Fraser River sockeye stocks. For example, the Cultus Lake sockeye is designated as endangered by COSEWIC. Also, Weaver Creek sockeye (a late-run timing group) returning to the Fraser River have exhibited abnormal migration behaviour, elevated in-river mortality and reduced spawning success (Pacific Salmon Commission, 2001).

The Cultus Lake sockeye recovery plan identifies contaminant exposure of Cultus Lake sockeye in the freshwater environment (Cultus Lake) as one potential threat to population recovery. Contaminants that represent an exposure risk to this population include mercury (Hg) and other trace metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzo furans (PCDFs), polybrominated diphenyl ethers (PBDEs) and pharmaceuticals & personal care products (PPCPs).

Potential sources of PAHs include combustion, petroleum spills, industrial and waste-water effluents, urban runoff. In particular, heavy boating activity on Cultus Lake may be an important source of PAHs to this freshwater system. Other organic contaminants such as pesticides, PCBs, PCDD/Fs, PBDE flame retardants and PPCPs may be deposited atmospherically through long range transport and/or discharged via septic fields, wastewater or runoff. Hg and other, trace elements in the environment can originate from both anthropogenic sources such as mining and combustion of fossil fuels as well as natural sources such as bedrock, volcanoes, forest fires (Nriagu, 1988). Elements are generally classified as being non-essential (e.g., Pb, Hg, Cd, Ni, As) or essential/beneficial (Mg, Mn, Cu, Zn, Se, Co). Potential toxic effects of these various environmental contaminants in fish include impacts on olfactory function and migration behaviour (Moore and Waring, 1996) and reproductive success (Guiney et al., 1979; Zitko and Saunders, 1979; Niimi, 1983; Walker and Peterson, 1991; Miller, 1993; Giesy et al., 2002;Jobling et al., 1998;), immunotoxicity (Arkoosh et al., 2001;Arkoosh and Collier, 2002) and abnormal development (Colborn, 2002;Jakka et al., 2007;Lema et al., 2007).

This study investigates the occurrence, levels and toxicological implications of key environmental contaminants in water and sediments from Cultus Lake sockeye spawning grounds and a nearby reference Lake (Chilliwack Lake). These environmental compartments represent the two primary exposure routes for developing Cultus Lake Sockeye embryos and alevins. Contaminants investigated include Hg and other trace elements, PAH's, PCDD/Fs, PCBs, PBDEs, PPCPs, and several legacy pesticides (e.g.

DDTs, chlordane and mirex) as well as current use pesticides (CUPs) such as atrazine and chlorpyriphos.

2. Study Objectives

Cultus Lake sockeye are currently designated as endangered by the Committee on the Status of Endangered Wildlife (COSEWIC) in Canada. The COSEWIC status report for Cultus sockeye salmon identified degradation of the groundwater water quality from human sources as a potential threat to recovery. In the Draft Recovery Plan for Cultus Lake sockeye salmon, pollution is identified as an unknown threat to the egg and alevin stages. The primary objectives of the study are to:

- determine concentrations of several key environmental contaminants of concern at known spawning locations of Cultus Lake sockeye.

- assess contaminant related risks to the health of Cultus Lake sockeye eggs and alevins.

2.1. Investigative Team members

This project was funded by Southern Boundary Restoration & Enhancement Fund of the Pacific Salmon Commission, grant SF-2007-H-18. Investigative team members were:

Christine Tovey – Project Support Biologist, DFO - Cultus Lake Lab (formerly)
Mike Bradford – Research Scientist, quantitative ecologist, DFO - SFU.
Jeremy Hume – Research Biologist, DFO - Cultus Lake Lab.
Peter S. Ross – Research Scientist, ecotoxicologist, DFO - IOS.
Lyse Godbout – Research Biologist, DFO PBS.
Jules Blais – Associate Professor, University of Ottawa.
Sue Grant – Assessment Biologist, DFO - Fraser River / BC Interior Area.
Neil Dangerfield – Technician, Marine Environment Quality, DFO - IOS
Cathy McPherson – Golder Associates Ltd. - Laboratory Manager – Field collection, water properties and sample shipment.
Kalai Pillay – Axys Analytical - Lab manager, Current Use Pesticides, pharmaceuticals, PAH analyses.
Brooks Rand – Contract Lab, Seattle, Washington – metals analyses.

3. Methods

3.1. Sampling

Samples were collected by Golder Associates Ltd. on November 7 to 9, 2007. Water temperature, pH, turbidity and dissolved oxygen were measured on site. Water samples were collected from the water column at two spawning locations on Cultus (Spring Bay and Lindell Beach) and two spawning locations on Chilliwack Lake (Chilliwack 1 and 2). Sediment samples were collected from four spawning locations on Cultus Lake (Lindell

Beach A and B, Spring Bay, Mallard Bay/Army Camp) and from the two spawning locations on Chilliwack Lake (Chilliwack 1 and 2). Maps of sampling locations on Cultus and Chilliwack Lakes are shown in Appendix I and II, respectively. Each sediment sample was a composite of three ponar grabs of the upper surface layer (5-10 cm). Sediment samples were homogenized, stored in appropriate laboratory containers and subsequently shipped for processing and analysis.

3.2. Contaminant Analysis

Water and sediment samples were analyzed for concentrations of mercury (Hg) and 22 other trace elements (Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Sb, Se, Ti, V, Zn) at Brooks-Rand laboratories, Seattle, WA. Chemical analysis of total mercury (Hg) and other trace elements was conducted using inductive coupled plasma mass spectrometry (ICP-MS), following standard methods (U.S. Environmental Protection Agency Method 6031), (USEPA, 1986). Sediment samples were analyzed for multi-residue pesticides, PPCPs and PAHs at AXYS analytical laboratories in Sidney, BC. Extraction, cleanup and quantification of PPCPs, pesticides and PAHs were conducted using standard operating procedures at AXYS analytical. Sediment samples were also analyzed for polychlorinated dibezno-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ether flame retardants (PBDEs) at the DFO trace contaminants laboratory at the Institute of Ocean Sciences (IOS) in Sidney, BC. Analytical methods for the analysis of PCBs, PCDD/Fs and PBDEs at the IOS laboratory are presented elsewhere (Ikonomou et al., 2001, Ikonomou et al., 2002). Concentrations of 2,3,7,8 TCDD toxic equivalents (TEQs) were also reported for various PCDD/Fs and dioxin like PCBs using World Health Organization toxic equivalency factors (WHO-TEFs) developed for assessing dioxin like effects on fish health (Van den Berg et al., 1998). TEQs for individual congeners were determined by multiplying their measured concentrations by the corresponding WHO-TEF (See Appendix III). ΣPCDD-TEQs, ΣPCDF-TEQs, ΣPCB-TEQs and an overall TEQ (ΣTEQ) were determined from the sums of the various contaminant class TEQs.

3.3. Data Analysis

Compiled contaminant concentrations in water samples were reported in units of μg/L, while concentrations in sediments were reported on a dry weight basis (i.e., either μg/g, ng/g or pg/g dry wt). Contaminant concentrations were evaluated and compared to current environmental quality standards derived by domestic regulatory agencies, including the British Columbia Ministry of Environment (BC-MOE), Canadian Council of Ministers of the Environment (CCME) and the Ontario Ministry of Environment (OMOE, 1987; Nagpal et al., 1998; CCME, 1999) as well as other regulatory standards such as the United States Environmental Protection Agency (USEPA) and New York State Department of Environmental Conservation (NYSDEC), (NYSDEC, 1994; USEPA, 1997). The results from Cultus Lake were also compared to a reference system (i.e,, Chilliwack Lake). Chilliwack Lake has a persistent lake shore sockeye spawning population and limited anthropogenic disturbances (e.g. residential and commercial development, boating, etc.) relative to Cultus Lake.

4. Results and Discussion

Field collections of water and surface sediments from Cultus and Chilliwack Lake sampling sites were obtained successfully. All water samples have been analyzed for Hg and trace element concentrations. All sediment samples have been analyzed for Hg and trace elements as well as PCBs, PCDD/Fs, PBDEs, PAHs, PPCPs and pesticides. The following sections detail observed levels and toxicological implications of those environmental contaminants in Cultus Lake sockeye spawning habitat.

4.1. Mercury and Other Trace Elements

Measured concentrations of mercury and 22 other trace elements in water and sediments from Cultus and Chilliwack Lake sampling sites are shown in Appendix IV and IV, respectively. Levels of Hg in water ranged from 460-1,140 pg/L. Compared to Hg, concentrations of other key metals of concern (As, Cd, Pb) in water were relatively low and ranged between 0.005 and 2.39 pg/L. Concentrations of Hg in sediment samples ranged from 0.017-0.144 μg/g dry wt. Arsenic concentrations in sediments ranged between 2.92 and 23.3 μg/g dry wt. Concentrations of other key metals (Cd, Pb, Cu) ranged between 0.17 and 18.4 μg/g dry wt.

The pattern of metals in water was dominated by Hg at all sites (Figure 1A). Conversely, concentrations of Fe, Al and Ti dominated in sediments at all sites (Figure 1B). Figure 1 reveals that while the pattern of metal contamination was generally comparable between the various sampling locations, concentrations can vary substantially between sites. For example, Hg concentration in water at Spring Bay (1,140 pg/L) was approximately 3 times higher than Hg water concentrations on Chilliwack 1 site (460 pg/L). No clear differences in sediment or water metal concentrations are apparent between Cultus and Chilliwack Lakes.

Figure 2 shows concentrations of Hg and other trace metals in Cultus and Chilliwack Lakes are comparable to previous reported Hg levels reported in sediments from six British Columbia Lakes (Kamloops, Harrison, and Moose Lakes) during the 1990s (Macdonald, 2000; Macdonald et al., 2000; Gallagher et al., 2003). For example, observed concentrations (μg/g dry wt) of Hg (range: 0.017-0.144), As (range: 2.92-6.39), Cd (range: 0.177-1.22) and Pb (range: 4.55-17.5) in Cultus Lake sediments are comparable to those levels observed in sediments sampled from nearby Chilliwack Lake and previously reported levels reported in other BC lakes (Figure 2). However, in some cases Cultus Lake sediments exhibited relatively high levels of Cr, Cd and Ni, compared to levels of those metals in other BC lakes (Figure 2).

Figure 1. Concentrations of metals in water (A) and sediments (B) at various sampling locations on Cultus and Chilliwack Lakes. Water concentrations are reported as pg/L and sediments as µg/g dry wt.

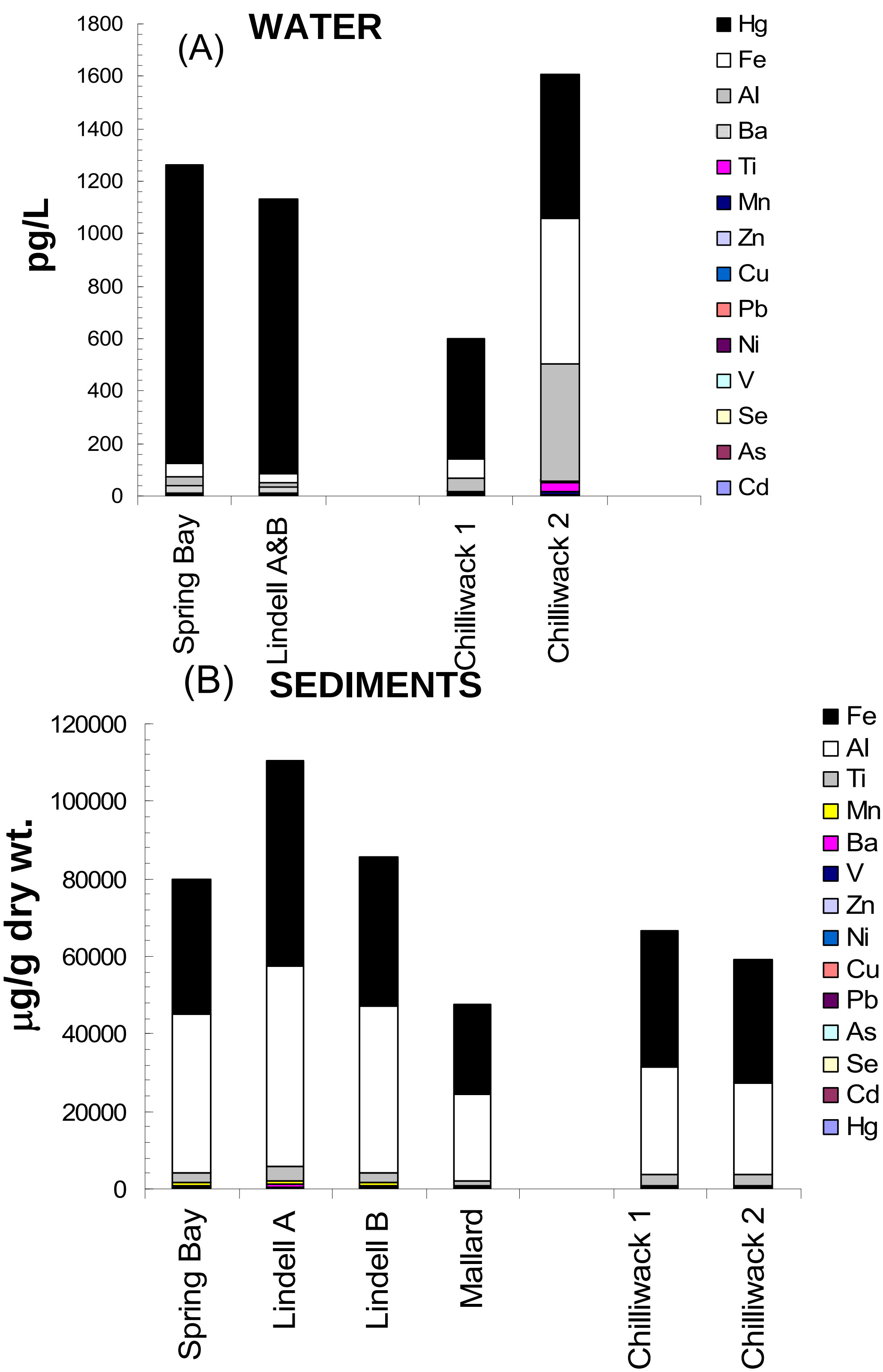
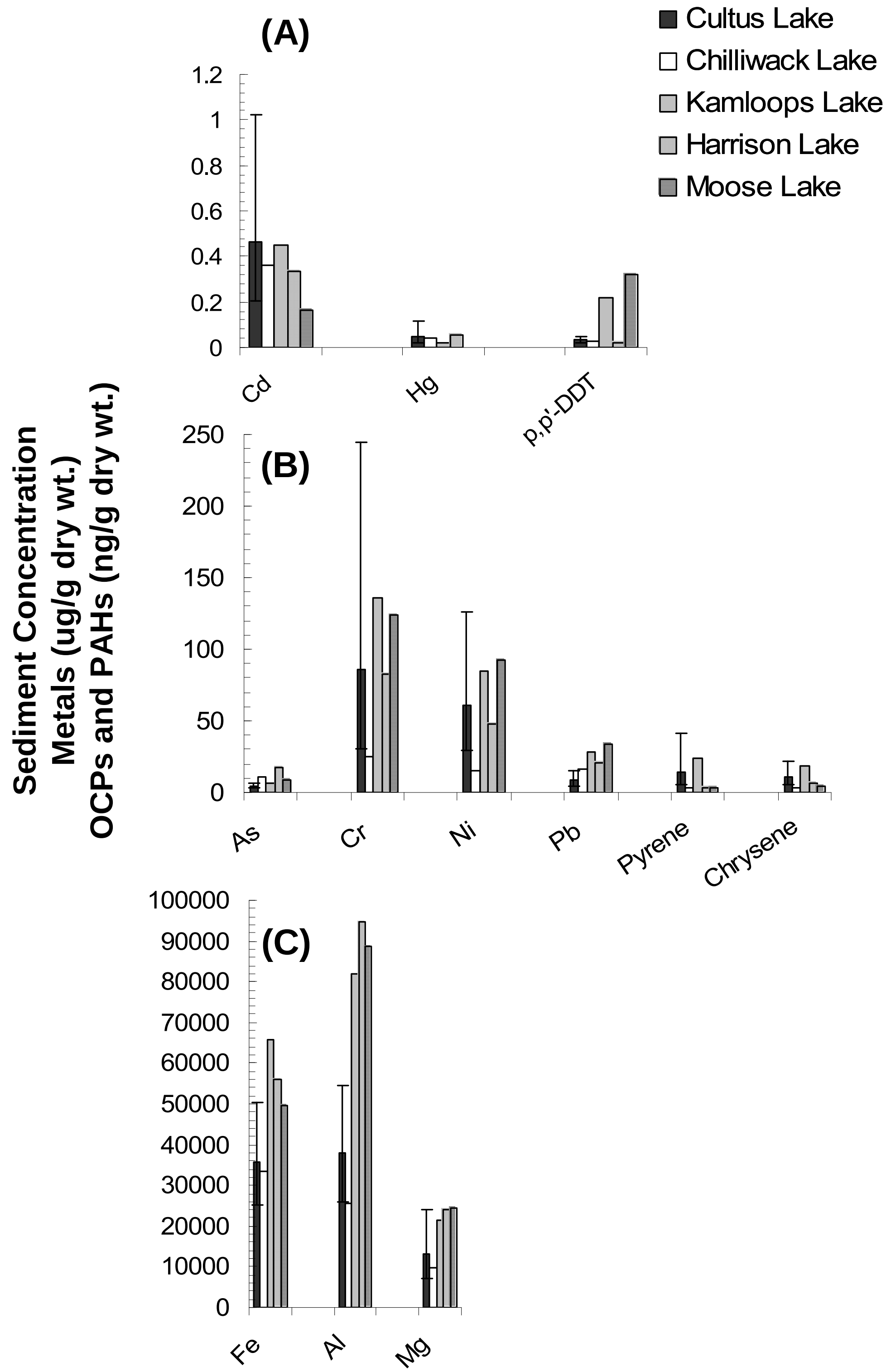


Figure 2. Concentrations of several metals and organic contaminants in Cultus and Chilliwack Lake sediments compared to concentrations previously reported in Harrison Lake, Kamloops Lake and Moose Lake in British Columbia (Macdonald, 2000; Macdonald et al., 2000; Gallagher et al., 2003). Plot A shows concentrations for Cd, Hg and p,p, DDT. Plot B shows concentrations of As, Cr, Ni, Pb, Pyrene and Chrysene. Plot C shows concentrations of Fe, Al and Mg. Metals are reported as μg/g dry wt. PAHs and DDT are reported as ng/g dry wt. Error bars represent range of 1 standard deviation of the calculated geometric mean of Cultus Lake sites.



4.2. PCBs and Dioxins

Measured concentrations of PCBs, PCDDs, PCDFs and 2,3,7,8 TCDD toxic equivalents (TEQs) are shown in Appendix VI. ∑PCB concentrations observed in Cultus Lake sediments ranged from 0.64 to 3.72 ng/g dry wt. Mean concentrations of dioxin-like PCBs (DL-PCBs) in Cultus Lake sediments ranged from 0.29 pg/g dry wt for PCB-169 to 44.4 pg/g dry wt for PCB-118.

Tetra- to hexachloro- PCBs were the dominant PCB congeners in Cultus and Chilliwack Lake sediments (Figure 3). The dominant PCB congeners included mainly di-ortho congeners such as PCB-28, PCB-52, PCB-138, PCB-153 and PCB 180 (Figure 4). While the PCB patterns were comparable at the various sampling locations, PCB concentrations varied substantially between sites. For example, ∑PCBs in sediments at Spring Bay (3.72 ng/g dry wt) were approximately 6 times higher than ∑PCBs at Lindell A (0.64 ng/g dry wt) on Cultus Lake. Similarly, concentrations at Chilliwack 2 (1.82 ng/g dry wt) were approximately 2 times higher than Chilliwack 1 (0.76 ng/g dry wt) at Chilliwack Lake. No clear differences between Cultus and Chilliwack Lake PCB levels or patterns are apparent.

Figure 3. Concentrations of PCB homologues (Di-Deca PCBs) in sediments (ng/g dry wt) from Cultus and Chilliwack Lakes.

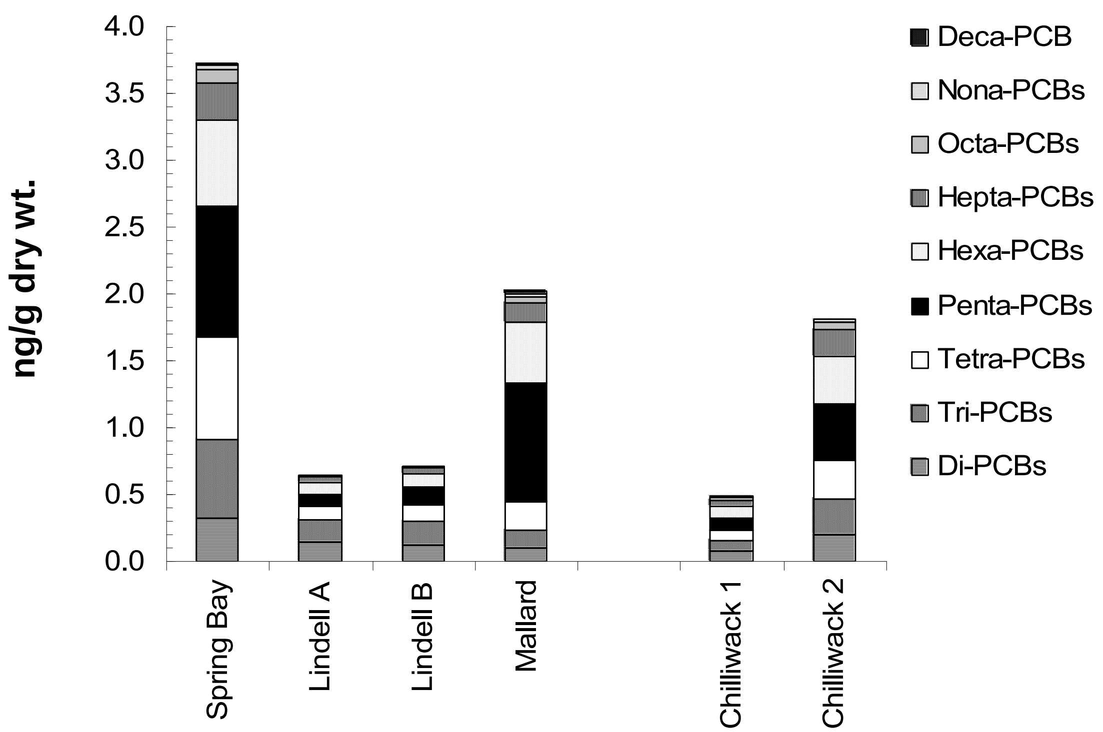


Figure 4. PCB congener concentrations in sediment samples (pg/g dry wt) from (A) Spring Bay on Cultus Lake and (B) Chilliwack 2 on Chilliwack Lake.

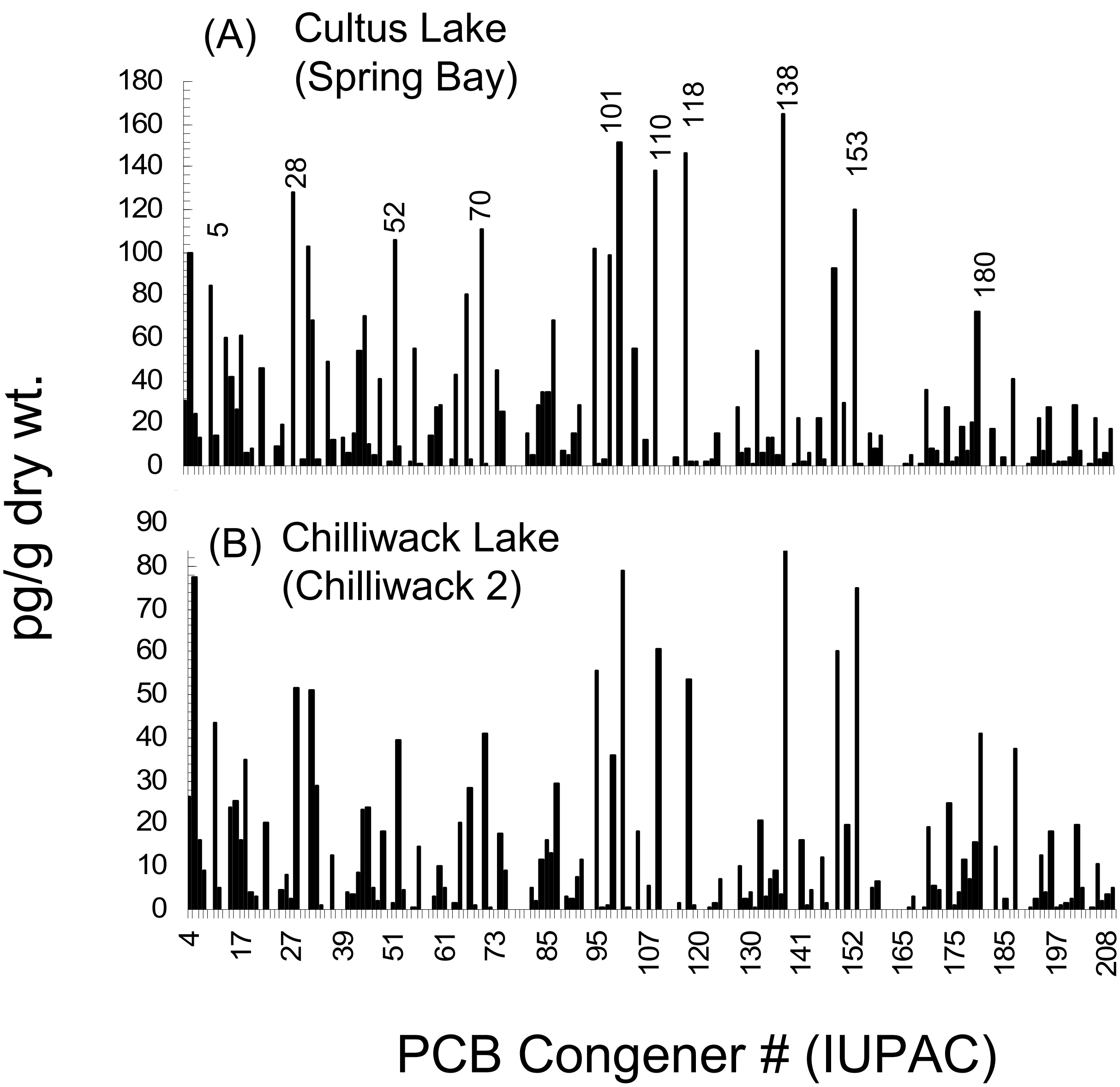


Figure 5 shows TEQ concentrations of several DL-PCBs. PCB TEQ concentration differences among sites were similar to those observed for ∑PCBs (i.e., highest concentrations were at Spring Bay and Chilliwack 2 sites). The DL-PCBs that most contributed to the overall PCB TEQs in sediment samples were PCB-169 and PCB-77.

∑PCDD concentrations (range: 5.6 – 278 pg/g dry wt) and ∑PCDF concentrations (range: 1.1-61.1 pg/g dry wt) in Cultus Lake sediment samples were several orders of magnitude below observed ∑PCB levels (Appendix VI). PCDDs and PCDFs were highest at Spring Bay, followed by Mallard and Chilliwack 2 sites. Figure 6 shows that OCDD and HpCDDs were the dominant PCDD compounds, while tetra-to octa- PCDFs each contributed equally approximately 20% of the total PCDF concentration. In terms of 2,3,7,8 TCDD toxic equivalents, PCDD TEQs were dominated by the presence of 1,2,3,7,8 PeCDD and 1,2,3,4,7,8 HxCDD, while PCDF TEQs were mainly comprised of 2,3,7,8 TeCDF, 2,3,4,7,8 PeCDF and 1,2,3,4,7,8 HxCDF (Figure 7).

Total 2,3,7,8 TCDD toxic equivalents (∑TEQs) ranged from 0.007 to 1.68 pg/g dry wt in Cultus Lake sediment samples. Similar to observations of PCB TEQs, PCDD and PCDF TEQs were highest at Spring Bay and Chilliwack 2 sites. Despite the fact that PCB concentrations in sediments were generally higher than PCDD/F concentrations, PCDD and PCDF TEQs were substantially higher than PCB TEQs and comprised the majority (> 90%) of the overall TEQ at all sites (Figure 8).

PCB concentrations observed in Cultus Lake sediments were comparable to Chilliwack Lake and previously reported concentrations in freshwater sediments. For example, ∑PCB concentrations in Cultus Lake sediments (mean = 1.36 ng/g dry wt, 95% CL = 0.29-6.35) are similar to ∑PCB levels (sum of 127 congeners) observed in sediments from Pacific salmon spawning Lakes in British Columbia and Alaska (Krummel et al., 2005). PCDD and PCDF TEQ concentrations observed in sediments from Cultus and Chilliwack Lakes are relatively low (50- 300 times lower) compared to PCDD/F TEQs in sediments from sites in the lower Great Lakes (Marvin et al., 2002).

Figure 5. Concentrations of dioxin-like PCBs in sediments (pg/g TEQ dry wt) from Cultus and Chilliwack Lakes.

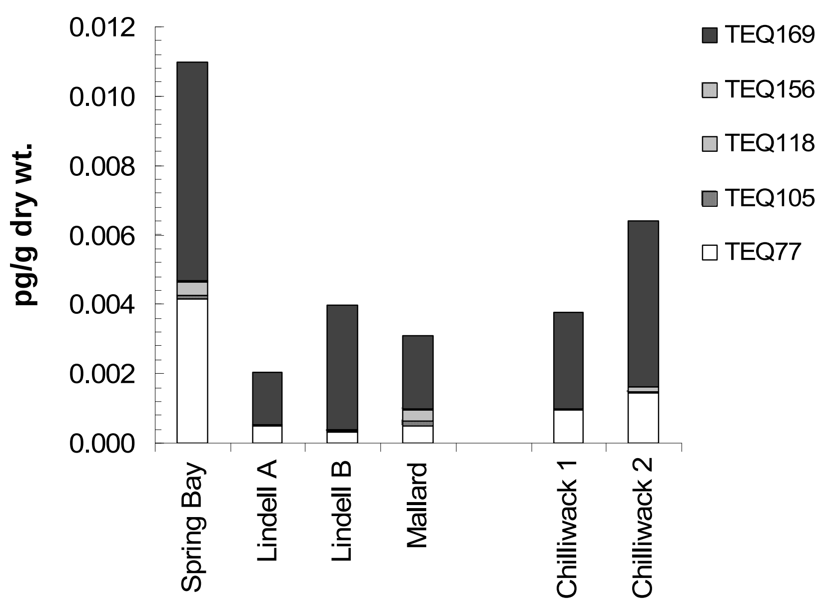


Figure 6. Concentrations of PCDD and PCDF homologues in Cultus Lake and Chilliwack Lake sediments.

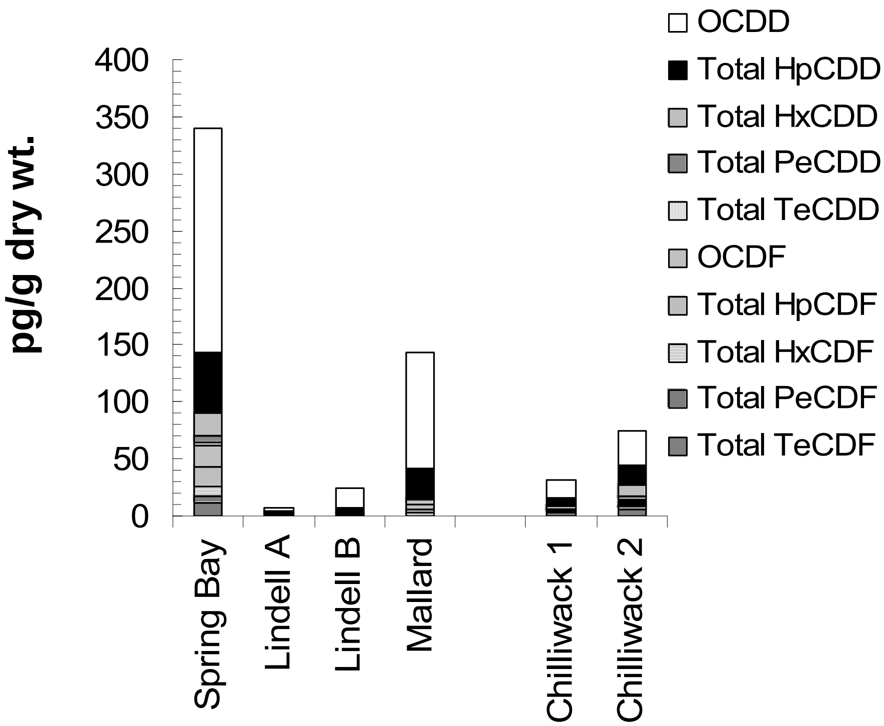


Figure 7. Concentration of individual PCDD and PCDF TEQs (pg/g dry wt) in Cultus and Chilliwack Lake sediments.

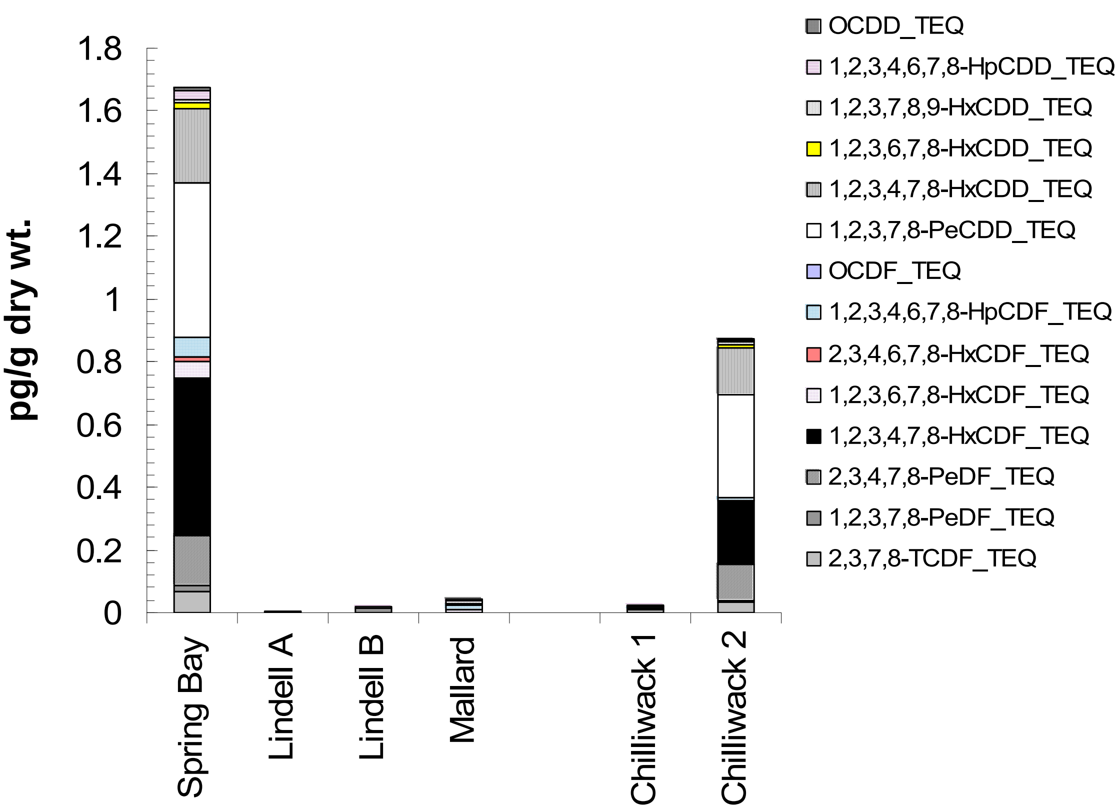
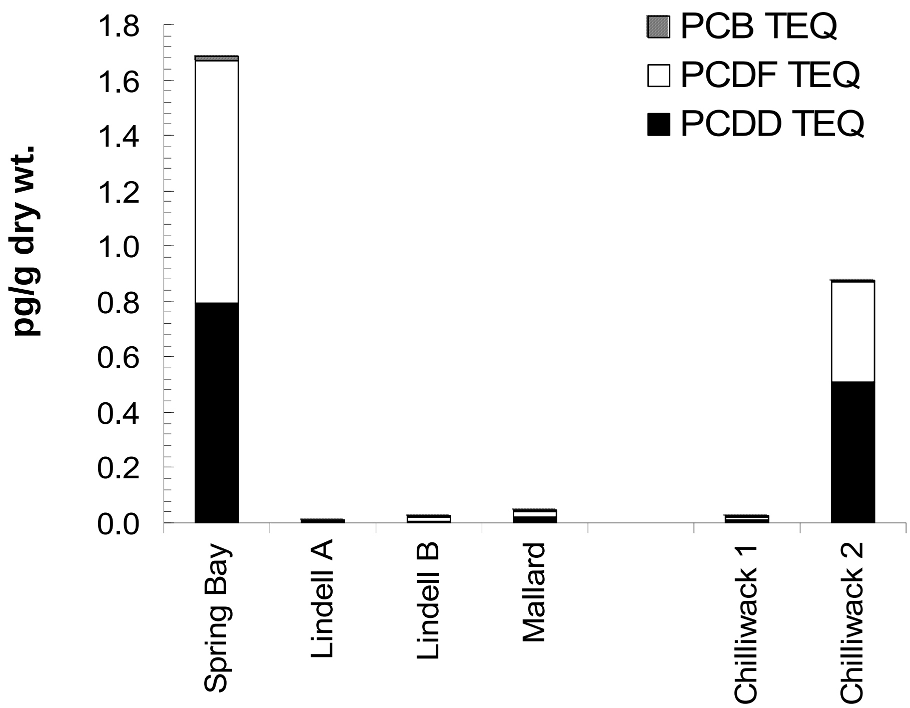


Figure 8. ∑PCB TEQs, ∑PCDD TEQs and ∑PCDF TEQs (pg/g dry wt.) in Cultus and Chilliwack Lake sediments.



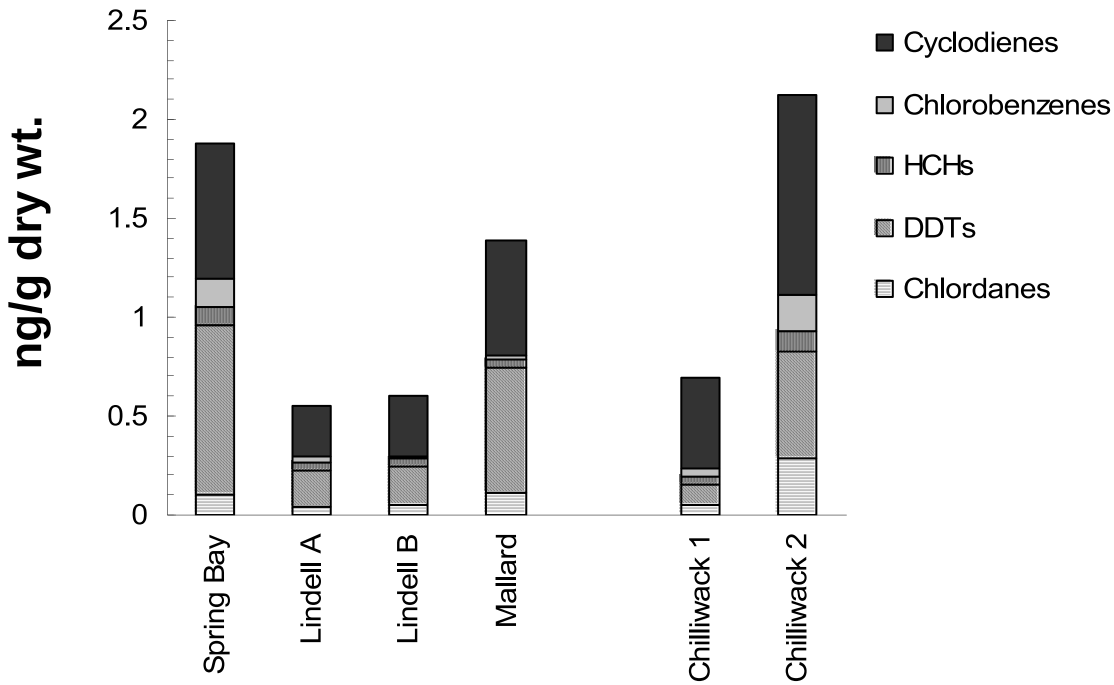
4.3. Pesticides and Pharmaceuticals & Personal Care Products (PPCPs)

Pesticide concentrations in sediments from Cultus Lake and Chilliwack Lake are summarized in Appendix VII. Pesticides detected in sediments consisted mainly of organochlorine compounds such as chlorobenzenes, cyclodienes (endosulfan, mirex, dieldrin), hexachlorocyclohexanes (HCHs), DDTs and Chlordanes. Concentrations of individual pesticides ranged from approximately 0.01 to 0.5 ng/g dry wt (Appendix VII). None of the 71 pharmaceuticals and personal care products (PPCPs) analyzed as part of this study (Appendix VIII) were detected in Cultus Lake or Chilliwack sediments. Method detection limits for PPCPs in sediments are shown in Appendix VIII.

Figure 9 illustrates that cyclodienes and DDTs were the predominant pesticides in Cultus Lake and Chilliwack Lake sediments, generally contributing > 80% of the total pesticide burden. While the pesticide pattern was comparable among sampling locations, concentrations varied substantially between sites (Figure 9). For example, the mean ∑cyclodiene concentration at Chilliwack 2 site (1.01 ng/g dry wt) was approximately 3 times higher than mean ∑cyclodienes in sediments at Lindell A (0.26ng/g dry wt). No clear difference in pesticide concentrations between Cultus and Chilliwack Lakes sites is evident from these data.

Harris et al., 2008) recently presented measured concentrations of legacy and current-use pesticides in sediments from salmon bearing tributaries (Musqueam and Nathan Creek) of the Fraser River. Concentrations of legacy organochlorine pesticides such as hexachlorobenzene, mirex and endosulfans and endrin in sediments reported by Harris et al. are comparable to levels observed in Cultus Lake sediments. Conversely, concentrations of Chlordanes in Cultus Lake sediments were substantially lower than concentrations reported by Harris et al. (2008). For example, *trans*-chlordane levels in Cultus Lake sediments (mean = 0.018, CL = 0.006-0.056 ng/g dry wt) were 20 and 200 times lower than *trans*-chlordane levels at Nathan Creek and Musqueam Creek, respectively. Similarly, levels of *p,p'* DDT in Cultus Lake sediments ranged between 0.024-0.051 ng/g dry wt, which is approximately 10 times lower than *p,p'* DDT levels previously reported in sediments from Kamloops and Moose Lakes (Figure 2).

Figure 9. Concentrations (ng/g dry wt) of different classes of pesticides in Cultus Lake and Chilliwack lake sampling locations.



4.4. Polycyclic aromatic hydrocarbons (PAHs)

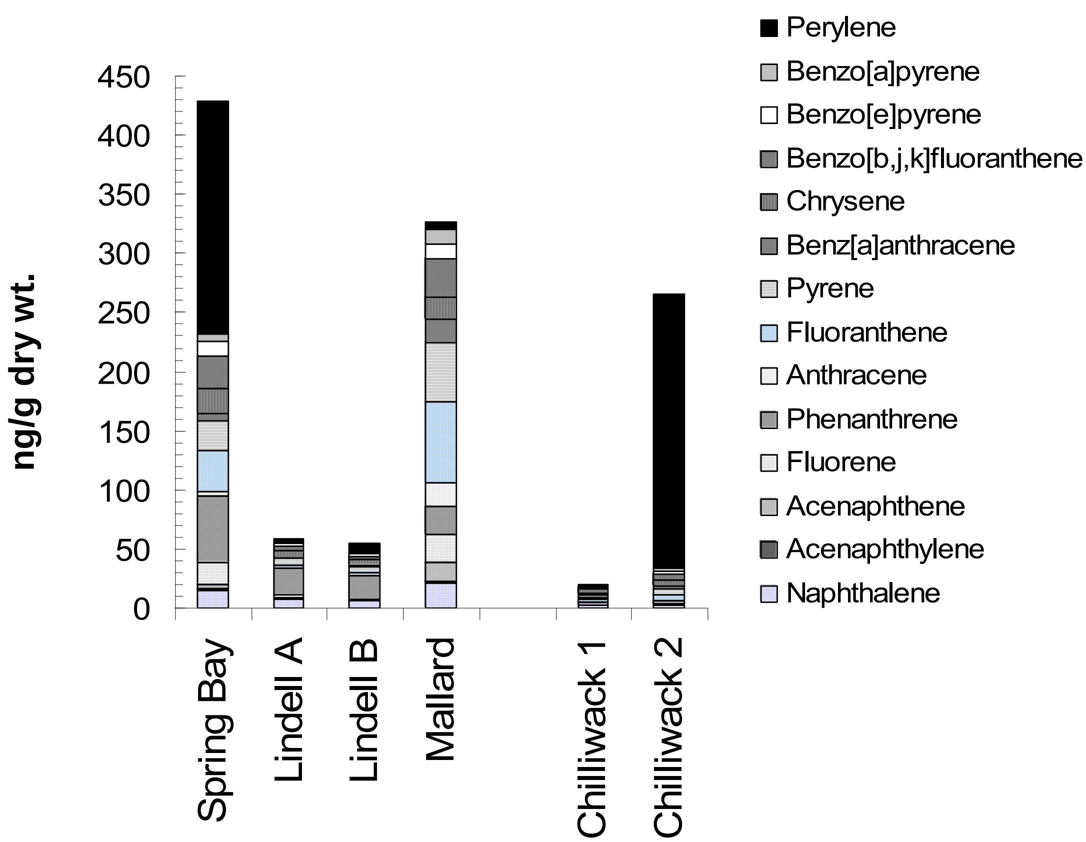
Concentrations of PAHs in sediments from Cultus Lake and Chilliwack Lake are shown in Appendix IX. PAHs are commonly classified low molecular weight PAHs (LPAH) or high molecular weight PAHs (HPAH). Differences in the structure and size of individual PAHs result in substantial variability in the physicochemical properties and hence environmental fate and partitioning of these substances. LPAH concentrations in Cultus Lake and Chilliwack Lake sediments ranged from 6.01 to 117 ng/g dry wt, while HPAH concentrations ranged from 10.0-172 ng/g dry wt.

PAH concentrations and patterns differed substantially between sampling sites (Figure 10). For example, the concentration of perylene at Spring Bay (196 ng/g dry wt) and Chilliwack 2 (232 ng/g dry wt) were orders of magnitude higher than those concentrations in sediments from other sites. Similarly, fluoranthene concentrations varied substantially from a low of 2.26 ng/g dry wt at Chilliwack 1to 34.8 ng/g dry wt at Spring Bay and 68.9 ng/g dry wt at Mallard. No clear PAH concentration differences between Cultus Lake and Chilliwack Lake was apparent.

PAH concentrations in Cultus Lake sediments are comparable to PAH levels observed in sediments from other BC Lakes (Macdonald, 2000; Macdonald et al., 2000; Gallagher et al., 2003). For example, mean concentrations of pyrene (mean = 14.3, CL = 2.44-83.9) and chrysene (mean = 10.4, CL =2.49-43.1) in Cultus Lake sediments is similar to concentrations of those compounds observed in nearby Chilliwack Lake, as well as previously reported concentrations in Harrison, Kamloops and Moose Lakes (Figure 2).

PAHs can also be classified as petroleum PAHs (e.g.C1-C4 Napthalenes) or combustion PAHs such as fluoranthene and benzo[a]pyrene (BaP). Combustion PAHs in Cultus Lake sediments are relatively low compared to levels observed in samples from Fraser River estuary and Vancouver harbour (Yunker et al., 1999). For example, combustion PAH levels in Cultus Lake sediments (mean = 0.069, CL range: 0.01-0.46 μg/g wet wt) is nearly 300 times lower than those levels reported in Burrard Inlet (11.3 ± 16.7μg/g wet wt) and 8 times lower than levels in the Fraser River estuary (0.36± 0.19 μg/g wet wt).

Figure 10. Concentrations of various PAHs in sediments (ng/g dry wt) at various sampling locations on Cultus and Chilliwack Lakes.



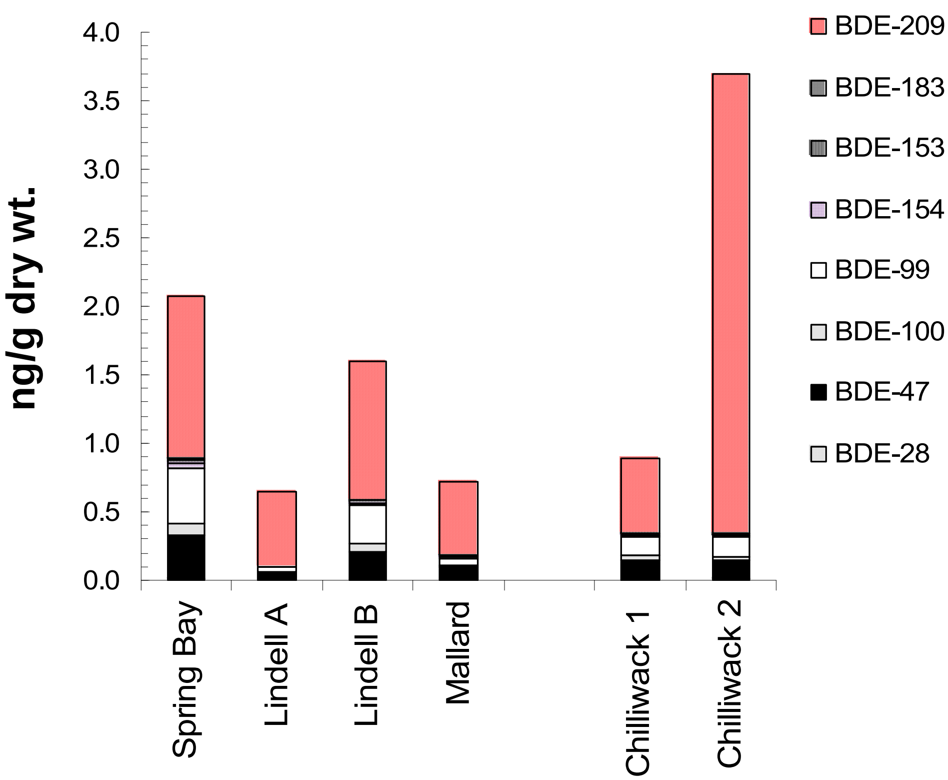
4.5. Polybrominated Diphenyl Ethers (PBDEs)

Measured concentrations of PBDEs in Cultus and Chilliwack Lake sediments are shown in Appendix X. $\sum Br_1$-Br_7PBDE concentrations observed in Cultus and Chilliwack Lake sediments ranged from 0.11 to 0.97 ng/g dry wt. $\sum Br_1$-Br_7PBDE concentrations (which includes concentrations of octa-deca PBDEs) ranged from 0.68 to 3.84 ng/g dry wt.

The dominant PBDE congeners in Cultus and Chilliwack Lake sediments included BDE-47, BDE-99 and BDE-209 (Figure 11). BDE-209 comprised 50-90% of the total PBDE burden in sediments. While PBDE patterns were generally comparable at the various sampling locations, PBDE concentrations varied substantially between sites. For example, $\sum Br\text{-}_1Br_{10}$ PBDEs in sediments at Spring Bay (2.30 ng/g dry wt) were approximately 3 times higher than $\sum Br\text{-}_1Br_{10}$PBDEs at Lindell A (0.68 ng/g dry wt) on Cultus Lake. Similarly, $\sum Br\text{-}_1Br_{10}$ PBDE concentrations at Chilliwack 2 (3.84 ng/g dry wt) were approximately 4 times higher than those concentrations at Chilliwack 1 (0.95 ng/g dry wt) on Chilliwack Lake. It is important to note that the relatively high $\sum Br\text{-}_1Br_{10}$PBDE concentrations Chilliwack 2 are the result of comparatively high PBDE-209 concentrations at that site.

Observed concentrations of PBDEs in Cultus Lake sediments are comparable to levels in nearby Chilliwack Lake, as well as previously reported levels of PBDEs in freshwater sediments. For example, concentrations of PBDE-47 (mean = 0.13 , 95% CL = 0.04-0.53) and PBDE-209 (mean = 0.79, 95% CL = 0.28-2.3) in Cultus Lake sediments are similar to observed PBDE concentrations in Lake Superior sediments (Song et al., 2004,Song et al., 2005b) and Lake Winnipeg (Law et al., 2006). Conversely, observed PBDE concentrations in Cultus and Chilliwack Lake sediments are slightly lower than other more urbanized/industrialized waters. For example, PBDE 209 levels of > 200 ng/g dry wt have been observed in Lake Ontario sediments (Song et al., 2005a).

Figure 11. Concentrations of individual PBDE congeners in sediments (ng/g dry wt) at various sampling locations on Cultus and Chilliwack Lakes.



4.6. Toxicological Implications

Contaminant exposure in fish can occur via water, sediments and/or food (Gobas, 1993; Morrison et al., 1996; Russell et al., 1999; Arnot and Gobas, 2004). Perhaps the life-history stage most vulnerable to contaminant exposure are the embryo and alevin stages (Guiney et al., 1979; Zitko and Saunders, 1979; Niimi, 1983; Walker and Peterson, 1991; Miller, 1993; Giesy et al., 2002). After deposition by spawning sockeye salmon, the egg and subsequent alevin stages incubate in spawning gravel substrate on the lake bottom. These stages may be exposed to contaminants in surrounding water and sediment. Both the development and survival of these stages can be affected by exposure to contaminants and can therefore affect subsequent recruitment (Guiney et al., 1979; Zitko and Saunders, 1979; Niimi, 1983; Walker and Peterson, 1991; Miller, 1993; Giesy et al., 2002).

Water quality guidelines (WQGs) and sediment quality guidelines (SQGs) are commonly used criteria used to assess contaminant related risks to aquatic life (Magliette et al., 1995; March et al., 2007; Apitz et al., 2007). Table 1 shows a comparison of the observed concentrations of metals in water from Cultus and Chilliwack Lakes versus current WQGs for metals used by the British Columbia Ministry of Environment (BC-MOE) for the protection of aquatic life. The data indicate that observed concentrations in Cultus and Chilliwack Lakes were below WQG.

Table 2 shows a comparison of the observed concentrations of metals in Cultus and Chilliwack Lake sediments (μg/g dry wt) versus current SQGs for metals used by the BC-MOE. The data indicate that concentrations of several metals in Cultus Lake and Chilliwack Lake sediments exceeded SQGs. For example, 3 sediment samples from Cultus Lake (Spring Bay, Lindell A and Lindell B) exhibited Cr concentrations that exceeded the SQG for that metal (35.7 μg/g dry wt). All sediment samples exhibited levels of Fe that exceeded the SQG of 21,200 μg/g dry wt. Also, some sediment samples from Cultus Lake had levels of Cd, Cu, Mn, Ni, Se and Zn that exceeded corresponding SQGs. In some cases, the upper bound 95% CL concentration (combined data for Cultus and Chilliwack Lake) of several metals in sediments (Hg, Ag, Al and Pb) exceeded the corresponding guidelines for the protection of freshwater organisms.

Table 3 shows a comparison of the observed concentrations for PCBs, dioxins, pesticides and PAHs in Cultus and Chilliwack Lake sediments versus current SQGs for those compounds used by the BC-MOE. The majority of sediment samples exhibited contaminant concentrations below SQG values. For example, levels of PCBs and pesticides detected in Cultus Lake sediments were below SQG levels. However, in some cases, concentrations of Total PCDD/F TEQs, Acenaphthene, Fluorene and LPAHs in Cultus Lake sediments exceeded the SQG levels derived to protect freshwater organisms. . In a limited number of samples, measured concentrations of two PAHs (acenaphthene, fluorene) and ∑PCDD/F TEQs slightly exceeded BC-MOE sediment quality guidelines (SQGs). Total PCDD/Fs TEQ concentrations in Cultus and Chilliwack Lake sediments (upper 95% CL = 0.99 pg/g dry wt) exceeded the 0.85 pg/g dry wt SQG. Also, upper 95% CL of several PAHs (2-methylnaphthalene, acenaphthene, fluorene, naphthalene, phenanthrene, pyrene) in Cultus and Chilliwack Lake sediments exceeded the SQG levels

SQGs are typically conservative estimates, derived by applying a series of safety factors to observed toxicological thresholds, and are generally below probable effect levels (PELs).

Thus, although the upper 95% CL of Hg in Cultus/Chilliwack Lake sediments (0.18 μg/g dry wt) slightly exceeds the current SQG (0.17 μg/g dry wt), the PEL for Hg in freshwater sediments is 0.486 μg/g dry wt. Hence, concentrations of Hg in Cultus Lake sediments do not appear to be sufficiently high to cause Hg related toxic effects. Similarly, levels of other contaminants that appear to be of concern in Cultus Lake sediments (PCDD/F TEQs, As, Al, Ba, Cd, Cu, Pb, Zn, acenaphthene and fluorene) were well below PELs of those compounds. For example, PCDD/F TEQs in Cultus Lake Lake sediments (range = 0.0062-1.67 pg/g dry wt) is relatively low compared to PEL of PCDD/F TEQs for freshwater sediments (21.5 pg/g dry wt).

However, observed concentrations of three metals (Cr ,Fe and Ni) in Cultus Lake sediments exceed BC-MOE guidelines associated with severe effect levels (SELs) for those substances. For example, concentrations of Fe in Cultus Lake sediments (range = 23,000-52,900 μg/g dry wt, in some cases exceeded the severe effects level for Fe in sediments (43,766 μg/g dry wt). Similarly, concentrations of Cr and Ni in Cultus Lake sediments in some cases exceeded severe effect levels (SELs) of those metals, which are 100 and 75 μg/g dry wt, respectively.

While Cr, Fe and Ni levels in Cultus Lake sediments exceed adverse affects thresholds for the protection of aquatic life, concentrations of those metals are comparable to levels in the reference lake (i.e., Chilliwack Lake), as well as concentrations previously observed in sediments in other BC freshwater lakes (Macdonald, 2000), (Figure 2). Thus, the seemingly high levels of Cr, Fe and Ni observed in Cultus Lake sediments are not unique compared to other British Columbia freshwater lake ecosystems.

Table 1. Comparison of metal concentrations in water from Cultus and Chilliwack Lakes (µg/L) and British Columbia's Ministry of Environment (BC-MOE) water quality guidelines (WQGs).

	Water Quality Assessment					
	Cultus Lake Water Range (pg/L)	Chilliwack Lake Water Range (pg/L)	Cultus/ Chilliwack Lake Water Upper 95% CL (pg/L)	BC-MOE Water Quality Guideline (pg/L)	Number of samples exceeding WQG *n* = 4	Concentrations Exceed WQG
Hg	1050-1140	460-550	2340	2.0×10^{4}	0/4	-
Ag	0.005-0.014	0.005-0.005	0.0216	1.0×10^{5}	0/4	-
Al	17.7-33.7	54.8-446	499	1.0×10^{8}	0/4	-
As	0.24-0.26	0.2-0.26	0.540	5.0×10^{6}	0/4	-
Ba	25.3-26.7	4.82-7.8	59.4	1.0×10^{9}	0/4	-
Be	0.012-0.012	0.012-0.012	0.0240	5.30×10^{6}	0/4	-
Cd	0.007-0.008	0.015-0.027	0.045	1.0×10^{4}	0/4	-
Co	0.059-0.063	0.035-0.208	0.306	1.1×10^{8}	0/4	-
Cr	0.11-0.17	0.09-0.323	0.537	1.0×10^{6}	0/4	-
Cu	0.79-1.42	0.72-2.19	3.89	9.40×10^{4}	0/4	-
Fe	29.2-50.6	72-554	632	3.0×10^{8}	0/4	-
Mn	2.45-3.02	2.88-11.1	15.7	8.0×10^{8}	0/4	-
Ni	0.27-0.79	0.52-0.95	1.99	2.5×10^{7}	0/4	-
Pb	0.8-2.39	0.36-0.77	3.71	7.0×10^{2}	0/4	-
Sb	0.072-0.073	0.043-0.045	0.150	2.0×10^{7}	0/4	-
Se	0.89-1.01	0.09-0.09	2.27	2.0×10^{6}	0/4	-
Ti	0.88-2.47	2.08-29	30.3	2.0×10^{9}	0/4	-
V	0.21-0.26	0.28-1.38	1.81	6.0×10^{6}	0/4	-
Zn	2.41-2.86	3.11-3.54	6.93	1.0×10^{7}	0/4	-

Table 2. Comparison of concentrations of metals in sediments from Cultus and Chilliwack Lakes (µg/g dry wt) and British Columbia's Ministry of Environment (BC-MOE) sediment quality guidelines (SQGs).

	Sediment Quality Assessment					
	Cultus Lake Sediment Range (µg/g dry wt)	**Chilliwack Lake Sediment Range (µg/g dry wt)**	**Cultus/ Chilliwack Lake Sediment Upper 95% CL (µg/g dry wt)**	**BC-MOE Sediment Quality Guideline (µg/g dry wt)**	**Number of samples with concentrations exceeding SQG in Cultus and Chilliwack Lake samples *n* = 6**	**Contaminant Risk for Cultus Lake Sockeye Embryos**
Hg	0.017-0.14	0.030-0.052	0.18	0.17	0/6	YES *
Ag	0.092-0.37	0.217-0.241	0.67	0.5	0/6	YES *
Al	22200-52000	23400-27700	94,500	58,000 [a]	0/6	YES *
As	**2.92-6.39**	**4.77-23.3**	**24.53**	**7.24**	**1/6 (Chilliwack L. only)**	**YES ****
Ba	**187-761**	**116-167**	**1,360**	**20 [a]**	**6/6 (Cultus and Chilliwack L.)**	**YES ****
Be	0.35-0.98	0.38-0.43	1.66	NA	0/6	NA
Cd	**0.17-1.22**	**0.35-0.37**	**1.60**	**0.6**	**1/6 (Cultus L. only)**	**YES ****
Co	7.48-19.65	9.36-11.0	34.6	50 [b]	0/6	-
Cr	**33.6-303**	**21.5-28.7**	**320**	**37.3**	**3/6 (Cultus L. only)**	**YES ****
Cu	**25.8-55.2**	**49.7-77.4**	**135**	**35.7**	**5/6 (Cultus and Chilliwack L.)**	**YES ****
Fe	**23000-52900**	**31900-35400**	**91,700**	**21,200**	**6/6 (Cultus and Chilliwack L.)**	**YES ****
Mn	**418-736**	**469-482**	**1360**	**460**	**5/6 (Cultus and Chilliwack L.)**	**YES ****
Ni	**24.2-133**	**14.7-16.1**	**190**	**16**	**5/6 (Cultus and Chilliwack L.)**	**YES ****
Pb	4.55-17.5	13.6-18.4	37.1	35	0/6	YES *
Sb	0.33-0.89	0.43-0.57	1.47	3.2 [c]	0/6	-
Se	**0.47-7.83**	**0.74-1.3**	**7.05**	**5**	**1/6 (Cultus L. only)**	**YES ****
Ti	1430-3680	2750-2820	6930	NA	0/6	NA
V	67.5-166	84.3-105	289	NA	0/6	NA
Zn	**88.3-153**	**72.9-80.1**	**276**	**123**	**3/6 (Cultus L. only)**	**YES ****

[a] sediment quality guideline from USEPA, 1997
[b] sediment quality guideline from Ontario Ministry of Environment (OMOE)
[c] sediment quality guideline from NYDEC, 1994
* 95% CL exceeded SQG
** actual measured concentrations exceeded SQG.

Table 3. Comparison of Cultus and Chilliwack Lake sediment concentrations of several organic contaminants, including PCBs, dioxins, pesticides and PAHs in sediments with British Columbia's Ministry of Environment (BC-MOE) sediment quality guidelines.

	Sediment Quality Assessment					
	Cultus Lake Sediment Range	**Chilliwack Lake Sediment Range**	**Cultus/Chilliwack Lake Sediment Upper 95% CL**	**BC-MOE Sediment Quality Guideline**	**Number samples exceeding SQG *n* = 6**	**Contaminant Risk for Cultus Lake Sockeye Embryos**
PCBs **(ng/g dry wt)**						
PCB-28	0.024-0.128	0.017-0.052	0.13	1.0 [a]	0/6	-
PCB-52	0.015-0.106	0.009-0.039	0.12	0.4 [a]	0/6	-
PCB-101	0.018-0.151	0.016-0.079	0.26	0.8 [a]	0/6	-
PCB-118	0.013-0.146	0.012-0.054	0.0035	0.8 [a]	0/6	-
PCB-138	0.018-0.165	0.021-0.083	0.26	1.0 [a]	0/6	-
PCB-153	0.017-0.120	0.020-0.075	0.18	1.0 [a]	0/6	-
PCB-180	0.008-0.071	0.011-0.041	0.10	1.2 [a]	0/6	-
Total PCBs	0.64-3.72	0.49-1.81	4.92	20	0/6	-
Dioxins/Furans **(pg/g dry wt)**						
2,3,7,8 TCDD	ND	ND	ND	0.01	0/6	-
Total PCDD/Fs TEQs	**0.0062-1.67**	**0.023-0.87**	**0.99**	**0.85**	**2/6 (Cultus and Chilliwack L.)**	**YES****
Pesticides **(ng/g dry wt)**						
Hexachlorobenzene	0.014-0.14	0.039-0.183	0.219	10	0/6	-
Heptachlor	0.014-0.022	0.016-0.025	0.043	0.6	0/6	-
α-HCH	0.01-0.058	0.01-0.073	0.082	6.0	0/6	-
Chlordane[b]	0.043-0.11	0.052-0.29	0.26	4.5	0/6	-
Heptachlor Epoxide	0.01-0.017	0.01-0.016	0.03	0.6	0/6	-
α-Endosulphan	0.087-0.15	0.1-0.14	0.285	2.9 [c]	0/6	-
β-Endosulphan	0.0277-0.1	0.1-0.12	0.282	14[c]	0/6	-
Endrin	0.01-0.01	0.01-0.012	0.021	2.67	0/6	-
Dieldrin	0.01-0.23	0.01-0.034	0.181	0.71	0/6	-
2,4'-DDE	0.01-0.051	0.01-0.025	0.066	1.42	0/6	-
4,4'-DDE	0.038-0.39	0.093-0.51	0.907	1.42	0/6	-
Mirex	0.01-0.21	0.015-0.021	0.156	7	0/6	-
PAHs **(ng/g dry wt)**						
2-Methylnaphthalene	6.78-18.8	1.04-1.46	40.6	20.2	0/6	YES *
Acenaphthene	0.38-16	0.44-0.95	**11.1**	**6.71**	**1/6 (Cultus L. only)**	**YES****

Sediment Quality Assessment	Cultus Lake Sediment Range	Chilliwack Lake Sediment Range	Cultus/Chilliwack Lake Sediment Upper 95% CL	BC-MOE Sediment Quality Guideline	Number samples exceeding SQG *n* = 6	Contaminant Risk for Cultus Lake Sockeye Embryos
Acenaphthylene	0.16-1.54	0.16-0.27	2.21	5.87	0/6	-
Anthracene	0.21-20	0.30-0.39	11.8	46.9	0/6	-
Benzo(a)anthracene	0.43-20.2	1.58-2.79	20.0	31.7	0/6	-
Benzo(a)pyrene	0.33-12.6	1.67-2.24	16.34	31.9	0/6	-
Chrysene	5.09-20.4	1.82-4.23	33.7	57.1	0/6	-
Dibenz(a,h)anthracene	0.64-3.22	0.65-2.16	5.47	6.2	0/6	-
Fluoranthene	2.43-68.9	2.26-4.08	65.7	111	0/6	-
Fluorene	1.23-24.5	0.16-0.40	**32.6**	**21.2**	**1/6 (Cultus L. only)**	**YES ****
Naphthalene	5.77-20.9	2.31-2.64	31.9	34.6	0/6	YES *
Phenanthrene	19.6-55.7	1.58-2.12	94.2	41.9	1/6	YES *
Pyrene	5.61-49.3	2.09-5.48	56.3	53	0/6	YES *
LPAHs	38.9-117	6.01-8.22	**240**	**100**	**2/6 (Cultus L. only)**	**YES ****
HPAHs	14.5-172	10.1-20.9	190	1,000	0/6	-

[a] sediment quality guideline from Netherlands National Institute of Public Health and Environmental Protection (NIPHEP), 1989
[b] Chlordane consists of the sum of *trans*-chlordane, *cis*-chlordane, *trans*-nonachlor and *cis*-nonachlor
[c] sediment quality guideline from USEPA, 1997
* 95% CL exceeded SQG
** actual measured concentrations exceeded SQG.

Table 4. Contaminant priority ranking based on relative observed levels relative to sediment quality guidelines (SQG) and severe effects level (SEL).

Priority Ranking 1= Highest Priority	Contaminant	Maximum Cultus Lake Sediment Concentration Exceeds SEL (Factor above SEL)	Maximum Cultus Lake Sediment Concentration Exceeds SQG (Factor above SQG)
1	Cr	2.8	8.1
2	Ni	1.8	8.3
3	Fe	1.2	2.5
4	Ba	< SEL	38.1
5	Acenaphthene	< SEL	2.4
6	Cd	< SEL	2.0
7	PCDD/F TEQs	< SEL	2.0
8	Mn	< SEL	1.6
9	Se	< SEL	1.6
10	Cu	< SEL	1.5
11	Zn	< SEL	1.2
12	LPAHs	< SEL	1.2
13	Fluorene	< SEL	1.2

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5. Conclusions and Recommendations

As a preliminary assessment of contaminant exposure risks to developing Cultus Lake sockeye embryos, this study reports on the occurrence and levels of several environmental contaminants of concern in water and sediments collected from spawning habitat for this endangered Pacific sockeye population. The results demonstrate that contaminant levels in Cultus Lake sockeye spawning habitat is generally comparable to, or in some cases lower than, concentrations in nearby Chilliwack Lake and other British Columbia freshwater ecosystems (Macdonald, 2000;Harris et al., 2008).

Concentrations of organic contaminants such as PCBs, dioxins, PAHs, pesticides and PBDEs, were generally highest at the Spring Bay site on Cultus Lake. However, organic contaminant concentrations at Mallard (on Cultus Lake) and Chilliwack 2 (reference site on Chilliwack Lake) were also consistently high, compared to other sampling sites. Site specific differences in organic contaminant concentrations may be related to differences in organic carbon content between these sites. For example, elevated organic carbon content in Spring Bay sediments (relative to sediments from other sites) would explain the consistently higher dry wt. concentrations of organic contaminants observed in those sediments. In contrast, concentrations of some metals (Al, Cr, Fe, Ni) were highest at Lindell A and Lindell B sites on Cultus Lake.

Evaluation of potential sources and distribution of chemical contaminants in Cultus Lake and Chilliwack Lake is beyond the scope of the present study. While levels of contaminants often differed substantially between sites, contaminant patterns were generally comparable between Cultus Lake and Chilliwack sampling locations. This suggests contaminant levels likely reflect natural background signatures, historical anthropogenic inputs and/or current regional atmospheric deposition patterns. However, the existence of current local point sources for some contaminants cannot be ruled out. For example, combustion derived PAHs were highest at Spring Bay and Mallard sites on Cultus Lake, which may be due to the fact those sites are in close proximity to pyrogenic sources such as highways (gas/diesel vehicles) and urban developments (wood burning ovens/stoves). This may also be the case for PBDEs, which have been used as flame retardants in many household products such as sofas and mattresses. In addition, factors such as topography/drainage may influence the distribution and transport and hence environmental concentrations of contaminants in Cultus Lake.

The evaluation of ambient contaminant concentrations in water and sediment from Cultus Lake in relation to WQGs and SQGs for the protection of aquatic life provided some insight into the potential toxicological implications for developing Cultus Lake sockeye embryos. The results indicate that ambient levels of thirteen environmental contaminants in Cultus Lake sediments are cause for concern (Table 4). Specifically, Cr, Ni and Fe levels in Cultus Lake sediments exceed severe effects levels (SELs) developed for the protection of freshwater aquatic organisms. In some cases, concentrations of several other metals and organic contaminants, including As, Ba, Cd, Cu, Mn, Se, Zn, PCDD/F TEQs, acenaphthene, fluorene and low molecular weight PAHs (LPAHs) exceeded BC-MOE sediment quality guidelines. Also, concentrations of several other metals (Hg, Ag, Al, Pb) and the PAH, 2-Methylnaphthalene, which were slightly below SQGs, exhibited upper 95 % confidence limits (CLs) that exceeded corresponding guidelines.

The consequences of current ambient contaminant levels on developing Cultus Lake sockeye embryos is not clear from results of the present study. It is important to note that predicting biological effects by comparison of observed concentrations to SQGs and SELs for a given contaminant is difficult due to other environmental and biological factors such as pH, bioavailability, species sensitivity, lifestage sensitivity and toxicological endpoints. In particular, SQGs and SELs are concentrations generally derived from laboratory exposure experiments with a particular focus on a given toxicological endpoint and fish species. Thus, laboratory derived SQGs and SELs may not necessarily include all toxicological endpoints and may underestimate effects in relatively more sensitive species. For example, salmonids tend to be more sensitive to contaminant exposure compared to other fish species (Cook et al., 2003).

The result of this study indicate ambient Cr, Ni and Fe concentrations in Cultus Lake sediments exceed SELs derived for the protection of aquatic life and warrant further investigation. Also, current levels of As, Ba, Cd, Cu, Mn, Se, Zn, PCDD/F TEQs, acenaphthene, fluorene and low molecular weight PAHs (LPAHs) in sediments at some locations in Cultus Lake are cause for some concern. No evaluation of PBDEs levels in Cultus Lake sediments was possible due to the absence of SQGs of those brominated flame retardants. SQGs of many current-use pesticides (CUPs) and pharmaceuticals and personal care products (PPCPs), which were below detection limits in Cultus Lake sediments, have also not yet been established by regulatory agencies.

Recent investigations have demonstrated that ambient levels of complex pesticide mixtures present in a Fraser Valley watershed (Nicomekl River) adversely affect rainbow trout olfaction and olfactory-mediated behaviours (Tierney et al., 2006;Tierney et al., 2008), indicating some cause for concern regarding water quality and salmon health in this region. Thus, further research into the effects of complex pesticide mixtures in Cultus Lake sockeye salmon is also warranted to further delineate risks to fish and ecosystem health.

Future studies to better asses toxicological effects of ambient concentrations of metals, pesticide mixtures and other emerging contaminants on developing Pacific sockeye embryos should include laboratory-based assays using field collected spawning substrate. Studies investigating effects of complex contaminant mixtures would benefit future risk assessments and foster better understanding of contaminant related impacts on the health and reproduction of Pacific sockeye salmon.

6. Future Reporting and Publication

The present document summarizes measurements and risk analyses of several environmental contaminants, including Hg and other trace elements, PCBs, PCDD/Fs and PBDEs, PAHs and pesticides in field collected samples of water and sediments from Cultus and Chilliwack Lakes. Future plans include preparation of a short scientific article summarizing the occurrence, levels of these environmental contaminants in Cultus Lake sockeye spawning habitat and toxicological implications for the health of Cultus Lake sockeye.

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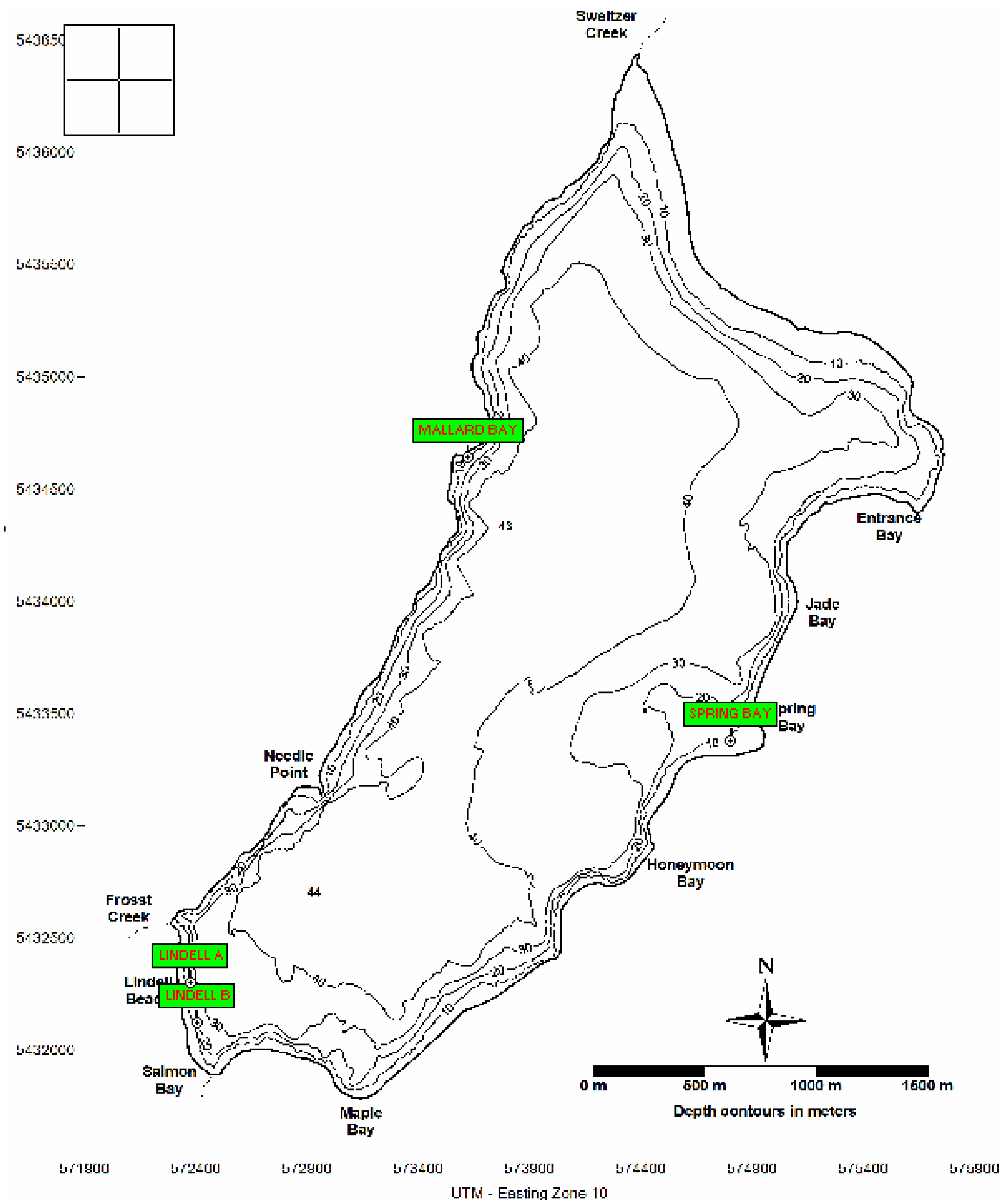
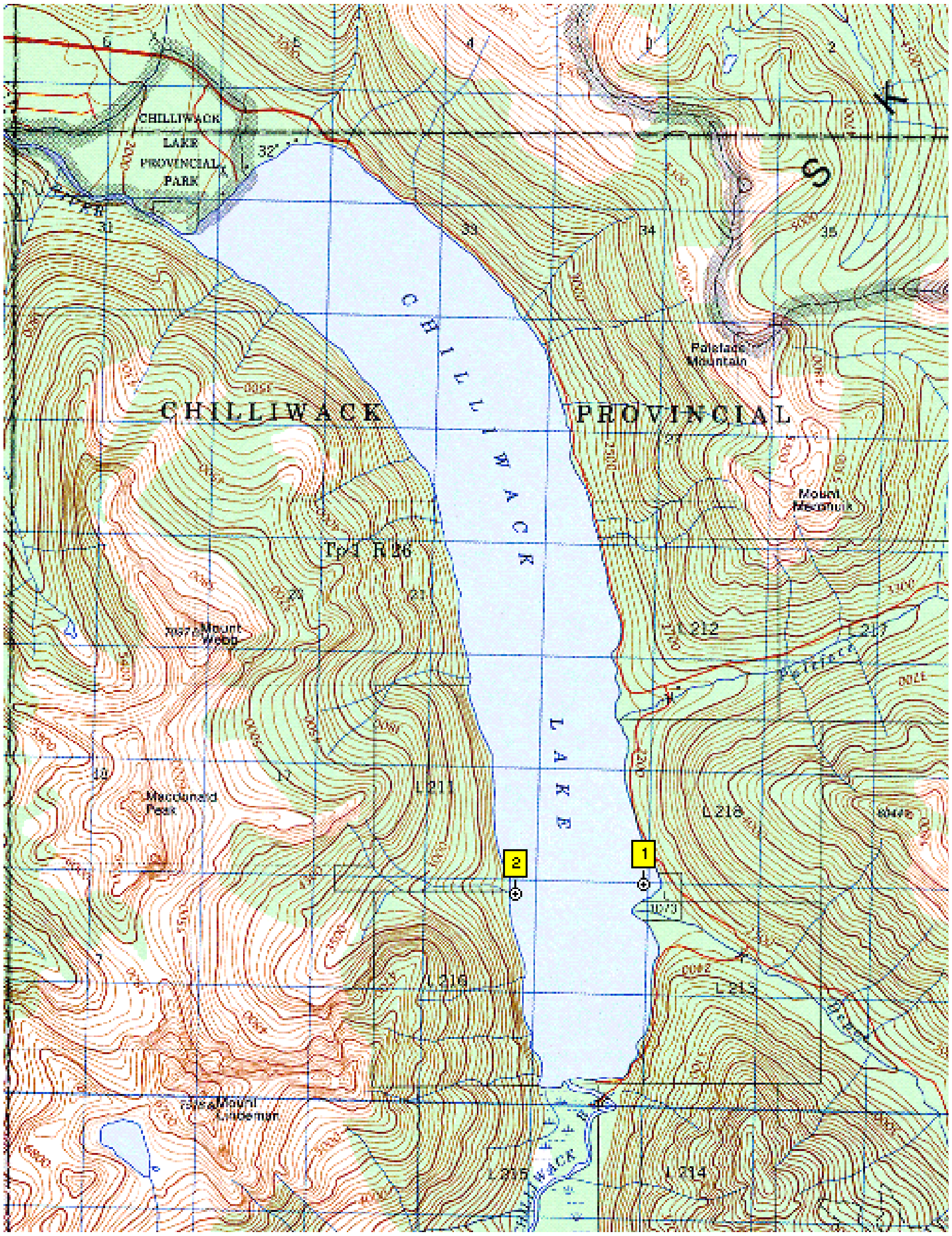
8. Appendices

Appendix I. Map showing sampling locations on Cultus Lake.



Appendix II. Map showing sampling locations on Chilliwack Lake.



Appendix III. WHO TEFs for fish (Van den Berg et al., 1998)

PCDFs	
2,3,7,8-TCDF_TEQ	0.05
1,2,3,7,8-PeDF_TEQ	0.05
2,3,4,7,8-PeDF_TEQ	0.5
1,2,3,4,7,8-HxCDF_TEQ	0.1
1,2,3,6,7,8-HxCDF_TEQ	0.1
2,3,4,6,7,8-HxCDF_TEQ	0.1
1,2,3,7,8,9-HxCDF_TEQ	0.1
1,2,3,4,6,7,8-HpCDF_TEQ	0.01
1,2,3,4,7,8,9-HpCDF_TEQ	0.01
OCDF_TEQ	< 0.0001 [a]
PCDDs	
2,3,7,8-TCDD_TEQ	1
1,2,3,7,8-PeCDD_TEQ	1
1,2,3,4,7,8-HxCDD_TEQ	0.5
1,2,3,6,7,8-HxCDD_TEQ	0.01
1,2,3,7,8,9-HxCDD_TEQ	0.01
Congener WHO-TEF for fish	
1,2,3,4,6,7,8-HpCDD_TEQ	0.001
OCDD_TEQ	< 0.0001[a]
Dioxin like PCBs	
TEQ77	0.00016
TEQ81	0.0005
TEQ105	< 0.000005[b]
TEQ114	< 0.000005[b]
TEQ118	< 0.000005[b]
TEQ123	< 0.000005[b]
TEQ126	0.005
TEQ156	< 0.000005[b]
TEQ157	< 0.000005[b]
TEQ167	< 0.000005[b]
TEQ169	0.01
TEQ189	< 0.000005[b]

[a] A value of 0.00005 was used to calculate congener TEQ
[b] A value of 0.0000025 was used to calculate congener TEQ

Appendix IV. Concentrations of mercury and other trace elements in water (pg/L) collected from Cultus and Chilliwack Lakes. Values following < symbol represent method detection limits. NQ = Not quantifiable. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spinger	Lindell A & B	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
Hg	1140	1050	460	550	460-1140	741 (235-2340)
Ag	0.005	0.014	0.005	0.005	0.005-0.014	0.0065 (0.0019-0.0216)
Al	33.7	17.7	54.8	446	17.7-446	61.7 (7.64-499)
As	0.24	0.26	0.2	0.26	0.20-0.260	0.238 (0.10-0.54)
Ba	26.7	25.3	4.82	7.8	4.82-26.7	12.6 (2.67-59.4)
Be	0.012	0.012	0.012	0.012	0.012-0.012	0.012 (0.006-0.024)
Ca	33100	31500	3110	3070	3070-33,100	9990 (1290-77,400)
Cd	0.007	0.008	0.015	0.027	0.0070-0.0270	0.012 (0.0033-0.045)
Co	0.063	0.059	0.035	0.208	0.035-0.208	0.072 (0.017-0.306)
Cr	0.17	0.11	0.09	0.323	0.090-0.323	0.15 (0.043-0.537)
Cu	1.42	0.79	0.72	2.19	0.720-2.190	1.15 (0.34-3.89)
Fe	50.6	29.2	72	554	29.2-554	87.6 (12.1-632)
K	441	457	454	554	441-554	474 (213-1050)
Mg	2880	2890	399	499	399-2890	1130

	Spinger	Lindell A & B	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
						(192-6690)
Mn	3.02	2.45	2.88	11.1	2.45-11.1	3.92 (0.974-15.7)
Na	3160	2990	967	915	915-3160	1700 (428-6740)
Ni	0.27	0.79	0.95	0.52	0.27-0.95	0.569 (0.163-1.99)
Pb	2.39	0.8	0.36	0.77	0.36-2.39	0.853 (0.19-3.71)
Sb	0.072	0.073	0.045	0.043	0.043-0.073	0.056 (0.0211-0.15)
Se	1.01	0.89	0.09	0.09	0.09-1.01	0.292 (0.037-2.27)
Ti	2.47	0.88	2.08	29	0.88-29.0	3.38 (0.37-30.4)
V	0.26	0.21	0.28	1.38	0.21-1.38	0.381 (0.080-1.81)
Zn	2.41	2.86	3.54	3.11	2.41-3.54	2.95 (1.26-6.93)

Appendix V. Concentrations of mercury and other trace elements in sediments (μg/g dry wt) collected from Cultus and Chilliwack Lakes. Values following < symbol represent method detection limits. NQ = Not quantifiable. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% moisture	81.24	32.99	26.0	35.09	58.46	76.94		
Hg	0.144	0.0487	0.0435	0.0171	0.030	0.0524	0.017-0.144	0.045 (0.011-0.182)
Ag	0.373	0.239	0.203	0.092	0.241	0.217	0.092-0.373	0.210 (0.066-0.67)
Al	40900	52000	43200	22200	23400	27700	22200-52000	33100 (11600-94500)
As	6.39	5.22	4.32	2.92	23.3	4.77	2.92-23.3	6.01 (1.47-24.5)
Ba	577	761	548	187	116	167	116-761	310 (70.5-1360)
Be	0.533	0.985	0.838	0.354	0.385	0.434	0.354-0.985	0.544 (0.178-1.66)
Ca	12400	15400	18100	5660	7800	8740	5660-18100	10500 (3370-32600)
Cd	1.22	0.521	0.397	0.177	0.378	0.351	0.177-1.22	0.425 (0.113-1.59)
Co	15.8	19.6	13.2	7.48	9.36	11.0	7.48-19.6	12.1 (4.27-34.5)
Cr	38.7	303	135	33.6	28.7	21.5	21.5-303	56.7 (10.0-320)
Cu	55.2	50.2	39.1	25.8	49.7	77.4	25.8-77.4	47.0 (16.2-135)

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% moisture	81.24	32.99	26.0	35.09	58.46	76.94		
Fe	34700	52900	38500	22900	31900	35400	23000-52900	35000 (13300-91700)
K	7580	9450	6670	4800	2420	3980	2420-9450	5300 (1620-7360)
Mg	8203	25600	18900	7160	8020	11900	7160-25600	11800 (3510-39800)
Mn	639	736	607	418	482	469	418-736	547 (220-1360)
Na	832	910	435	516	1570	1670	435-1670	874 (2520-3050)
Ni	49.5	132	84.8	24.1	16.1	14.7	14.7-133	38.4 (7.75-190)
Pb	17.5	6.59	4.55	10.7	18.4	13.6	4.55-18.4	10.6 (3.03-37.1)
Sb	0.533	0.895	0.554	0.339	0.578	0.434	0.339-0.895	0.531 (0.192-1.46)
Se	7.83	1.19	1.40	0.478	0.746	1.344	0.478-7.83	1.35 (0.26-7.04)
Ti	2650	3690	2440	1433	2820	2750	1430-3690	2540 (927-6930)
V	125	165	111	67.4	84.2	105	67.4-165	105 (38.6-288)
Zn	134	153	110	88.2	80.0	72.9	72.9-153	102 (38.1-276)

Appendix VI. Concentrations of ΣPCBs (ng/g dry wt), dioxin-like PCBs (pg/g dry wt), PCDD/Fs (pg/g dry wt), and 2,3,7,8 TCDD Toxic equivalents (TEQs, pg/g dry wt) in Cultus Lake and Chilliwack Lake sediments. Values following < symbol represent method detection limits. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM	95% CL
% Moisture:	73.54	25.52	51.55	30.30	42.73	64.77			
ΣPCBs (ng/g dry wt)[a]	3.72	0.64	0.71	2.05	0.76	1.82	0.49-3.72	1.22	0.30-4.92
DL-PCBs (pg/g dry wt)									
PCB77	25.9	3.10	2.04	3.13	5.87	8.91	2.04-25.8	4.94	1.13-21.7
PCB81	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-	-
PCB105	55.1	4.27	5.71	50.3	3.76	18.01	3.76-55.1	13.6	2.08-88.9
PCB114	4.18	0.30	0.35	2.56	0.21	1.41	0.21-4.18	0.89	0.14-5.47
PCB118	147	12.8	15.6	133	11.9	53.5	12.0-147	39.3	6.46-240
PCB123	2.84	0.36	0.50	2.07	0.42	1.62	0.36-2.84	1.02	0.23-4.60
PCB126	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-	-
PCB156	14.9	1.12	1.17	11.9	1.36	5.25	1.12-14.9	3.68	0.60-22.6
PCB157	8.36	1.68	2.57	5.25	2.21	6.33	1.68-8.36	3.91	1.14-13.4
PCB167	5.55	0.25	0.69	4.69	0.76	3.16	0.25-5.55	1.64	0.27-10.2
PCB169	0.63	0.15	0.36	0.21	0.00	0.48	0.15-0.63	0.29	0.09-0.96
PCB189	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-	-
Dioxins/Furans (pg/g dry wt)									
2,3,7,8-TCDD	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	-	-	-
1,2,3,7,8-PeCDD	0.49	< 0.08	< 0.08	< 0.08	< 0.08	0.33	0.08-0.49	0.23	0.05-1.22
1,2,3,4,7,8-HxCDD	0.48	< 0.1	< 0.1	< 0.1	< 0.1	0.3	0.30-0.48	0.38	0.14-1.06
1,2,3,6,7,8-HxCDD	1.76	< 0.1	0.18	0.33	0.26	0.7	0.18-1.76	0.37	0.08-1.68
1,2,3,7,8,9-HxCDD	0.97	< 0.1	0.11	0.28	0.25	0.99	0.11-0.99	0.35	0.07-1.67
1,2,3,4,6,7,8-	26.9	0.86	2.82	9.75	3.32	7.89	0.86-26.9	4.46	0.79-25.1

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM	95% CL
HpCDD									
OCDD	196	2.78	18.17	102	15.2	30.5	2.78-196	24.1	3.28-177
2,3,7,8-TCDF	1.37	< 0.05	< 0.05	< 0.05	0.2	0.67	0.16-1.37	0.41	0.07-2.29
1,2,3,7,8-PeCDF	0.37	< 0.06	< 0.06	< 0.06	0.08	ND	0.08-0.37	0.17	0.03-1.02
2,3,4,7,8-PeCDF	0.32	< 0.06	< 0.06	< 0.06	< 0.06	0.24	0.24-0.32	0.28	0.11-0.68
1,2,3,4,7,8-HxCDF	0.5	< 0.08	< 0.08	< 0.08	< 0.08	0.2	0.20-0.50	0.32	0.08-1.21
1,2,3,6,7,8-HxCDF	0.52	< 0.08	< 0.08	0.08	< 0.08	< 0.08	0.08-0.52	0.15	0.03-0.88
2,3,4,6,7,8-HxCDF	0.15	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	0.09-0.15	0.12	0.04-0.33
1,2,3,7,8,9-HxCDF	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	ND	ND	ND
1,2,3,4,6,7,8-HpCDF	6.36	0.15	ND	1.41	0.33	0.87	0.15-6.36	0.60	0.08-4.41
1,2,3,4,7,8,9-HpCDF	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3,4,6,8,9-HpCDF	11.05	0.11	0.37	2.11	0.22	0.42	0.11-11.05	0.57	0.06-5.61
OCDF	17.9	0.14	0.65	3.94	0.39	0.97	0.14-17.92	0.90	0.10-8.43
ΣPCDDs [b]	299	6.44	26.1	137	29.92	72.2	6.44-299	42.54	6.50-278
ΣPCDFs [b]	61.1	1.2	1.56	9.66	4.4	12.4	1.13-61.1	4.73	0.60-37.3
2,3,7,8 TCCD Toxic Equivalents (TEQs) (pg/g dry wt) [c]									
ΣPCDD TEQ	0.79	0.001	0.0053	0.021	0.009	0.51	0.001-0.79	0.027	0.0013-0.55
ΣPCDF TEQ	0.88	0.0052	0.014	0.022	0.013	0.37	0.000033-0.88	0.018	0.0004-0.81
ΣPCB TEQ	0.011	0.0020	0.004	0.003	0.001	0.006	0.001-0.011	0.0034	0.0008-0.015
ΣTEQs	1.68	0.0083	0.024	0.046	0.023	0.88	0.007-1.68	0.065	0.004-0.95

[a] Full congener PCB (209 congeners) and includes all di-ortho, mono-ortho and non-ortho PCBs.
[b] PCDDs (7 congeners), PCDFs (10 congeners).

[c] TEQs were calculated using WHO-TEFs for fish from Van den Berg et al. (1998). ΣPCDD TEQs were calculated from concentrations and WHO-TEFs of 2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,6,7,8-HxCDD, 1,2,3,7,8,9-HxCDD, 1,2,3,4,6,7,8-HpCDD, OCDD. ΣPCDF TEQs were calculated from concentrations and WHO-TEFs of 2,3,7,8-TCDF, 1,2,3,7,8-PeDF, 2,3,4,7,8-PeDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, 2,3,4,6,7,8-HxCDF, 1,2,3,7,8,9-HxCDF, 1,2,3,4,6,7,8-HpCDF, 1,2,3,4,7,8,9-HpCDF, OCDF. ΣPCB TEQs were calculated from concentrations and WHO-TEFs of PCB77, PCB81, PCB105, PCB114, PCB118, PCB123, PCB126, PCB156, PCB157, PCB167, PCB169, PCB189. ∑TEQ = ΣPCDD TEQ + ΣPCDF TEQ + ΣPCB TEQ

Appendix VII. Pesticide concentrations in sediments (ng/g dry wt) collected from Cultus and Chilliwack Lakes. Values following < symbol represent method detection limits. NQ = Not quantifiable. NDR = not detectable due to isotope ratio on HRMS. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spring Bay	**Lindell A**	**Lindell B**	**Mallard**	**Chilliwack 1**	**Chilliwack 2**	**Range**	**GM (95% CL)**
% Moisture:	72.1	21.3	21.9	23.7	49.3	64.8		
Organochlorines (OC)								
Hexachlorobenzene	0.139	0.032	0.016	0.014	0.039	0.183	0.014-0.183	0.044 (0.009-0.219)
Heptachlor	0.022	0.017	0.018	0.014	0.016	0.025	0.014-0.025	0.018 (0.008-0.043)
α-HCH	0.058	< 0.01	< 0.01	< 0.01	0.011	0.073	0.01-0.073	0.019 (0.004-0.082)
γ-HCH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
β-HCH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
δ-HCH	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
Quintozene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Octachlorostyrene	< 0.0181	< 0.01	< 0.01	< 0.01	< 0.01	< 0.011	-	-
Oxychlordane	< 0.0135	< 0.01	< 0.0146	< 0.01	< 0.01	< 0.0175	-	-
Heptachlor Epoxide	0.017	< 0.01	< 0.01	< 0.01	< 0.01	0.016	0.01-0.016	0.012 (0.005-0.030)
trans-Chlordane	0.027	< 0.0115	< 0.0125	0.026	< 0.0117	0.075	0.0115-0.075	0.021 (0.007-0.066)
cis-Chlordane	0.037	< 0.0103	< 0.0112	0.026	< 0.0105	0.083	0.0103-0.083	0.021 (0.006-0.078)
trans-Nonachlor	0.022	< < 0.0109	< 0.0118	0.043	0.019	0.087	0.0109-0.087	0.024 (0.007-0.084)
cis-Nonachlor	0.015	< 0.01	< 0.0116	0.017	< 0.0111	0.045	0.01-0.045	0.016

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% Moisture:	72.1	21.3	21.9	23.7	49.3	64.8		
								(0.006-0.039)
α-Endosulphan	0.156	0.102	0.087	0.106	0.113	0.138	0.087-0.138	0.115 (0.046-0.285)
β-Endosulphan	0.1	< 0.0277	0.082	0.071	0.129	0.113	0.0277-0.129	0.079 (0.022-0.282)
Endosulphan Sulphate	0.049	< 0.0232	< 0.0271	0.027	0.101	0.36	0.0232-0.36	0.056 (0.015-0.206)
Aldrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	-
Endrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.012	0.01-0.012	0.010 (0.005-0.021)
Endrin Ketone	< 0.0341	< 0.0193	< 0.0184	< 0.0161	< 0.022	< 0.0375	-	-
Dieldrin	0.021	< 0.01	< 0.01	0.229	< 0.01	0.034	0.01-0.229	0.023 (0.003-0.181)
2,4'-DDD	0.074	0.011	0.013	0.041	< 0.01	< 0.01	0.011-0.041	0.026
4,4'-DDD	0.306	0.059	0.091	0.15	< 0.01	< 0.01	0.059-0.15	0.125
2,4'-DDE	0.014	< 0.01	< 0.01	0.051	< 0.01	0.025	0.01-0.051	0.016 (0.004-0.066)
4,4'-DDE	0.393	0.052	0.038	0.356	0.093	0.515	0.038-0.515	0.154 (0.026-0.907)
2,4'-DDT	0.0249	< 0.0118	< 0.0177	< 0.0128	NQ	NQ	-	-
4,4'-DDT	0.051	0.037	< 0.0239	0.026	NQ	NQ	0.0239-0.037	0.033
Methoxychlor	< 0.4	< 0.0446	< 0.1	< 0.0436	NQ	NQ	-	-
Mirex	0.21	0.015	< 0.01	0.011	0.015	0.021	0.01-0.021	0.022

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% Moisture:	72.1	21.3	21.9	23.7	49.3	64.8		
								(0.003-0.156)
Triazines (TZ)								
Desethylatrazine	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Simazine	< 0.194	< 0.1	< 0.1	< 0.1	< 0.1	< 0.106	-	-
Atrazine	< 0.239	< 0.1	< 0.1	< 0.1	< 0.118	< 0.231	-	-
Ametryn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Metribuzin	< 0.164	< 0.1	< 0.1	< 0.1	< 0.1	< 0.261	-	-
Cyanazine	< 0.214	< 0.127	< 0.1	< 0.1	< 0.255	< 0.312	-	-
Hexazinone	< 0.158	< 0.1	< 0.1	< 0.1	< 0.202	< 2.07	-	-
Organophosphates (OPs)								
Methamidophos	< 1.07	< 0.502	< 0.47	< 0.497	< 0.647	< 1.1	-	-
Phorate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Terbufos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Diazi non-Oxon	< 0	< 0			0		-	-
Diazinon	< 0.163	< 0.1	< 0.1	< 0.1	< 0.116	< 0.156	-	-
Disulfoton							-	-
Fonofos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Dimethoate	< 0.359	< 0.236	< 0.2	< 0.271	< 0.214	< 0.287	-	-
Chlorpyriphos-Methyl	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Parathion-Methyl	< 0.767	< 0.314	< 0.27	< 0.253	< 0.221	< 0.382	-	-
Pirimphos-Methyl	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Chlorpyriphos	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Fenitrothion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Malathion	< 0.794	< 0.371	< 0.331	0.435	< 0.3	< 0.494	-	-

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% Moisture:	72.1	21.3	21.9	23.7	49.3	64.8		
Parathion-Ethyl	< 0.109	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Chlorpyriphos-Oxon	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Disulfoton Sulfone	NQ	NQ	NQ	NQ	NQ	NQ	-	-
Ethion	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Phosmet	< 0.106	< 0.1	< 0.1	< 0.1	< 0.17	< 0.153	-	-
Azinphos-Methyl	< 0.362	<0.0872	< 0.053	< 0.0957	< 0.296	< 2.28	-	-
Other								
Tecnazene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Dacthal	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Captan	NQ	NQ	NQ	NQ	NQ	NQ	-	-
Trifluralin	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Linuron	< 0.589	< 0.25	< 0.149	< 0.219	< 0.145	< 0.449	-	-
Alachlor	< 0.377	< 0.1	< 0.1	< 0.1	1	11.9	-	-
Methoprene	< 17.2	< 43.8	< 20.1	< 13.8	< 16	< 71	-	-
Butralin	< 0.874	< 0.158	< 0.194	< 0.117	< 0.216	< 0.517	-	-
Flufenacet	< 1.26	< 0.1	< 0.1	< 0.1	< 0.1	< 0.928	-	-
Metolachlor	< 0.216	< 0.1	< 0.1	< 0.1	< 0.1	< 0.341	-	-
Pendimethalin	< 1.9	< 0.122	< 0.225	< 0.114	< 0.339	< 0.941	-	-
Flutriafol	< 0.462	< 0.1	< 0.1	< 0.234	< 0.1	< 2.14	-	-
Tebuconazol	< 1.04	< 0.1	< 0.1	< 0.105	< 0.104	< 0.403	-	-
Chlorothalonil	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Triallate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Dimethenamid	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Permethrin	< 0.315	< 0.1	< 0.1	< 0.1	< 0.257	< 3.14	-	-
Cypermethrin	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% Moisture:	72.1	21.3	21.9	23.7	49.3	64.8		
Butylate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Ethalfluralin	< 0.111	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	-	-
Perthane	< 0.656	< 0.167	< 0.203	< 0.137	< 0.352	< 1.38	-	-

Appendix VIII. List of pharmaceutical compounds analyzed in Cultus and Chilliwack Lake sediments. DL = detection limit (ng/g dry wt)

Compound	DL (ng/g dry wt)	Compound	DL (ng/g dry wt)	Compound	DL (ng/g dry wt)
Anhydrochlortetracycline	18.1	Ciprofloxacin	4.24	Penicillin G	2.57
Anhydrotetracycline	6.77	Clarithromycin	0.673	Penicillin V	5.14
Chlortetracycline	2.69	Clinafloxacin	7.44	Roxithromycin,Sarafloxacin	0.435
Demeclocycline	6.73	Cloxacillin	1.35	Sulfachloropyridazine	1.28
Doxycycline	2.69	Codeine	1.35	Sulfadiazine	1.28
4-Epianhydrochlortetracycline	42.5	Cotinine	1.12	Sulfadimethoxine	0.513
4-Epianhydrotetracycline	6.73	Dehydronifedipine	0.269	Sulfamerazine	0.514
4-Epichlortetracycline	7.89	Diphenhydramine	0.269	Sulfamethazine	1.35
4-Epioxytetracycline	5.34	Diltiazem	0.135	Sulfamethizole	0.514
4-Epitetracycline	5.55	Digoxin	8.62	Sulfamethoxazole	0.514
Isochlortetracycline	2.69	Digoxigenin	2.69	Sulfanilamide	12.8
Minocycline	26.9	Enrofloxacin	2.01	Sulfathiazole	1.28
Oxytetracycline	2.69	Erythromycin-H2O	0.135	Thiabendazole	1.28
Tetracycline	2.9	Flumequine	0.673	Trimethoprim	1.28
Albuterol	0.3	Fluoxetine	0.673	Tylosin	16.8
Cimetidine	0.6	Lincomycin	1.35	Virginiamycin	17.5
Metformin	30	Lomefloxacin	1.35	1,7-Dimethylxanthine	128
Ranitidine	0.6	Miconazole	0.673	Gemfibrozil	0.673
Acetaminophen	26.9	Norfloxacin	6.79	Ibuprofen	6.73
Azithromycin	0.673	Norgestimate	1.35	Naproxen	1.35
Caffeine	6.73	Ofloxacin	0.673	Triclocarban	1.35
Carbadox	0.673	Ormetoprim	0.269	Triclosan	26.9
Carbamazepine	0.673	Oxacillin	1.35	Warfarin	0.673
Cefotaxime	3.04	Oxolinic Acid	0.181		

Appendix IX. Polycyclic aromatic hydrocarbon (PAH) concentrations in sediments (ng/g dry wt) collected from Cultus and Chilliwack Lakes. Values following < symbol represent method detection limits. NQ = Not quantifiable. NDR = not detectable due to isotope ratio on HRMS. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
% moisture	73.2	22.5	22.3	24.1	52.8	67.7		
Naphthalene	14.6	7.46	5.77	20.9	2.31	2.64	2.31-20.9	6.56 (1.35-31.9)
Acenaphthylene	1.54	0.164	0.159	1.44	< 0.165	0.266	0.159-1.54	0.434
Acenaphthene	3.33	0.504	0.382	16	< 0.447	< 0.948	0.382-16	1.79
Fluorene	19.1	2.64	1.23	24.5	< 0.166	0.398	0.398-24.5	3.60
Phenanthrene	55.7	22.3	19.6	22.8	1.58	2.12	1.58-55.7	11.1 (1.30-94.3)
Anthracene	4.22	0.296	0.211	20	0.302	0.39 (NDR)	0.211-20	0.923 (0.072-11.8)
Fluoranthene	34.8	2.85	2.43	68.9	2.26	4.08	2.26-68.9	7.31 (0.814-65.7)
Pyrene	25.1	6.04	5.61	49.3	2.09	5.48	2.09-49.3	8.84 (1.39-56.3)
Benz[a] anthracene	6.65	0.475	0.431	20.2	1.58 (NDR)	2.79 (NDR)	0.431-20.2	2.22 (0.247-20.0)
Chrysene	20.4	5.97	5.09	18.6	1.82	4.23	1.82-20.4	6.67 (1.32-33.6)

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
Benzo[b,j,k]fluoranthene	28.3	3.81	3.11	33	2.96	5.23	2.96-33	7.45 (1.22-45.3)
Benzo[e]pyrene	11.6	2.83	2.27	11.7	1.23	2.26	1.23-11.7	3.66 (0.717-18.7)
Benzo[a]pyrene	6.97	0.331	0.38	12.6	1.67	2.24 (NDR)	0.331-12.6	(1.85 0.211-16.3)
Perylene	196	3.27	8.78	6.34	1.51	232	1.51-232	15.2 (0.90-256)
Dibenz[a,h]anthracene 3	3.22 (NDR)	0.799	0.64	2.32 (NDR)	< 0.655	2.16 (NDR)	0.64-3.22	1.52
Indeno[1 ,2,3-c,d]-pyrene	14.1	0.725	0.595	8.44	1.77 (NDR)	2.28	0.595-14.1	2.43 (0.338-17.4)
Benzo[g,h,i]perylene	18.3	3.13	2.21	7.19	1.61 (NDR)	3.43 (NDR)	1.61-18.3	4.13 (0.85-20.0)
2-Methylnaphthalene	18.8	16.8	11.6	6.78	1.04	1.46	1.04-18.8	5.79 (0.8257-40.6)
1-Methylnaphthalene	8.11	5.17	3.8	3.42	0.486	0.613	0.486-8.11	2.33 (0.363-15.0)
C2 Phenanthrenes/Anthracenes	50.5	19.1	14.3	12	1.32	2.16	1.32-50.5	8.82 (1.10-70.3)
C1 Phenanthrenes/Anthracenes	51.1	34.8	29.2	23.3	2.21	7.09	2.21-51.1	16.3 (2.49-106)
C1-Naphthalenes	26.9	21.9	15.4	10.2	1.52	2.07	1.52-26.9	8.14 (1.19-55.6)
Biphenyl	9.76	3.01	2.66	4.84	0.896	0.72	0.72-9.76	2.49 (0.46-13.4)
C2-Naphthalenes	45.6	26.5	18.2	18	3.67	7.81	3.67-45.6	14.9 (3.05-73.6)

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
2,6-Dimethylnaphthalene	17.3	10.4	7.17	7.62	0.726	1.18	0.726-17.3	4.51 (0.63-32.2)
C3-Naphthalenes	29.1	14.4	8.3	13.6	1.14	7.45	1.14-29.1	8.58 (1.42-51.6)
2,3,5-Trimethylnaphthalene	6.11	2.66	1.75	2.41	< 0.905	< 0.516	1.75-6.11	2.87
C4-Naphthalenes	17.5 (NDR)	5.92 (NDR)	3.81 (NDR)	6.71 (NDR)	2.95 (NDR)	9.5 (NDR)	2.95-17.5	6.48 (1.71-24.5)
Dibenzothiophene	1.73	0.27 (NDR)	0.22 (NDR)	6.48	< 0.18	< 0.209	0.22-6.48	0.903
C1-Dibenzothiophenes	1.85	0.434	0.211	2.22	< 0.217	< 0.374	0.211-2.22	0.783
C2-Dibenzothiophenes	12.4	1.27	1.18	3.43	1.82	7.93	1.18-12.4	3.11 (0.583-16.6)
1-Methylphenanthrene	13	3.21	2.94	3.03	2.21	7.09	2.21-13	4.24 (1.08-16.6)
4,5-Methylene phenanthrene	6.86	0.68	0.882	11.4	< 0.303	< 8.58	0.68-11.4	2.61
4,5-Methylene phenanthrene	6.86	0.68	0.882	11.4	< 0.303	< 8.58	0.68-11.4	2.61
3,6-Dimethylphenanthrene	5.71 (NDR)	2.51 (NDR)	1.85 (NDR)	1.39 (NDR)	< 0.371	< 0.682	1.39-5.71	2.46
C3-Phenanthrenes/Anthracenes	34.5	8.28	6.89	7.6	2.29	22.7 (NDR)	2.29-34.5	9.58 (1.83-50.1)
Retene	291	3.31	10.8	52.3	103	7700	3.31-7700	86.9 (2.87-2630)
C4-Phenanthrenes/Anthracenes	339	13.9	19.3	79.2	108	7740	13.9-7740	134 (6.73-2,700)
C1-Fluoranthenes/Pyrenes	29.7	5.78	5.34	29.2	10.5	136	5.34-136	18.3 (2.66-126)
C2-Fluoranthenes/Pyrenes	28.4	9.43	8.35	10.6	3.22	8.8	3.22-28.4	9.35 (2.33-37.4)

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM (95% CL)
C3-Fluoranthenes/Pyrenes	3.39 (NDR)	2.11 (NDR)	2.17 (NDR)	2.02 (NDR)	1.82	9.41	1.82-9.41	2.85 (0.764-10.6)
C4-Fluoranthenes/Pyrenes	2.37 (NDR)	0.53 (NDR)	0.66 (NDR)	1.04 (NDR)	1.22	< 1.97	0.53-2.37	1.01
LPAH [a]	117	50.1	38.9	6.01	8.22	112	6.01-117	32.9 (4.59-236)
HPAH [b]	97.1	16.4	14.5	10.0	20.98	171	10.0-172	30.8 (4.87-194)
Petroleum PAHs[c]	610	146	117	125	7,800	182	117-7,800	351 (34.2-3,600)
Combustion PAHs[d]	166	26.1	22.1	16.9	32.0	229	16.9-230	47.9 (7.85-292)

[a] Low molecular weight PAHs (LPAH) consist of Naphthalene, Acenaphthylene, Acenaphthene, Fluorene, Phenanthrene, Anthracene, 2-Methylnaphthalene.
[b] High molecular weight PAHs (HPAH) consist of Fluoranthene, Pyrene, Benz[a]anthracene, Chrysene.
[c] Petroleum PAHs (HPAH) consist of C2 Phenanthrenes/Anthracenes, C1 Phenanthrenes/Anthracenes, C1-Naphthalenes, C3-Naphthalenes, C4-Naphthalenes, Dibenzothiophene, C1-Dibenzothiophenes, C2-Dibenzothiophenes, C3-Phenanthrenes/Anthracenes
C4-Phenanthrenes/Anthracenes
[d] Combustion PAHs consist of Fluoranthene,Pyrene,Benz[a]anthracene,Chrysene, Benzo[b,j,k]fluoranthene, Benzo[e]pyrene, Benzo[a]pyrene, Indeno[1 ,2,3-c,d]-pyrene, Benzo[g,h,i]perylene

Appendix X. Concentrations of PBDEs in Cultus Lake sediments (ng/g dry wt). Values following < symbol represent method detection limits. GM = geometric mean. 95% CL = 95 % confidence limits.

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM	95% CL
% Moisture:	73.54	25.52	51.55	30.30	42.73	64.77			
PBDEs (ng/g dry wt) [d]									
BDE-17	0.008	0.0014	0.0021	0.003	0.0020	0.0017	0.001-0.008	0.002	0.0006-0.0079
BDE-28	0.015	0.0034	0.0055	0.0046	0.0055	0.0063	0.0034-0.015	0.006	0.0017-0.017
BDE-47	0.31	0.054	0.2	0.092	0.14	0.14	0.054-0.31	0.12	0.033-0.44
BDE-49	0.023	0.0027	0.007	0.0066	0.0053	0.0053	0.0027-0.023	0.006	0.002-0.024
BDE-66	0.011	0.0018	0.0052	0.0022	0.0041	0.0032	0.0018-0.011	0.004	0.001-0.013
BDE-100	0.086	0.0074	0.057	0.013	0.033	0.030	0.0074-0.086	0.025	0.005-0.12
BDE-101	0.0039	0.0004	0.0014	0.0008	0.0006	< 0.0001	0.0004-0.0039	0.0009	0.0002-0.004
BDE-99	0.40	0.03	0.28	0.055	0.14	0.14	0.030-0.40	0.11	0.02-0.59
BDE-118	0.0013	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-	-
BDE-85	0.024	0.0013	0.015	< 0.0001	0.0069	0.0073	0.0013-0.024	0.006	0.001-0.039
BDE-126	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	-	-
BDE-138	0.0039	0.0008	0.0011	< 0.0001	0.0006	0.0017	0.0005-0.0039	0.001	0.0003-0.005
BDE-155	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0007	< 0.0001	-	-	-
BDE-154	0.037	0.0019	0.019	0.0045	0.0087	0.01	0.0019-0.037	0.008	0.0016-0.043
BDE-153	0.030	0.0027	0.015	0.0047	0.0067	0.0076	0.0027-0.030	0.008	0.0017-0.035
BDE-183	0.013	0.0034	0.0043	0.0048	0.005	0.0078	0.0034-0.013	0.006	0.002-0.018
BDE-202	0.0023	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	-	-
BDE-201	0.0041	< 0.001	< 0.001	0.0012	< 0.001	< 0.001	0.0010-0.0041	0.002	0.0004-0.007
BDE-204/197/199	0.0074	0.0010	0.0016	0.0028	0.0019	0.0031	0.001-0.007	0.003	0.0007-0.009
BDE-200'/203/198	0.0071	0.0014	0.0019	0.0019	0.0017	0.0023	0.0014-0.007	0.002	0.0007-0.008
BDE-196	0.006	0.0010	0.0018	0.0018	< 0.001	0.0039	0.001-0.006	0.002	0.0006-0.008
BDE-208	0.018	0.0029	0.0048	0.0052	0.0048	0.008	0.0029-0.018	0.006	0.002-0.017
BDE-207	0.025	0.0069	0.0071	0.0098	0.0079	0.029	0.0069-0.029	0.012	0.003-0.041

	Spring Bay	Lindell A	Lindell B	Mallard	Chilliwack 1	Chilliwack 2	Range	GM	95% CL
BDE-206	0.058	0.015	0.026	0.018	0.017	0.072	0.015-0.072	0.027	0.0074-0.096
BDE-209	1.18	0.54	1.02	0.54	0.55	3.36	0.53-3.36	0.87	0.23-3.28
$\sum Br_{-1}.Br_{7}$ PBDEs	0.97	0.11	0.62	0.19	0.36	0.36	0.11-0.97	0.31	0.073-1.34
$\sum Br_{-1}.Br_{10}$PBDEs	2.30	0.68	1.68	0.78	0.95	3.84	0.68-3.84	1.28	0.34-4.81

Appendix XI. Budget and expenditures

Project Title: Contaminant exposure risk to developing Cultus Lake sockeye embryo's

	Items Identified in Budget	Actual Expenditures	Comment
PSC Funding			
Received June 2007	-$41,400		
Holdback - August 2008	-$4,600		
Total	-$46,000		
Project Support Biologist (hired externally)	$4,500	$4,479	DFO funded- C. Tovey salary
Field Sampling	$6,450	$9,278	Golder contract included most field costs
field crew travel to sites	$500		
boat rental and field sampling equipment	$500		
shipping and storage of samples	$500		
Laboratory analysis:	$33,550	$22,600	AXYS Analytical - includes Brooks Rand
		$9,500	LEACA Analysis - IOS
Balance		-$143	

Appendix XII. Particle size, total organic carbon (TOC), acid volatile sulphides (AVS) and simultaneously extractable metals (SEM) from sediment samples at each site.

Sample ID Description Client ID Sampled Date Sampled Time	07-NOV-07 LINDELL A	07-NOV-07 LINDELL B	07-NOV-07 SPRING Bay	09-NOV-07 MALLARD Bay	08-NOV-07 CHILLIWACK 1	08-NOV-07 CHILLIWACK 2
% Moisture (%)	27.8	18.5	82.7	23.3	61.4	77.9
Acid Volatile Sulphides (umol/g)	<0.22	<0.20	1.6	1.06	<0.33	0.75
Extractable Metals (umol/g)						
Cadmium (Cd)	<0.0050	<0.0050	0.011	<0.0050	<0.0050	<0.010
Copper (Cu)	0.236	0.122	0.578	0.092	0.35	0.411
Lead (Pb)	<0.020	<0.020	0.085	0.029	0.066	0.046
Mercury (Hg)	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Nickel (Ni)	0.238	0.074	0.28	<0.050	<0.050	<0.10
Zinc (Zn)	0.384	0.198	1.01	0.23	0.236	0.27
Total Organic Carbon (%)	0.4	0.9	7.7	0.2	3.3	5.4
Particle Size (%)						
Gravel (>2mm)	6	21	<1	9	<1	3
Sand (2.0 - 0.063 mm)	89	71	33	87	37	70
Silt (0.063mm - 4 um)	2	6	49	2	56	23
Clay (<4 um)	2	3	18	2	7	5