POLYCHLORINATED DIOXINS AND -FURANS IN LAKE ROOSEVELT (COLUMBIA RIVER) SPORTFISH, 1990

by
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EXECUTIVE SUMMARY

Lake Roosevelt, in the northeast corner of Washington State, is the 151-mile long Columbia River reservoir formed by Grand Coulee Dam in 1941. The Washington State Department of Ecology (Ecology) conducted a survey of polychlorinated dioxins (PCDDs) and -furans (PCDFs) in Lake Roosevelt sportfish during May - October 1990.

The impetus for this survey was the detection, by Environment Canada and the British Columbia Ministry of Environment, of contaminated lake whitefish and mountain whitefish below the Celgar bleached kraft pulp mill in Castlegar, B.C., about 30 river miles upstream of Lake Roosevelt. The contaminants of concern were 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF). A health advisory was issued in British Columbia to limit consumption of whitefish caught below the mill. Celgar was established in the early 1960s and discharges approximately 98,000 m^3/day (26 million gallons) of untreated effluent to the Columbia River.

The objective of Ecology's Lake Roosevelt survey was to obtain an accurate estimate of mean TCDD and TCDF concentrations in muscle tissues of major sportfish species from popular fishing areas. The survey also included analysis of limited fish samples from Rufus Woods Lake, the Columbia River reservoir below Lake Roosevelt. Preliminary findings resulted in the Washington State Department of Health issuing an advisory in August 1990 that children under four years old, or weighing less than 40 pounds, should not eat whitefish from Lake Roosevelt. A final assessment of potential hazards to human health from eating fish caught in Lake Roosevelt is currently being prepared by the Health Department and will be available as a separate report (Mariën *et al.*, 1991. *Health implication of PCDD and PCDF concentrations reported from Lake Roosevelt sportfish*. Office of Toxic Substances, Washington State Department of Health, Olympia.) The human health issue is not addressed in the present report.

PCDDs and PCDFs are unintended byproducts of several industrial and combustion processes including pulp mills that bleach with chlorine, trace contaminants in chlorophenols (e.g., pentachlorophenol), and municipal waste incineration. Spills and fires with PCBs are additional major sources of PCDFs. These compounds are a potential hazard to aquatic life, wildlife, and human health due to their toxicity, persistence, and potential for bioaccumulation. Only 17 of the 210 different forms (congeners) of PCDDs/PCDFs are considered to be highly toxic; TCDD is the most toxic of these, with TCDF considered to be 1/10 as toxic as TCDD.

The toxicity of mixtures of PCDDs/PCDFs was evaluated in the present study using a set of toxicity equivalency factors (TEFs) to convert concentrations of individual congeners to equivalent concentrations of TCDD - referred to as TCDD toxicity equivalents or TEQs. For example, a fish sample having 2.3 parts per trillion (ppt) of TCDD and 177 ppt of TCDF would have a TEQ of 20 ppt (2.3 X 1 + 177 X 0.1 = 20; the TEFs for TCDD and TCDF being 1 and 0.1, respectively). In other words, the combined toxicity of the TCDD and TCDF concentrations in this sample would be equivalent to a sample having 20 ppt of TCDD.

There is currently much disagreement on the levels of PCDDs and PCDFs in fish or other food that warrant advisories for human health. The health advisories issued for whitefish in British Columbia were based on Health and Welfare Canada's legal limit of 20 ppt TCDD (in this instance applied to TEQs) and the B.C. Ministry of Environment's preliminary health advisory level for the Columbia River of 11.4 ppt TEQ. As of this writing, the Washington State Department of Health has not completed their human health assessment for PCDDs and PCDFs in Lake Roosevelt fish.

Ecology analyzed muscle tissue samples from Lake Roosevelt walleye (12 samples), rainbow trout (12 samples), lake whitefish (12 samples), white sturgeon (4 samples), kokanee--a land-locked sockeye salmon (2 samples), and burbot--a freshwater cod (2 samples). Walleye, rainbow trout, and lake whitefish (2 - 3 samples each) were analyzed from Rufus Woods Lake. Each sample was a composite of tissues from five individual fish (four in the case of burbot). Forty-four composites were analyzed from Lake Roosevelt and seven composites from Rufus Woods Lake, representing a total of 253 individual fish.

TCDD was detected in all samples of Lake Roosevelt kokanee, lake whitefish, and sturgeon, and in most rainbow trout samples. It was not detected in burbot or in the majority of walleye samples. TCDF was detected in all species. TCDF concentrations in Lake Roosevelt fish (0.9 - 222 ppt) consistently exceeded TCDD concentrations (not detected - 4.4 ppt) by one- to two-orders of magnitude and accounted for 76% of the combined toxicity estimate (TEQ). Analysis of selected lake whitefish and sturgeon samples for other potentially toxic PCDDs and PCDFs showed these were not present in high concentrations, contributing less than 5% to the TEQ.

The following mean concentrations were observed in Lake Roosevelt fish:

	Upper Lake Roosevelt				Lower Lake Roosevelt			
	LIPID	TCDD	TCDF	TEQ	LIPID	TCDD	TCDF	TEQ
burbot:	0.4%	ND*	2.8	0.3	(no samples)			
walleye:	0.2%	ND	3.0	0.5	0.3%	ND	2.0	0.4
rainbow trout:	3.3%	1.2	38	5.1	2.4%	ND	12	1.6
kokanee:	(no samples)**				10.5%	0.8	53	6.0
lake whitefish:	6.0%	1.9	126	15	6.6%	1.7	145	16
white sturgeon:	9.0%	2.4	147	17	(no samples)**			

* ND = not detected (on average) ** species uncommon here

Species differences were generally more important than location. This appeared to be largely a function of lipid (fat) content. A significant decrease was observed in TCDD/TCDF levels in rainbow trout between upper and lower Lake Roosevelt, but not for walleye or lake whitefish. Lake whitefish and sturgeon had much higher concentrations of TCDD and TCDF than other species, with average TEQs in the range of 15 - 17 ppt. One sample each of liver and eggs from lake whitefish was also analyzed and showed higher TEQs of 32 and 87 ppt, respectively.

Results from analysis of the limited number of fish samples from Rufus Woods Lake showed walleye and rainbow trout had low concentrations of TCDF (1.7 - 4.9 ppt) and little or no TCDD detected (0.2 ppt or less). However, concentrations in lake whitefish (2.1 - 2.2 ppt TCDD and 122 - 163 ppt TCDF) were comparable to those measured in Lake Roosevelt whitefish.

The whitefish sampled in Rufus Woods Lake may have originated in Lake Roosevelt and been flushed downstream during spring draw-down of the lake. This phenomena is commonly observed in other species. Evidence suggests no significant TCDD/TCDF sources between the border and Rufus Woods Lake. It further suggests substantial attenuation of these compounds between Lake Roosevelt and Rufus Woods Lake. This evidence includes Ecology data from analyses for PCDDs, PCDFs, and PCBs (a potential source of TCDF) in whitefish from both lakes, and PCDD/PCDF analysis of a series of bottom fish samples (largescale suckers) collected between the international border and Rufus Woods Lake.

The levels of TCDD and TCDF in Lake Roosevelt fish were compared to background concentrations, results of similar surveys in the lower Columbia River conducted by the Northwest Pulp & Paper Association and EPA, and data from an EPA national fish survey. Mountain whitefish analyzed by Ecology from a background lake in Washington (Lake Wenatchee) had low concentrations of TCDF (0.2 - 0.4 ppt) and no detectable TCDD. The level of TCDF in Lake Roosevelt fish, especially lake whitefish and sturgeon, is very high from both a local and national perspective. TCDD concentrations, although substantially elevated above background in several Lake Roosevelt species, were generally comparable to those in resident fish in the lower Columbia River and can be characterized as low to moderate based on the EPA national survey.

By virtue of their TCDF levels, TEQs in all Lake Roosevelt species are elevated to some degree. The TEQs in lake whitefish and sturgeon from Lake Roosevelt are the highest so far reported in the Columbia (other than in the immediate vicinity of the Celgar outfall) and rank among the top 10% of TEQs in EPA's national fish survey.

The biological significance of these findings for fish and their predators in Lake Roosevelt is not known. Fish are among the most sensitive organisms to PCDDs/ PCDFs. Recent research on the impact of these compounds shows TEQs of 1 to 65 ppt in fish tissue have effects that range from increased activity of detoxifying liver enzymes to significant mortality of eggs and fry. Experiments have shown TCDD concentrations of 1,000 - 2,000 ppt in tissues of young rainbow trout and carp are associated with 50% lethality. A U.S. Fish and Wildlife Service review has recommended that TCDD concentrations in food items should not exceed 10 to 12 ppt to protect birds and other wildlife.

The Celgar Pulp Co. has received approval to expand its Castlegar, B.C., mill and proposes to install the latest available technology to reduce discharge of PCDDs and PCDFs. These steps are in line with the dioxin control strategy proposed for Washington pulp and paper mills. It is the opinion of the Canadian Department of Fisheries & Oceans and Department of Environment that the new mill will not contribute significantly to the present levels of contamination in fish. Because process changes and installation of treatment facilities will take at least two to three years and because of the persistence of PCDDs/PCDFs in sediments, it may take some years for concentrations to decline in Lake Roosevelt fish.

Based on results of Ecology's survey it is recommended that:

1. The earliest possible installation of wastewater treatment and implementation of PCDD/PCDF control at Celgar be encouraged.

2. A monitoring program be established for Lake Roosevelt to follow trends in fish contamination.

3. Studies be undertaken to determine if adverse biological effects are occurring in the lake.

INTRODUCTION

Lake Roosevelt, in the northeast corner of Washington State, is the largest of 11 Columbia River reservoirs in Washington and sixth largest reservoir in the United States (Figure 1). Created by completion of Grand Coulee Dam in 1941, the lake has a full-pool length of 151 miles and average depth of 118 feet. The lake and shoreline constitute the Coulee Dam National Recreation Area, which is managed by the National Park Service. Over one million people visit the recreation area each year.

Thirty river miles (48 km) upstream of Lake Roosevelt is the Celgar pulp mill in Castlegar, British Columbia. Celgar uses the bleached kraft process to produce softwood pulp. In operation since the early 1960s, it was the first inland pulp mill in the province. The mill's effluent, about 98,000 m^3/day (26 million gallons) is discharged to the Columbia River without treatment.

During the spring of 1988, Environment Canada conducted a survey of polychlorinated dioxins (PCDDs) and -furans (PCDFs) in fish and sediments at ten inland pulp mills in British Columbia (Mah *et al.*, 1989). Celgar was one of the mills investigated. Environment Canada found high concentrations of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) in muscle tissue of lake whitefish below Celgar. TCDD and TCDF concentrations were 6.6 - 10.5 parts per trillion (ppt) and 647 - 908 ppt, respectively. As a result, a health advisory was issued that recommended consumption of lake whitefish from an area up to seven kilometers downstream of the mill should be limited to no more than 40 grams (1.4 oz.) per week (Kirkpatrick, 1989).

The B.C. Ministry of Environment analyzed additional fish muscle samples collected below Celgar in November 1989. Their results showed elevated levels of TCDF (up to 170 ppt) in a second species, mountain whitefish. An advisory was subsequently issued to restrict consumption of mountain whitefish to a maximum of 205 grams (7.2 oz.) per week (B.C. Ministry of Environment, 1990).

Concerned that contamination might extend into Lake Roosevelt, the Washington State Department of Ecology (Ecology) analyzed muscle tissue samples from two walleye and two white sturgeon collected in the upper lake during June - July 1989 (Johnson, 1990a). TCDD and TCDF were detected. Because of the small sample size and a wide range in concentrations, the results were considered inconclusive.

In light of this information, Ecology initiated an intensive survey of Lake Roosevelt fish during 1990. The objective was to obtain an accurate estimate of mean TCDD and TCDF concentrations in muscle tissue of major sportfish species from popular fishing areas. The survey included analysis of limited fish samples from Rufus Woods Lake, the reservoir below Lake Roosevelt. Although the focus was on TCDD and TCDF, a subset of samples was also analyzed for other potentially toxic PCDDs and PCDFs.

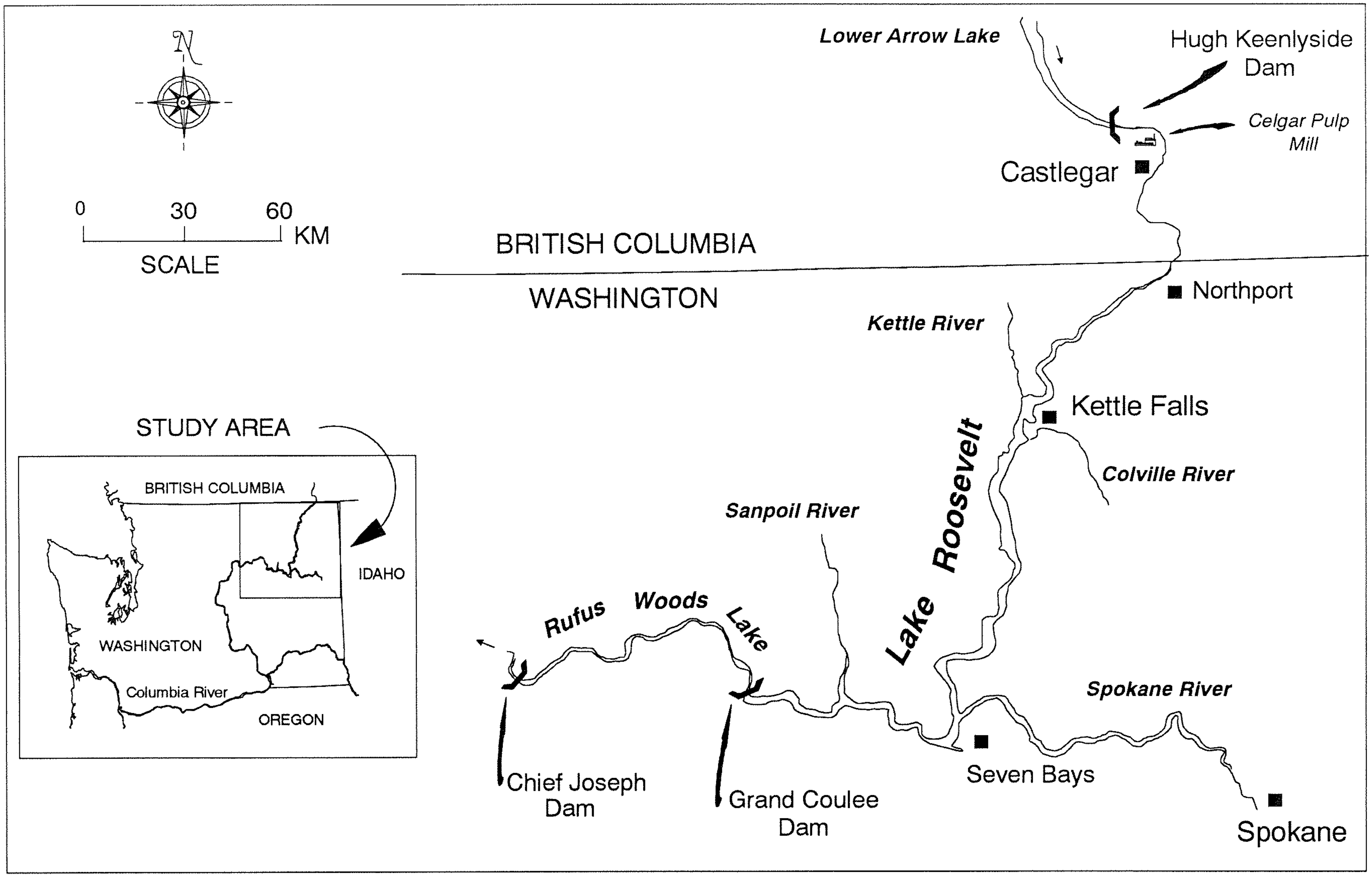

Figure 1. Study Area for Ecology 1990 Survey of PCDDs and PCDFs in Lake Roosevelt Sportfish

The final results of Ecology's sportfish survey are reported here. Preliminary results were made public through progress reports and press releases in August and November 1990 (Johnson *et al.*, 1990 b,c). From the survey's outset, Ecology has provided analytical results to the Washington State Department of Health as they became available. In response to preliminary findings, a limited advisory was made in August that "children under four years old, or weighing less than 40 pounds, should not eat whitefish from Lake Roosevelt" (Gebbie, 1990). A final assessment of potential risks to human health from eating fish caught in Lake Roosevelt has been prepared by the Health Department and is available as a separate report (Mariën *et al.*, 1991). The human health issue is not addressed in the present report.

Related work conducted by Ecology in Lake Roosevelt during 1990 included analysis of PCDDs and PCDFs in water samples (particulate fraction) collected near the international border and an attempt to evaluate trends in concentrations of these compounds through the lake using sediment and bottom fish samples. Some of the bottom fish data are included in the present report; the complete results of the above studies will be available in April 1991.

BACKGROUND ON PCDDs AND PCDFs

PCDDs and PCDFs are synthetic compounds that enter the environment as unintended byproducts of several industrial and combustion processes. The most significant sources are pulp mills that bleach with chlorine, as trace contaminants in chlorophenols (pentachlorophenol; 2,4,5-trichlorophenol; 2,4-D; 2,4,5-T; hexachlorophene), and municipal waste incinerators; spills and fires involving PCBs are an additional major source of PCDFs (EPA, 1987; Palmer *et al.*, 1988; Environment Canada/Health and Welfare Canada, 1990).

Chemical structures are shown in Figure 2. There are 75 different forms (congeners) of PCDDs and 135 congeners of PCDFs. The most toxic congeners have chlorine atoms substituted at the lateral positions on the molecule (i.e., position numbers 2, 3, 7, and 8). Seven PCDDs and ten PCDFs have this configuration. 2,3,7,8-substituted TCDD is the most toxic of these; 2,3,7,8-substituted TCDF is considered to be 1/10 as toxic as TCDD (see below).

Being widespread in the environment, PCDDs and PCDFs are commonly detected in air, sediments, and biota (Petty *et al.*, 1983; Czuczaw and Hites, 1986). They represent a potential hazard to aquatic life, wildlife, and human health because of their toxicity, persistence, and potential for bioaccumulation (NRCC, 1981; Eisler, 1986).

PCDDs and PCDFs have a low solubility in water; less than one part per billion (Crummet and Stehl, 1973). When discharged to aquatic environments, their primary fate is sorption to the sediments and accumulation in biota. By virtue of their solubility in lipid (fat), concentrations in fish may exceed water concentrations by factors of 5,000 - 100,000 (Maybe *et al.*, 1982; EPA, 1984; Opperhuizen and Sijm, 1990). Uptake is thought to be greatest for species that live in contact with the sediments and/or are part of food webs linked to sediments; 2,3,7,8-substituted congeners are preferentially accumulated (Cook, 1987; Kuehl *et al.*, 1987). The

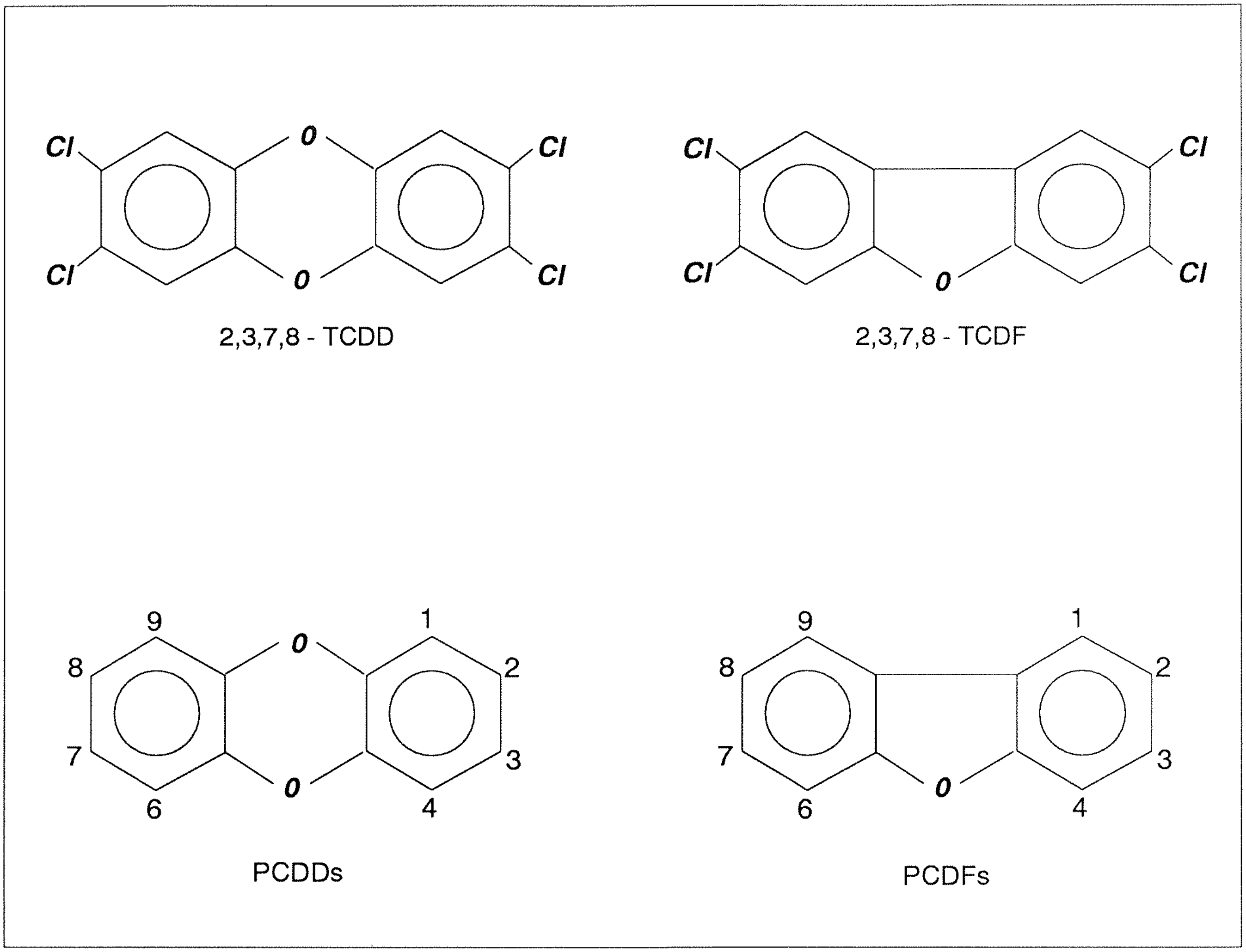

Figure 2. Chemical Structure of TCDD and TCDF and Numbering System for PCDDs and PCDFs

half-life of PCDDs/PCDFs in aquatic sediments probably exceeds one year and may be ten years or more (Callahan *et al.*, 1979; Eisler, 1986; CCREM, 1987).

In the present report, the toxicity of PCDD/PCDF mixtures in fish tissues is evaluated using a set of toxicity equivalency factors (TEFs) to convert concentrations of individual congeners to equivalent concentrations of 2,3,7,8-TCDD--referred to as toxicity equivalents or TEQs. This approach, adopted by EPA, uses results from a variety of studies that have shown the relative potency of different PCDDs/PCDFs is generally consistent across a range of experimental endpoints (Bellin and Barnes, 1987; Olson *et al.*, 1989; Barnes *et al.*, 1989).

Table 1 shows EPA's most recent estimate of TEFs for 2,3,7,8-substituted PCDDs/PCDFs and an example of their use in calculating a TEQ for a hypothetical fish sample. Although non-2,3,7,8 congeners do have some toxic properties, they are assigned a TEF of zero because it is the 2,3,7,8-congeners that have been shown to predominate in a variety of biological tissues, including fish (Barnes *et al.*, 1989).

There is currently much disagreement on the concentrations of PCDDs and PCDFs in fish or other food that warrant advisories for human health. Canadian health advisories on consumption of lake and mountain whitefish downstream of the Celgar mill have been based on Health and Welfare Canada's legal limit of 20 ppt TCDD (here applied to TEQs) and the B.C. Ministry of Environment's preliminary health advisory level for the Columbia River of 11.4 ppt TEQ. As of this writing, the Washington State Department of Health has not completed their human health assessment for PCDDs and PCDFs in Lake Roosevelt fish.

The U.S. Food and Drug Administration (Hall, 1981) has advised that TCDD concentrations less than 25 ppt are little cause for human health concern. Ecology, on the other hand, uses a criterion of 0.07 ppt TCDD in fish tissue to assess violations of state surface water quality standards. This value is for an increased lifetime cancer risk of 1 in 1,000,000 and is derived from the EPA health criterion for TCDD of 0.013 parts per quadrillion in water and a bioconcentration factor of 5,000 (EPA, 1986).

SAMPLING DESIGN

Species and Sampling Locations

Information on fishing patterns in Lake Roosevelt was obtained from the Upper Columbia United Tribes (UCUT) Fisheries Research Center (Peone *et al.*, 1991), Beckman *et al.*, (1985), and interviews with the following people:

Dr. Allan Scholz - Eastern Wash. University
Dr. Ann Setter - University of Idaho
Tim Peone - UCUT Fisheries Research Ctr.
Kirk Truscott - Colville Tribe
Larry Goodrow - Spokane Tribe
Lyle Bennet - local citizen
Jack Tenter - local citizen

Gig Lebret - National Park Service
John Hisata - Department of Wildlife
Joe Foster - Department of Wildlife
Jim Meskan - Department of Wildlife
Jim Ebel - Department of Wildlife
Bill Zook - Department of Fisheries
Larrie LaVoy - Department of Fisheries

Table 1. Toxicity Equivalency Factors (TEF) for PCDDs and PCDFs (from Barnes et al., 1989) and Example of TEQ Calculation

Compound	TEF
PCDDs:	
Mono-, Di-, and TriCDDs	0
2,3,7,8-TCDD	1
Other TCDDs	0
1,2,3,7,8-PeCDD	0.5
Other PeCDDs	0
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
Other HxCDDs	0
1,2,3,4,6,7,8-HpCDD	0.01
Other HpCDDs	0
OCDD	0.001
PCDFs:	
Mono-, Di-, and TriCDFs	0
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
Other PeCDFs	0
1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
Other HxCDFs	0
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
Other HpCDFs	0
OCDF	0.001

Example TEQ Calculation:

Compound	Fish Tissue Concentration		TEF	
2,3,7,8-TCDD	2.3 ppt	X	1	= 2.3 ppt
2,3,7,8-TCDF	177 ppt	X	0.1	= + 17.7 ppt
Combined estimate of 2,3,7,8,-TCDD toxicity equivalents (TEQ)				= 20 ppt

Based on the above sources, sampling efforts in Lake Roosevelt centered on four species--walleye (*Stizostedion vitreum*), rainbow trout (*Oncorhyncus mykiss*, formerly *Salmo gairdneri*), white sturgeon (*Acipenser transmontanus*), and lake whitefish (*Coregonus clupeaformis*). Limited numbers of kokanee (*Oncorhyncus nerka*, a land-locked sockeye salmon) and burbot (*Lota lota*, a freshwater cod) were also collected for analysis. The samples in Rufus Woods Lake consisted of walleye, rainbow trout, and lake whitefish.

There are no commercial fisheries (tribal or otherwise) on Lake Roosevelt. Walleye and rainbow trout are the most popular sportfish. The 1989 catch was estimated to be 80,600 and 65,500 fish, respectively (Peone *et al.*, 1991). The upper reaches of Lake Roosevelt have the only significant remaining sport fishery for sturgeon in the upper Columbia River. About 300 fish are taken annually, primarily off Marcus Island just above Kettle Falls (National Park Service creel census). There is no sturgeon fishery in the lower lake.

The fourth target species, lake whitefish, is commercially important in other parts of the U.S. and Canada. Although abundant in Lake Roosevelt, they are primarily taken incidentally by anglers fishing for other species. Lake whitefish were considered a priority for analysis because of the high TCDD/TCDF concentrations reported in this species on the Canadian side of the border.

Fish were collected in two areas of Lake Roosevelt (Figure 3)--the upper lake between Northport and Kettle Falls (river miles 735 - 700) and the lower lake between Seven Bays and Spring Canyon (river miles 637 - 600). These are the reaches that get the most fishing pressure. Sturgeon and burbot samples were from the upper lake; kokanee were only encountered in the lower lake. Samples from Rufus Woods Lake were collected near Chief Joseph Dam at Bridgeport State Park (river miles 550 - 546).

Sampling in Lake Roosevelt was conducted over a six-month period between May and October 1990. Rufus Woods Lake samples were collected in August 1990.

Sample Size

Assessments of risk to human health from consumption of chemically contaminated fish are based on long-term average exposure. Therefore, following recommendations by EPA (1989), composite samples were analyzed to provide an efficient estimate of mean TCDD and TCDF concentrations. Each sample consisted of muscle tissue from five individual fish (four in the case of burbot).

For the four major target species--walleye, rainbow trout, lake whitefish, and sturgeon--an effort was made to analyze six composites per species each in upper and lower (except sturgeon) Lake Roosevelt. Ultimately only four sturgeon composites (i.e., 20 fish) could be obtained. As shown in Table 2, a total of 51 composite tissue samples--44 from Lake Roosevelt, seven from Rufus Woods Lake--representing 253 fish were analyzed during the course of the survey.

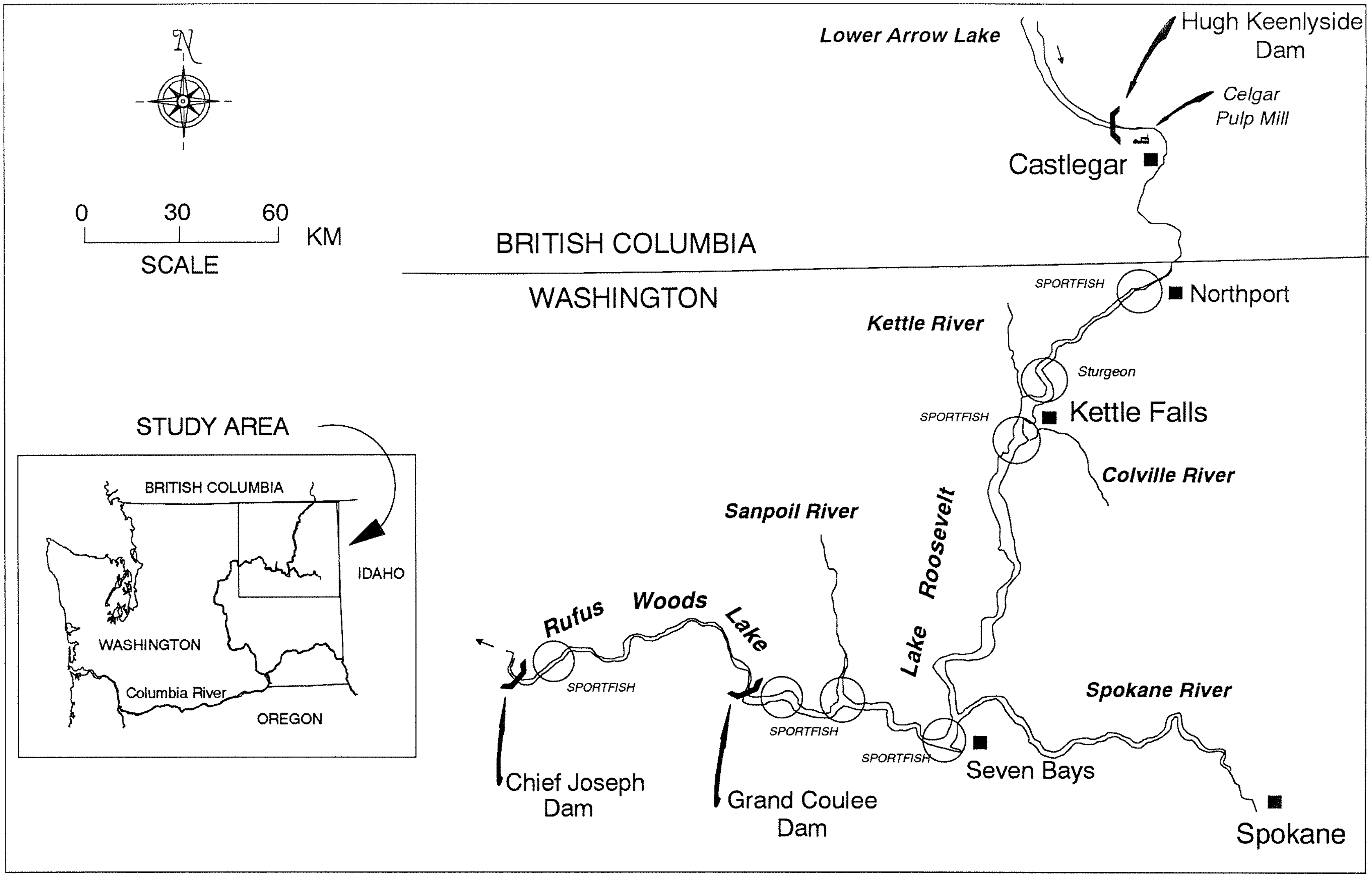

Figure 3. Approximate Location of Ecology Sportfish Samples Collected in Lake Roosevelt and Rufus Woods Lake During 1990

Table 2. Sportfish Samples Collected in Lake Roosevelt and Rufus Woods Lake, May–October 1990 (each sample a five fish composite)

Species	Upper Lake Roosevelt	Lower Lake Roosevelt	Rufus Woods Lake
Walleye	6	6	2
Rainbow Trout	6	6	3
Lake Whitefish	6	6	2
White Sturgeon	4	0	0
Kokanee	0	2	0
Burbot *	2	0	0
Total composites each site	24	20	7

* Four fish composite

Sample size was selected to compare favorably with other surveys of PCDDs/PCDFs in Columbia River fish and to afford a reasonable opportunity to detect significant differences between species and sampling sites. Fish samples from the Columbia have been analyzed for PCDDs/PCDFs by Environment Canada (Mah *et al.*, 1989), EPA (Tetra Tech, Inc. 1990 - draft), the Northwest Pulp & Paper Association (Beak Consultants, Inc., 1989; Keenan *et al.*, 1990) and the B.C. Ministry of Environment (1990). In the first three of these investigations, the number of individual fish per composite ranged from three to eight with two to five composites per species per sampling site. The B.C. Ministry of Environment analyzed individual fish.

Variance estimates were not available to determine the sample size required to detect statistically significant differences between species or sampling sites in Lake Roosevelt. Tetra Tech, Inc. (1986) evaluated the effects of sample replication on statistical power of sampling designs for contaminants in fish and shellfish. They recommended five composite samples of five to ten individual organisms each for moderate levels of variability in chemical residue data.

FISH COLLECTION AND SAMPLE PREPARATION

Fish were collected by electroshocking, gill net, or, in the case of sturgeon, hook-and-line. An effort was made to take only legal size fish as samples. In a few instances, smaller than legal fish were included to achieve the desired sample size. Lake whitefish and burbot have no size limits; only individuals large enough to reasonably be kept for consumption were retained.

Fish selected for analysis were individually wrapped in aluminum foil, placed in polyethylene bags, and stored on ice for transport to the EPA/Ecology Manchester, Washington laboratory where they were frozen for later dissection. Time on ice typically ranged from one to three days. Total length and fresh weight (except sturgeon) were measured on each fish. Age was estimated from scales, otoliths, or pectoral spines.

At the request of the Washington State Department of Fisheries, tissue samples for sturgeon came primarily from the sport catch. These were obtained through the Washington State Department of Wildlife and National Park Service and consisted of the head severed behind the base of the pectoral spine, packaged as described above, and frozen within 24 hours of collection. Tissue samples were also collected by Ecology from five sturgeon taken for research purposes by the University of Idaho.

Tissue samples were prepared by compositing approximately 40 grams of anterior, epaxial muscle from each of five fish. The tissue was excised with stainless steel scalpels and forceps by removing a rectangular block of muscle above the lateral line and forward of the dorsal fin; skin was discarded. In addition to muscle tissue, one sample each of liver and eggs was composited from three lake whitefish.

For sturgeon, 40 grams of epaxial muscle was removed from the back of each head after paring away tissue exposed in the field. In keeping with local consumption practice, excess fat was trimmed from the sturgeon samples.

New scalpel blades were used between each composite. Scalpel handles and forceps were washed with Liqui-Nox® detergent followed by sequential rinses with Milli-Q® water, pesticide-grade acetone, and pesticide-grade hexane. Sample containers were eight oz. amber glass with teflon lid-liners, specially cleaned for low level organics analysis (I-Chem, Hayward, CA; series 300).

ANALYTICAL METHODS

Tissue homogenation and chemical analyses were done by Triangle Laboratories, Inc. in Research Triangle Park, North Carolina. Each sample was analyzed for TCDD, TCDF, and percent lipids. Selected samples were analyzed for all 2,3,7,8-substituted PCDDs and PCDFs.

TCDD, TCDF, and other PCDDs/PCDFs were analyzed using EPA Method 8290 (isotope-dilution, high resolution GC/MS). Figure 4 diagrams the procedure. The 5 mL of extract used for lipid analysis was evaporated to 1 mL, transferred to a pre-weighed aluminum drying dish by rinsing with petroleum ether, dried in a fumehood overnight, and re-weighed for determination of percent lipid.

DATA QUALITY

All data were reviewed for qualitative and quantitative accuracy by Dr. William J. Luksemburg of Alta Analytical Laboratory, Inc., El Dorado Hills, California, an independent expert under contract to Ecology. The review included all ion chromatograms, initial and daily continuing calibrations, column performance check mixes, calculations of positive values and detection limits, isotopic abundance ratios for internal/surrogate/recovery standards and positive natives, matrix spikes and spike duplicates, and calculation of percent lipids. The review resulted in re-analysis or revised calculations for approximately 10% of the samples.

The precision associated with the data contained in this report can be estimated from results on duplicate sample aliquots (Table 3). On average, measurements of TCDD and TCDF concentrations in fish tissue agreed within 12%. Based on these data, analytical variability (pooled estimate of standard deviation) was approximately +/- 0.2 ppt TCDD, +/- 2.5 ppt TCDF (low level samples), and +/- 16 ppt TCDF (high level samples). Analysis of lipids was less precise, with duplicate results differing by 5.5 - 78%.

Standard reference materials were not available to assess the accuracy of PCDD/PCDF analysis in a fish tissue matrix (Foster *et al.*, 1990). In lieu of this, a fish tissue homogenate (smelt/carp composite from Petenwell Reservoir, Wisconsin River) prepared by the EPA Environmental Research Laboratory, Duluth, Minnesota and known to contain elevated levels of TCDD was submitted to Triangle Laboratories as a blind performance evaluation sample. The material was provided by Dr. Brian Butterworth.

Triangle's analysis of the performance evaluation sample agreed well with values given by the EPA Duluth laboratory. Triangle reported 24.2 +/- 1.3 ppt TCDD (n=2) compared to 19.6 +/- 2.0 ppt TCDD (n=12) reported by EPA.

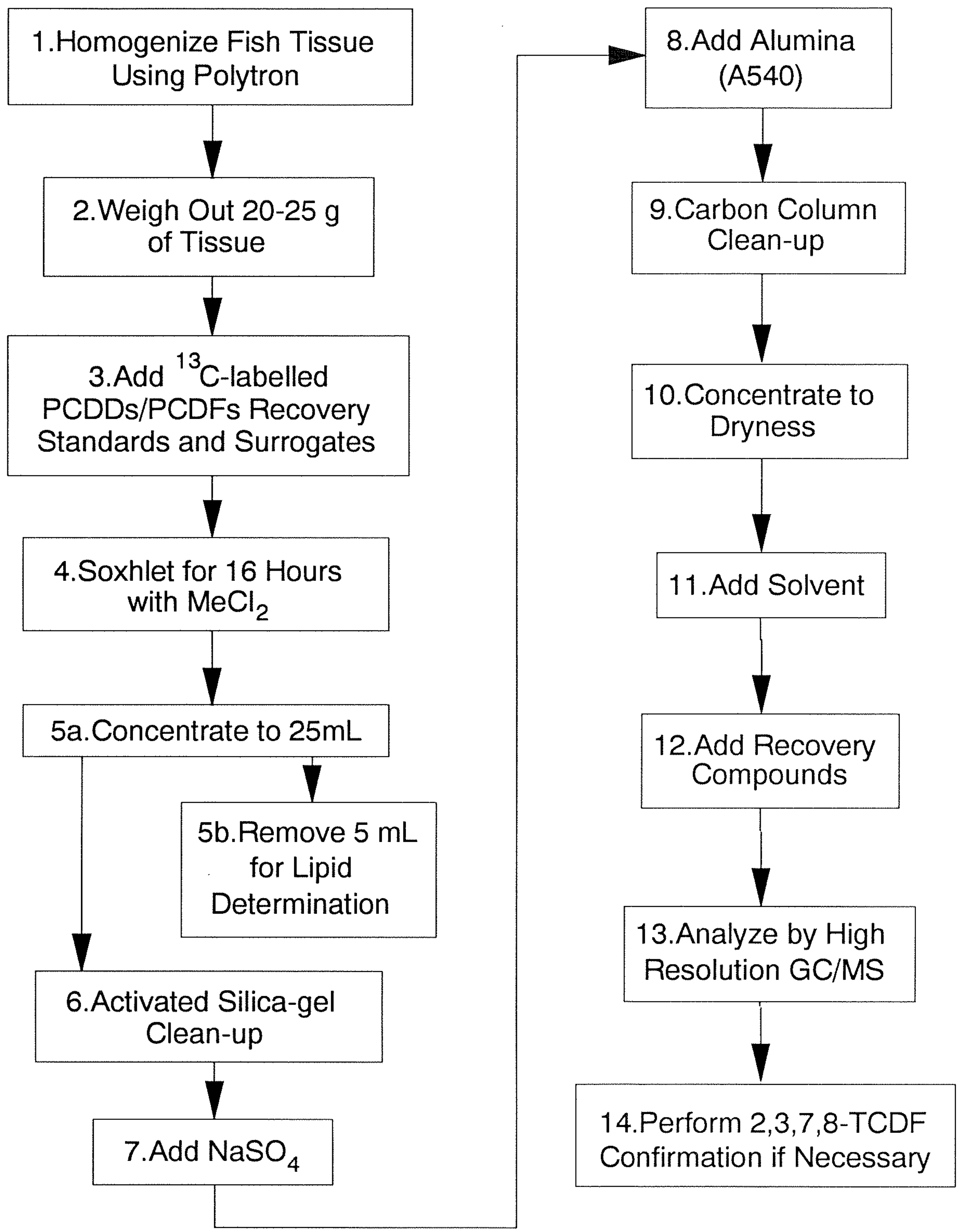

Figure 4. Schematic of Analytical Procedures for PCDDs and PCDFs

Table 3. Precision of Duplicate Analyses

Sample Number	2,3,7,8-TCDD (ppt) (1)	(2)	RPD
188234	ND(0.6)	ND(0.7)	--
328088	0.7	0.7	0%
328086	1.2	1.4	15%
188243	2.1	2.5	17%
428109	2.0	2.1	4.9%
368108	1.9	2.4	23%
	2,3,7,8-TCDF (ppt) (1)	**(2)**	**RPD**
188234	5.5	6.5	17%
328088	44.2	46.5	5.1%
328086	84.8	90.4	6.4%
188243	143	164	14%
428109	142	172	19%
368108	154	171	10%
	Lipid(%) (1)	**(2)**	**RPD**
188234	0.3	0.5	50%
328088	3.4	4.3	23%
328086	4.7	9.8	70%
188243	2.1	4.8	78%
428109	7.8	9.2	16%
368108	10.6	11.2	5.5%

RPD = relative percent difference (range as percent of mean)
ND = not detected; detection limit in parenthesis

INTERCOMPARISON WITH CANADA

An interlaboratory comparison exercise was conducted to establish a basis for comparing data between Environment Canada, the B.C. Ministry of Environment, and Ecology. Samples used in this study were composite muscle tissues (one each) from Columbia River mountain whitefish (*Prosopium williamsoni*), walleye, and largescale suckers (*Catostomus macrocheilus*) collected below the Celgar mill. The composites were prepared by Environment Canada and supplied to Ecology by Dr. Taina Tuominen.

Release of these data awaits a health risk assessment currently being conducted in Canada. Preliminary results show good agreement on measurements of TCDD and TCDF between Triangle and the two participating Canadian laboratories. Coefficients of variation calculated from the preliminary data were 37% for TCDD (detected in one sample only) and 8.5%, 17%, and 61% (a low level sample) for TCDF. The Canadian data are expected to become available in April 1991.

RESULTS[1]

1. Lake Roosevelt

TCDD/TCDF Concentrations

The concentrations of TCDD and TCDF measured in muscle tissues of Lake Roosevelt sportfish and resulting TEQs are shown in Table 4. Appendix A gives the location, date, length, weight, and estimated age of each fish included in the composites. For a given species, the average size and age of the fish in each composite were generally comparable. Lake whitefish samples from lower Lake Roosevelt were composed of fish that were one year older, on average, than those in the upper lake.

TCDD was detected in all samples of Lake Roosevelt kokanee, lake whitefish, and sturgeon, and in most (8 of 12) rainbow trout samples. Concentrations detected in these species ranged from 0.5 - 4.4 ppt. The highest concentrations (generally 1.5 ppt or greater) occurred in lake whitefish and sturgeon. TCDD was not detected in burbot or in the majority (8 of 12) of walleye samples. The detection of TCDD in walleye (0.2 - 0.3 ppt) was near the detection limit of the analytical method (0.1 - 0.2 ppt).

All species in both the upper and lower lake had detectable concentrations of TCDF ranging from 0.9 - 222 ppt. TCDF consistently exceeded TCDD by one to two orders of magnitude. Lake whitefish and sturgeon again had the highest levels, exceeding 100 ppt in most samples.

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[1]Results are expressed on a wet weight basis in units of parts per trillion (ppt). All calculations of means, TEQs, and statistical tests in this report assumed a concentration of half the detection limit for non-detected values.

Table 4. TCDD and TCDF Concentrations in Muscle Tissue of Lake Roosevelt Sportfish Collected May–October 1990 (parts per trillion, wet weight basis; each sample a five fish composite)

	Upper Lake Roosevelt					Lower Lake Roosevelt				
Species	Sample Number	Lipid (%)	2,3,7,8-TCDD	2,3,7,8-TCDF	TEQ	Sample Number	Lipid (%)	2,3,7,8-TCDD	2,3,7,8-TCDF	TEQ
Burbot*	448081	0.4	ND(0.1)	2.7	0.3	--	--	--	--	--
	448080	0.4	ND(0.1)	2.9	0.3	--	--	--	--	--
	mean±1SD=	0.4±0	ND	2.8±0.1	0.3±0		No Samples			
Walleye	328084	0.2	ND(0.2)	0.9	0.2	448084	0.3	ND(0.1)	1.1	0.2
	328083	0.2	ND(0.2)	2.1	0.3	448086	0.6	ND(0.2)	1.1	0.2
	188236	0.1	ND(0.2)	2.8	0.4	448085	0.4	ND(0.1)	1.8	0.2
	328085	0.2	ND(0.1)	0.9	0.6	188242	0.1	0.2 EMPC	1.2	0.3
	188235	0.2	0.3	5.1	0.8	188241	0.3	0.2 EMPC	2.2	0.4
	188234	0.4	ND(0.6)	6.0	0.9	188240	0.2	0.3 EMPC	4.9	0.8
	mean±1SD=	0.2±0.1	ND	3.0±2.1	0.5±0.3	mean±1SD=	0.3±0.2	ND	2.0±1.5	0.4±0.2
Rainbow Trout	428105	2.1	0.8	24.2	3.2	328082	1.4	ND(0.1)	3.7	0.4
	328087	3.5	1.5 EMPC	21.9	3.7	188230	2.3	ND(0.2)	6.2	0.7
	428108	4.0	1.3	37.1	5.0	328081	2.8	ND(0.2)	8.0	0.9
	428107	3.7	1.6	44.3	6.0	328080	2.1	ND(1.2)	7.9	1.4
	328086	2.2	0.9	53.2	6.2	188232	2.3	1.1	9.7	2.1
	428106	4.4	1.3	50.3	6.3	188231	3.3	0.7 EMPC	35.6	4.3
	mean±1SD=	3.3±1.0	1.2±0.3	38±13	5.1±1.3	mean±1SD=	2.4±0.6	ND	12±12	1.6±1.4

Table 4. (Continued)

Species	Upper Lake Roosevelt Sample Number	Upper Lipid (%)	Upper 2,3,7,8-TCDD	Upper 2,3,7,8-TCDF	Upper TEQ	Lower Lake Roosevelt Sample Number	Lower Lipid (%)	Lower 2,3,7,8-TCDD	Lower 2,3,7,8-TCDF	Lower TEQ
Kokanee	--	--	--	--	--	448082	16.4	0.7	42.1	4.9
	--	--	--	--	--	188233	4.6	0.9	63.3	7.2
		No Samples				mean±1SD=	10.5±8.3	0.8±0.1	53±15	6.0±1.6
Lake Whitefish	428111	7.6	1.2	77.6	9.0	188239	3.6	0.5	41.6	4.7
	428110	7.7	1.9	118	14	448087	8.0	1.2	122	13
	188245	7.1	1.9	120	14	188238	4.2	1.5	133	15
	188244	1.4	1.9	131	15	188237	1.3	2.3	174	20
	428109	8.5	2.0	157	18	448089	12.1	1.9	196	22
	188243	3.4	2.3	154	18	448088	10.4	2.7	205	23
	mean±1SD=	6.0±2.9	1.9±0.4	126±29	15±3.3	mean±1SD=	6.6±4.2	1.7±0.8	145±61	16±6.9
White Sturgeon	328088	6.0	0.8	72.5	8.0	--	--	--	--	--
	328090	7.8	1.7	117	13	--	--	--	--	--
	448083	10.5	4.4	176	22	--	--	--	--	--
	328089	11.5	2.6	222	25	--	--	--	--	--
	mean±1SD=	9.0±2.5	2.4±1.5	147±66	17±7.9		No Samples			

* four fish composites
ND = not detected; detection limit in parenthesis
SD = standard deviation
EMPC = estimated maximun possible concentration
Note: 1/2 detection limit used to calculate means and TEQs for non-detected values

TEQs calculated from these data were between 0.2 and 25 ppt. On average, TCDF accounted for 76% of the combined toxicity estimate. TEQs in lake whitefish and sturgeon were generally over 10 ppt, with TCDF contributing an average of 88% of the TEQ in these species.

Figures 5a,b summarize the levels of TCDD, TCDF, and TEQs found in Lake Roosevelt sportfish. The following mean concentrations were observed (ppt):

	Upper Lake Roosevelt				Lower Lake Roosevelt			
	LIPID	TCDD	TCDF	TEQ	LIPID	TCDD	TCDF	TEQ
burbot:	0.4%	ND*	2.8	0.3		(no samples)		
walleye:	0.2%	ND	3.0	0.5	0.3%	ND	2.0	0.4
rainbow trout:	3.3%	1.2	38	5.1	2.4%	ND	12	1.6
kokanee:		(no samples)**			10.5%	0.8	53	6.0
lake whitefish:	6.0%	1.9	126	15	6.6%	1.7	145	16
white sturgeon:	9.0%	2.4	147	17		(no samples)**		

* ND = not detected (on average)
** = species uncommon here

Results of analysis on liver and eggs from lake whitefish are in Table 5. These organs, particularly the eggs, had much higher concentrations of TCDD and TCDF than found in muscle tissue. Concentrations in eggs were substantially elevated at 8.5 ppt TCDD, 787 ppt TCDF, and a TEQ of 87 ppt.

Importance of Species and Location

Species differences appeared to be more important than location. There was a general pattern of increasing TCDD/TCDF concentrations following the order: burbot < walleye < rainbow trout < kokanee < lake whitefish and sturgeon. This seemed to be largely a function of lipid (fat) content.

Figure 6 plots TCDD and TCDF concentrations against percent lipids (pooled data for upper and lower lake). With the exception of one outlier with low TCDD/TCDF concentrations for its lipid content, TCDD and TCDF were well correlated with lipid (Spearman's rho, $r_s = 0.76$ and 0.85, respectively; outlier excluded). These correlations did not change appreciably when upper and lower lake data were considered separately.

Sample size was appropriate to test the significance of species and location differences for walleye, rainbow trout, and lake whitefish. Pair-wise comparisons (Wilcoxon rank sum test) showed that, except for TCDD in walleye and rainbow trout from the lower lake, between-species differences in TCDD and TCDF concentrations were significantly different ($p \leq .05$ probability level) in the upper lake and in the lower lake. When results for each of these species were compared between locations, only rainbow trout showed a significant ($p \leq .05$) change (decrease) in TCDD and TCDF concentrations going from the upper to lower lake.

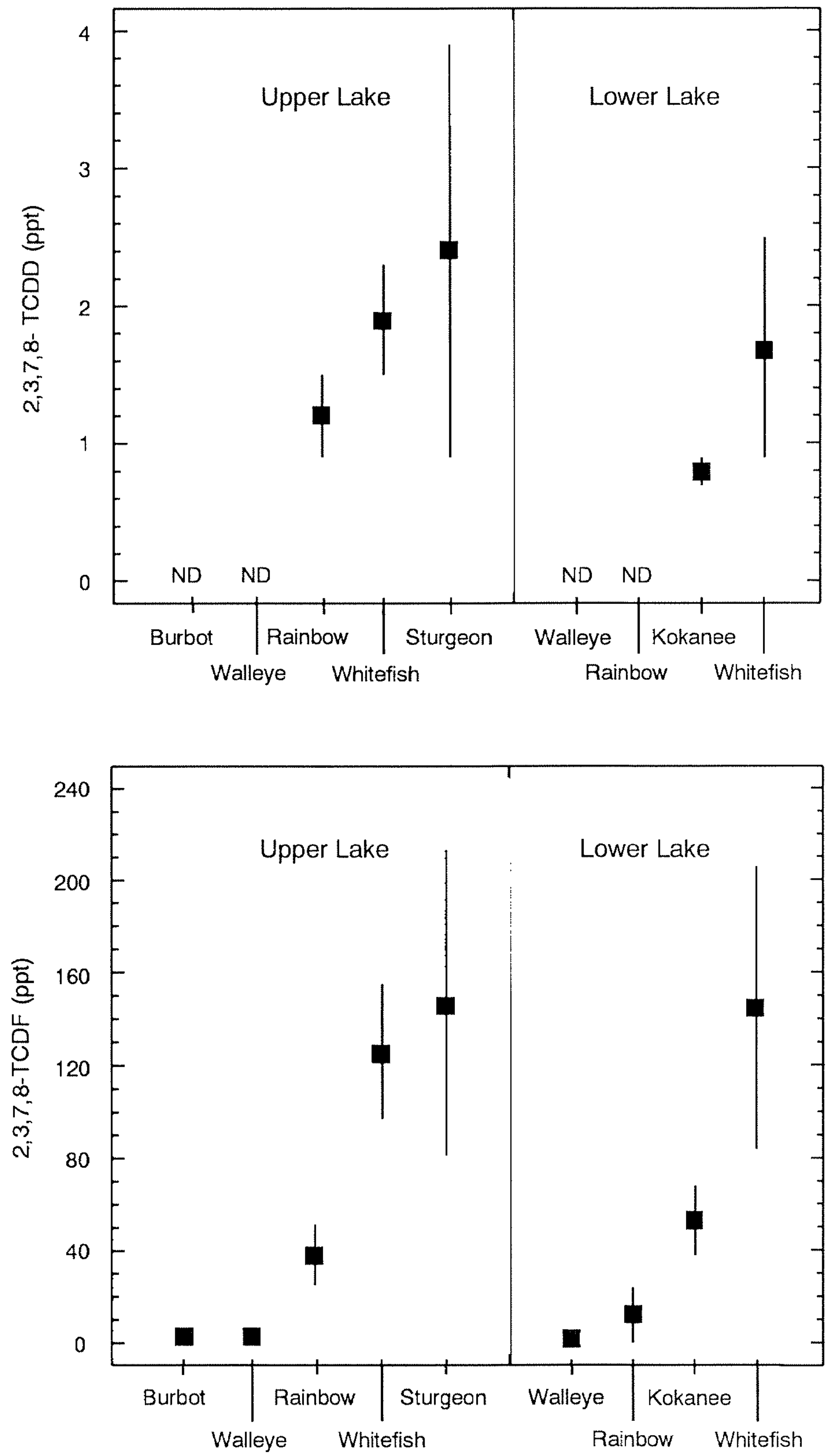


Figure 5a. TCDD and TCDF Concentrations in Lake Roosevelt Sportfish (mean ± 1 S.D.; ND = not detected)

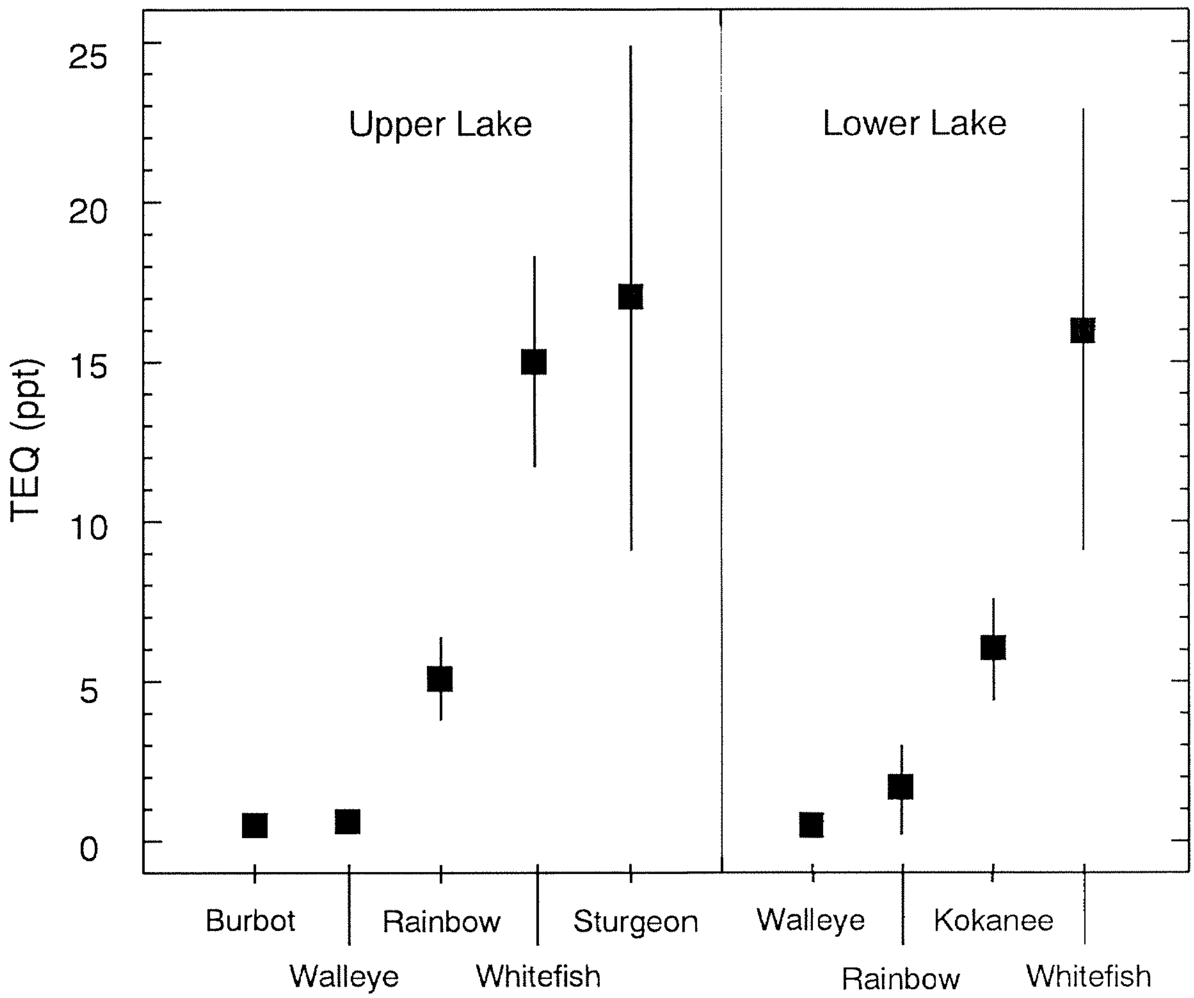
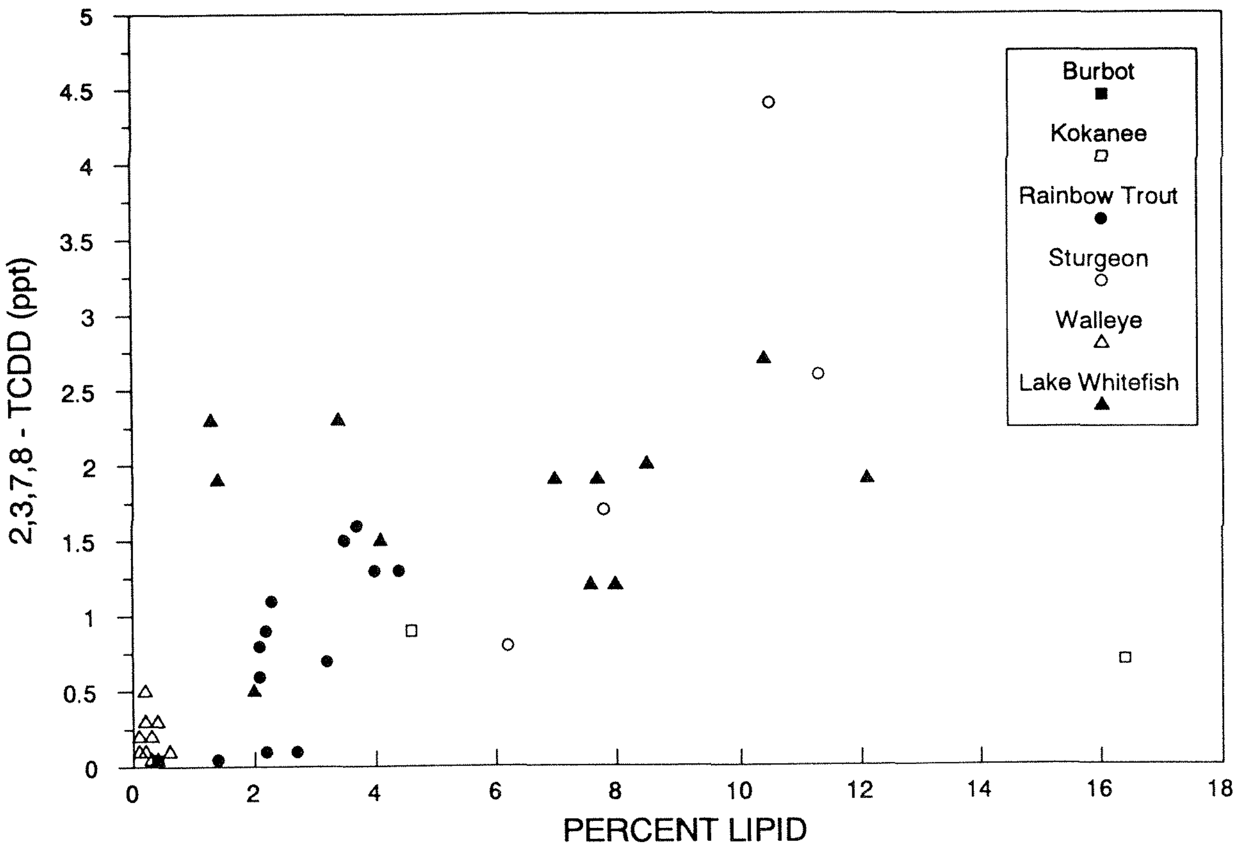


Figure 5b. TEQ Concentrations in Lake Roosevelt Sportfish. (mean ± 1 S.D.)

Table 5. TCDD and TCDF Concentrations in Liver and Eggs of Lake Roosevelt Lake Whitefish Collected near Kettle Falls October 1990 (parts per trillion; wet weight basis; each sample a three fish composite)

Tissue	Sample Number	Lipid (%)	2,3,7,8-TCDD	2,3,7,8-TCDF	TEQ
Liver	458155	13.4	3.1	289	32
Eggs	458157	45.4	8.5	787	87



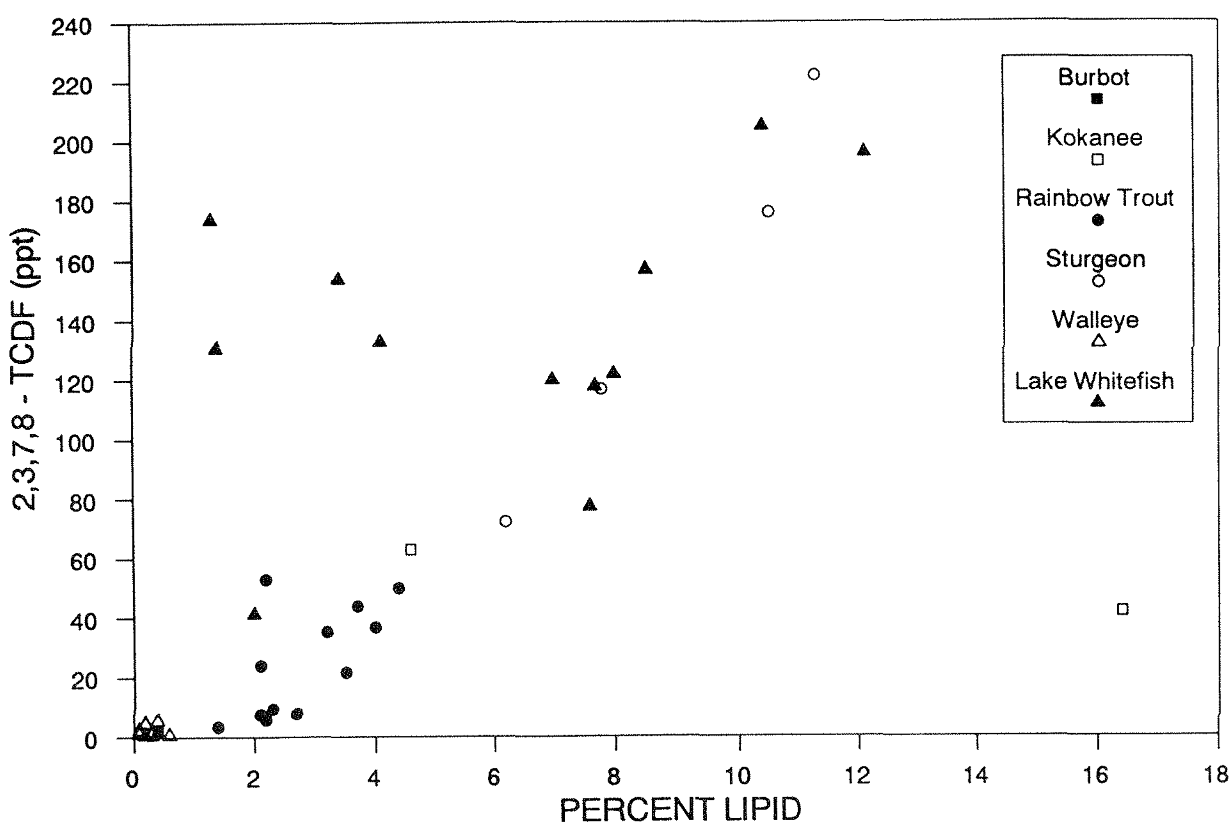


Figure 6. Relation Between TCDD, TCDF and Lipid in Lake Roosevelt Sportfish

Normalizing the data[2] to percent lipids narrowed the concentration range between species. TCDF concentrations in lake whitefish, however, remained substantially higher than in the other species. Lipid-normalized TCDF in burbot, walleye, rainbow trout, sturgeon, and lake whitefish from the upper lake averaged 700 ppt, 1600 ppt, 1200 ppt, 1600 ppt, and 3300 ppt, respectively. Normalized concentrations in lower lake walleye, rainbow trout, kokanee, and lake whitefish were 900 ppt, 460 ppt, 820 ppt, and 4000 ppt of TCDF, respectively.

The erratic precision of the lipid measurements (Table 3) and range of lipid results obtained for some species (Table 4), preclude drawing strong conclusions from these data about the reasons for species differences. The high ratio of TCDF:lipid in lake whitefish, a bottom feeder, may reflect the previously mentioned role of sediments in accumulation of PCDDs/PCDFs. On the other hand, similar results were not obtained for other bottom dwelling species like sturgeon and burbot which consume the same food (Scott and Crossman, 1973). Other factors may be involved such as use of feeding/rearing areas having different accumulations of PCDDs/PCDFs in the sediments, or interspecies differences in polar and nonpolar components of lipid (Schneider, 1982).

Relative Importance of Other Congeners

Selected lake whitefish and sturgeon samples were analyzed for all 2,3,7,8-substituted PCDDs and PCDFs (Table 6). Other than TCDD and TCDF, the congeners detected most frequently and at the highest concentrations were OCDD (3.5 - 40.9 ppt) and PeCDFs (0.4 - 1.3 ppt). One or two samples contained detectable levels of PeCDD (0.1 ppt), HxCDD (0.2 ppt), HpCDD (0.3 - 1.5 ppt), HxCDF (0.4 ppt), HpCDF (0.2 ppt), and OCDF (1.3 - 1.4 ppt).

Because of their low toxicity relative to TCDD, the other PCDDs and PCDFs detected in these samples do not contribute significantly to the TEQ. As calculated in Table 6, the fraction of the TEQ due to the presence of penta-through-octa CDDs and CDFs was estimated to be 1-5%. This point is further illustrated in Figure 7. Because non-detected values were assigned a concentration equal to half the detection limit, this comparison may overestimate even the relatively low importance of these compounds assigned through this analysis.

These findings are consistent with the analyses conducted by Environment Canada and the B.C. Ministry of Environment on fish collected below Celgar. Employing detection limits in the range of 2 - 40 ppt, the only other PCDD/PCDF detected in these surveys has been 13.4 ppt of PeCDF (all isomers) in lake whitefish (Mah *et al.*, 1989).

2. Rufus Woods Lake

TCDD/TCDF Concentrations

Results for the limited numbers of fish analyzed from Rufus Woods Lake are shown in Table 7. The rainbow trout collected here tended to be one year old fish compared to the average age of

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[2] $$\text{lipid-normalized concentration} = \frac{\text{wet weight concentration}}{\text{percent lipid x 0.01}}$$

Table 6. Analysis of Selected Lake Roosevelt Fish Samples for 2,3,7,8-substituted PCDDs and PCDFs (parts per trillion, wet weight basis)

Species:	Lake Whitefish		White Sturgeon	
Location:	Upper Lake	Lower Lake	Upper Lake	
Sample Number:	188243	188237	328089	328090
PCDDs:				
2,3,7,8-TCDD	1.4	1.2	1.9	1.1
1,2,3,7,8-PeCDD	0.1	ND(0.4)	ND(0.2)	ND(0.5)
1,2,3,4,7,8-HxCDD	ND(0.2)	ND(0.4)	ND(0.2)	ND(0.6)
1,2,3,6,7,8-HxCDD	0.2	ND(0.4)	0.2	ND(0.6)
1,2,3,7,8,9-HxCDD	ND(0.2)	ND(0.5)	ND(0.3)	ND(0.7)
1,2,3,4,6,7,8-HpCDD	0.3	ND(0.7)	1.5	ND(1.6)
OCDD	3.7	3.5	40.9	3.5
PCDFs:				
2,3,7,8-TCDF	155	150	261	136
1,2,3,7,8-PeCDF	0.4	ND(0.4)	0.9	0.5
2,3,4,7,8-PeCDF	1.1	0.9	1.3	0.5
1,2,3,4,7,8-HxCDF	ND(0.1)	ND(0.3)	ND(0.2)	ND(0.5)
1,2,3,6,7,8-HxCDF	ND(0.1)	ND(0.3)	ND(0.2)	ND(0.4)
2,3,4,6,7,8-HxCDF	0.4 EMPC	ND(0.4)	ND(0.2)	ND(0.6)
1,2,3,7,8,9-HxCDF	ND(0.2)	ND(0.5)	ND(0.3)	ND(0.8)
1,2,3,4,6,7,8-HpCDF	ND(0.2)	ND(0.2)	0.2 EMPC	ND(0.6)
1,2,3,4,7,8,9-HpCDF	ND(0.4)	ND(0.4)	ND(0.4)	ND(0.9)
OCDF	ND(0.5)	ND(1.3)	1.4 EMPC	ND(4.4)
TEQ =	17.7	16.9	28.3	15.5
% TEQ Contribution:				
2,3,7,8-TCDF	87.5%	88.8%	92.2%	87.7%
2,3,7,8-TCDD	7.9%	7.1%	6.7%	7.1%
other congeners	4.6%	4.1%	1.1%	5.2%

ND = not detected; detection limit shown in parenthesis

EMPC = estimated maximum possible concentration

Note: 1/2 detection limit used to calculate TEQ for non-detected values

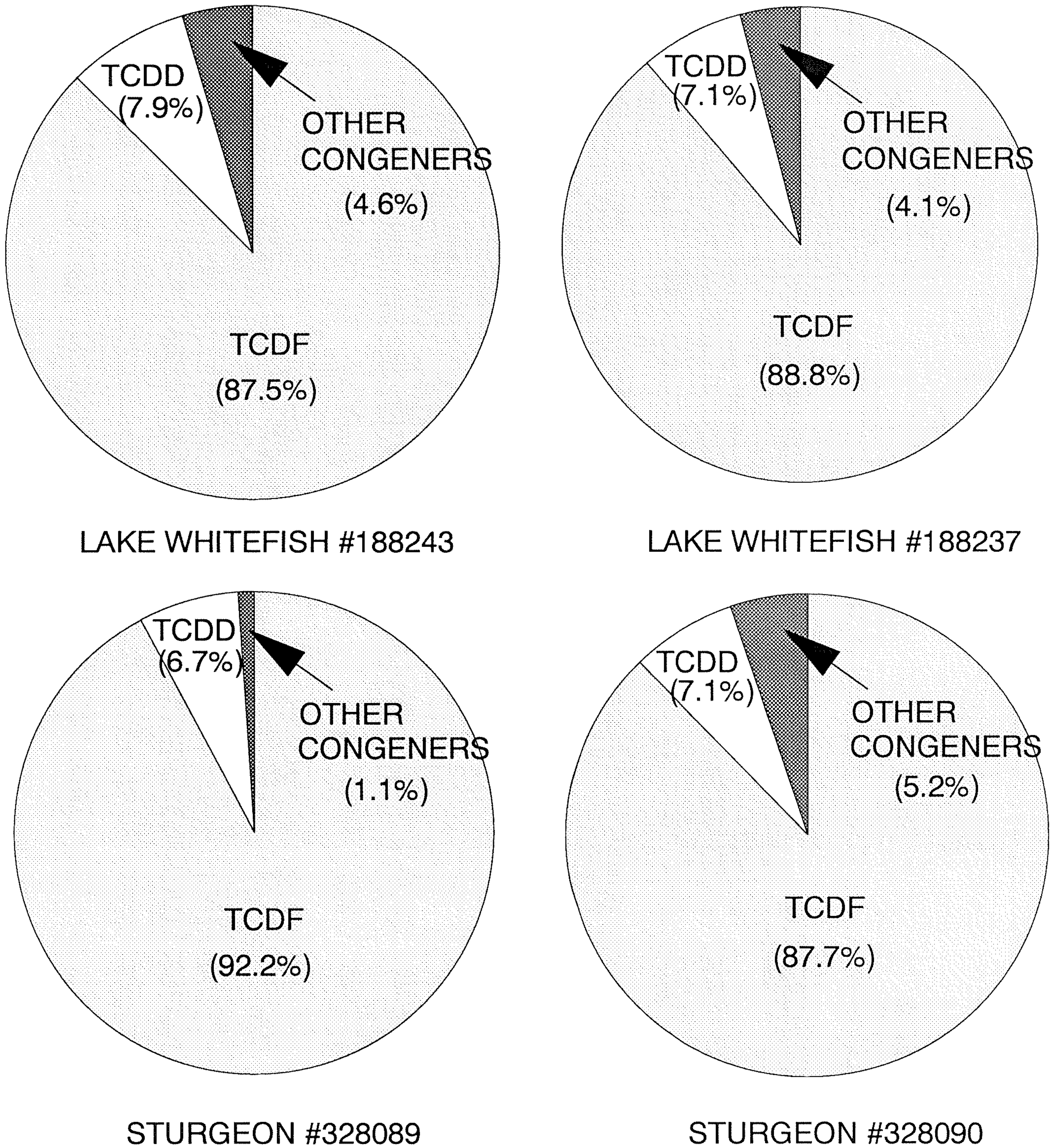


Figure 7. Contribution of 2,3,7,8-substituted PCDDs/PCDFs to TEQ in Selected Lake Roosevelt Samples

Table 7. TCDD and TCDF Concentrations in Muscle Tissue of Rufus Woods Lake Sportfish Collected August 1990 (parts per trillion, wet weight basis; each sample a five fish composite)

Species	Sample Number	Lipid (%)	2,3,7,8-TCDD	2,3,7,8-TCDF	TEQ
Walleye	368110	0.5	ND(0.4)	1.7	0.4
	368111	0.9	ND(1.8)	3.6	1.3
	mean±1SD=	0.7±0.3	ND	2.6±1.3	0.8±0.6
Rainbow Trout	368106	1.4	0.2 EMPC	3.6	0.6
	368105	1.8	0.2 EMPC	4.5	0.6
	368107	1.6	0.2 EMPC	4.9	0.7
	mean±1SD=	1.6±0.2	0.2±0	4.3±0.7	0.6±0.1
Lake Whitefish	368109	8.0	2.1	122	14
	368108	10.5	2.2	163	18
	mean±1SD=	9.2±1.8	2.2±0.1	142±29	16±2.8

ND = not detected; detection limit in parenthesis
SD = standard deviation
EMPC = estimated maximum possible concentration
Note: 1/2 detection limit used to calculate TEQs for non-detected values

two to three years for the rainbow analyzed from Lake Roosevelt (Appendix A). The average age and size of the walleye and lake whitefish sampled in Rufus Woods Lake were comparable to those collected in Lake Roosevelt.

Walleye and rainbow trout from Rufus Woods Lake had low concentrations of TCDF (1.7 - 4.9 ppt) and little or no TCDD (not detected - 0.2 ppt). The levels of these compounds were as low or lower than the least contaminated of the walleye and rainbow from Lake Roosevelt. Lake whitefish, on the other hand, showed unexpectedly high concentrations of both TCDD (2.1 - 2.2 ppt) and TCDF (122 - 163 ppt). Possible explanations for this finding are discussed later in the report.

DISCUSSION

Comparison with Background

In order to evaluate the extent that the TCDD and TCDF concentrations measured in Lake Roosevelt fish are elevated above background levels, muscle tissue samples were analyzed from mountain whitefish collected during September 1990 at the inlet to Lake Wenatchee, a large undeveloped lake high in the Cascade mountain range. Previous Ecology analyses of mountain whitefish and bottom sediments from this lake had shown no evidence of chemical contamination (Johnson and Norton, 1990d). Atmospheric transport was considered to be the only likely source of PCDDs or PCDFs to this lake (Czuczwa *et al.*, 1984).

The results of analysis on three composite mountain whitefish samples are in Table 8. TCDD was not detected at detection limits of 0.1 - 0.3 ppt. Low levels of TCDF (0.2 - 0.4 ppt), however, were common to all samples. Similar results have been obtained by Ecology (Serdar *et al.*, 1991 - in prep) and the Northwest Pulp & Paper Association (Beak Consultants, Inc., 1989; Keenan *et al.*, 1990) for chinook, coho, and steelhead returning from the open ocean to the Columbia River.

Elevations above background were calculated by dividing the mean concentrations in Lake Roosevelt fish by the mean of the three Lake Wenatchee samples. Because this ratio is sensitive to small changes in concentrations used for background and because no allowance was made for species differences, the elevations derived for Lake Roosevelt should be considered estimates. This is especially true for TCDD where background concentrations were too low to measure.

The results are illustrated in Figure 8. Mean concentrations of TCDD in Lake Roosevelt burbot, walleye, and lower lake rainbow trout were not elevated above background levels (i.e., generally not detected). Kokanee, lake whitefish, sturgeon, and upper lake rainbow had TCDD concentrations approximately 8 - 24 times higher than background. TCDF concentrations were moderately to highly elevated for all species throughout Lake Roosevelt, ranging from 12 - 60 times background in burbot, walleye, and lower lake rainbow trout to 190 - 740 times in kokanee, upper lake rainbow trout, lake whitefish, and sturgeon.

Table 8. TCDD and TCDF Concentrations in Muscle Tissue of Lake Wenatchee (background area) Mountain Whitefish Collected September 1990 (parts per trillion, wet weight basis; each sample a five fish composite)

Species	Sample Number	Lipid (%)	2,3,7,8-TCDD	2,3,7,8-TCDF	TEQ
Mountain Whitefish	398187	5.5	ND(0.1)	0.3	0.1
"	398186	4.0	ND(0.2)	0.2	0.1
"	398185	2.6	ND(0.3)	0.4 EMPC	0.2
	mean±1SD=	4.0±1.4	ND	0.3±0.1	0.1±0.1

ND = not detected; detection limit shown in parenthesis

SD = standard deviation

EMPC = estimated maximun possible concentration

Note: 1/2 detection limit used to calculate TEQs for non-detected values

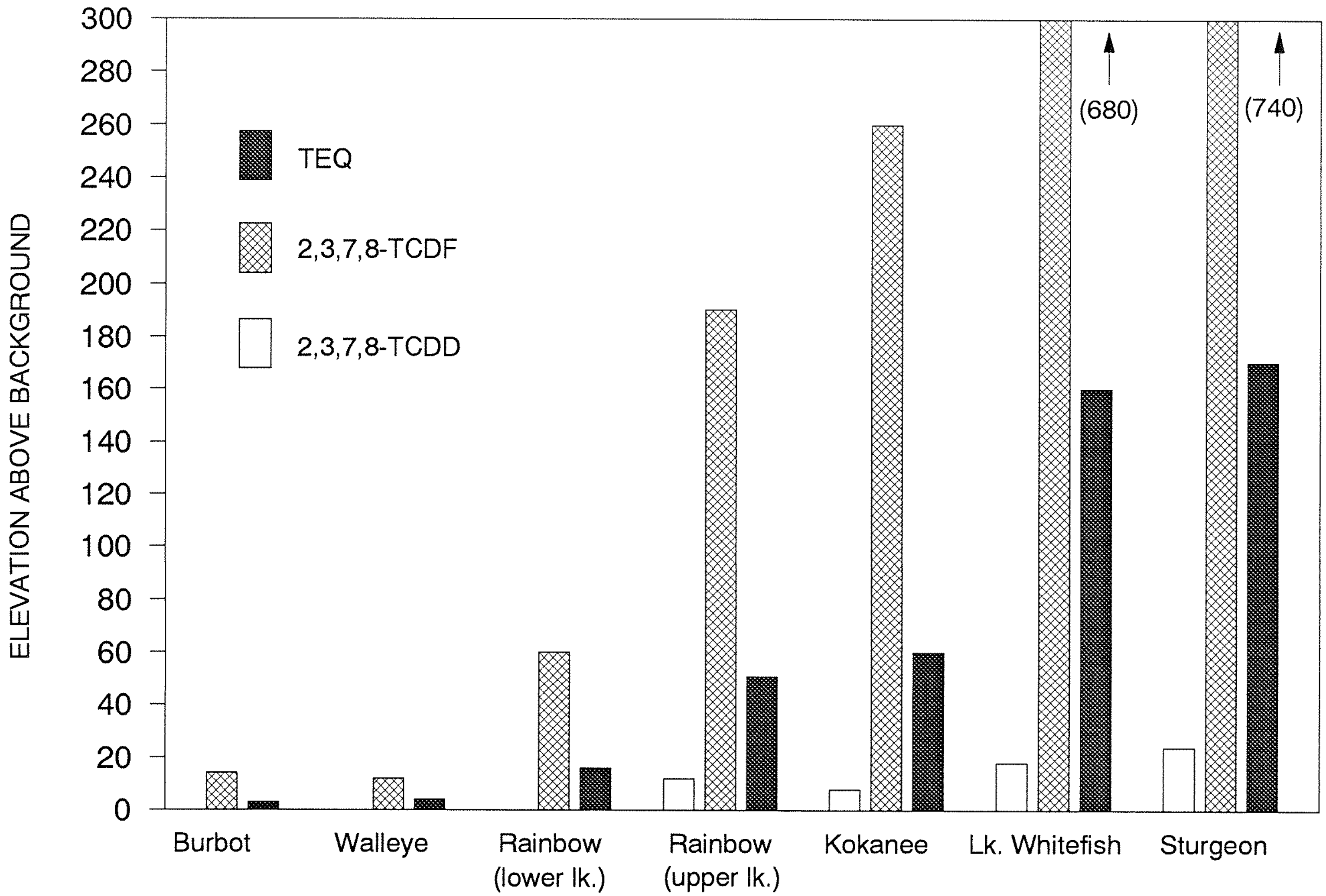


Figure 8. Mean TCDD, TCDF and TEQs in Lake Roosevelt Sportfish Expressed as Elevations above Background

Summary of Available Data on Columbia River Fish

PCDD/PCDF data are presently available on fish from two reaches of the Columbia River (Figure 9)--the upper river between Castlegar, B.C., and Chief Joseph Dam, and the lower river between Richland and the mouth. The lower river data come from the previously mentioned surveys of the Northwest Pulp & Paper Association (Beak Consultants, Inc., 1989; Keenan *et al.*, 1990) and EPA (Tetra Tech, Inc., 1990 - draft). Information on the occurrence of PCDDs/PCDFs in the 250 mile reach of the river between Chief Joseph and McNary dams is currently being collected by Ecology (Serdar *et al.*, 1991 - in prep).

As in Lake Roosevelt, TCDD and TCDF are the dominant congeners in lower river fish. The data on TCDD/TCDF in muscle tissue samples from resident species along the Columbia main stem have been plotted as TEQs in Figure 10. Data on migratory salmonids and whole fish were not used.

Most of the lower river data are on species that have not been analyzed in Lake Roosevelt. The highest concentrations in lower river fish have been reported in white sturgeon, channel catfish (*Ictalurus punctatus*), and carp (*Cyprinus carpio*) from Lake Wallula, the reservoir behind McNary Dam. TEQs in samples of these species range from 4.5 - 8.4 ppt.

TEQs in the majority of muscle tissue samples so far analyzed from Columbia River fish are less than 5 ppt. TEQs substantially in excess of 5 ppt are limited to lake whitefish, mountain whitefish, and sturgeon in the upper river, and sturgeon and channel catfish from Lake Wallula. TCDD appears to contribute a greater portion of the TEQ in lower river fish than in the upper river where TCDF predominates. The available data indicate Lake Roosevelt has a much greater degree of TCDF contamination than the lower river and that, except for Lake Wallula, TCDD levels are roughly comparable between Lake Roosevelt and the lower river.

Status of Pulp Mills on the Lower Columbia

There are four Washington and three Oregon bleached kraft pulp mills located on the lower Columbia. All have secondary biological treatment of their effluent. To address the dioxin issue, Ecology has developed a dioxin control program for chlorine bleaching pulp and paper mills in Washington. This program requires mills to comply with proposed dioxin (TCDD) discharge limits. Compliance is to be achieved within three years after EPA approval of the control program. For the Columbia River mills, the dioxin limits were derived based on the EPA (1991) *Total Maximum Daily Load for 2,3,7,8-TCDD in the Columbia River Basin*. Oregon has issued discharge permits for their mills; compliance with TCDD limits is also expected within three years.

A major source of the contamination in Lake Wallula has been identified as a defoamer that was being used by the Boise Cascade bleached kraft pulp mill at Wallula. The mill reduced its discharge of TCDD by approximately 70% when it changed defoamers in 1989. Further reductions in the levels of TCDD and other PCDDs/PCDFs in the mill's effluent are expected with construction of a new chlorine dioxide generator and implementation of up to 70% chlorine

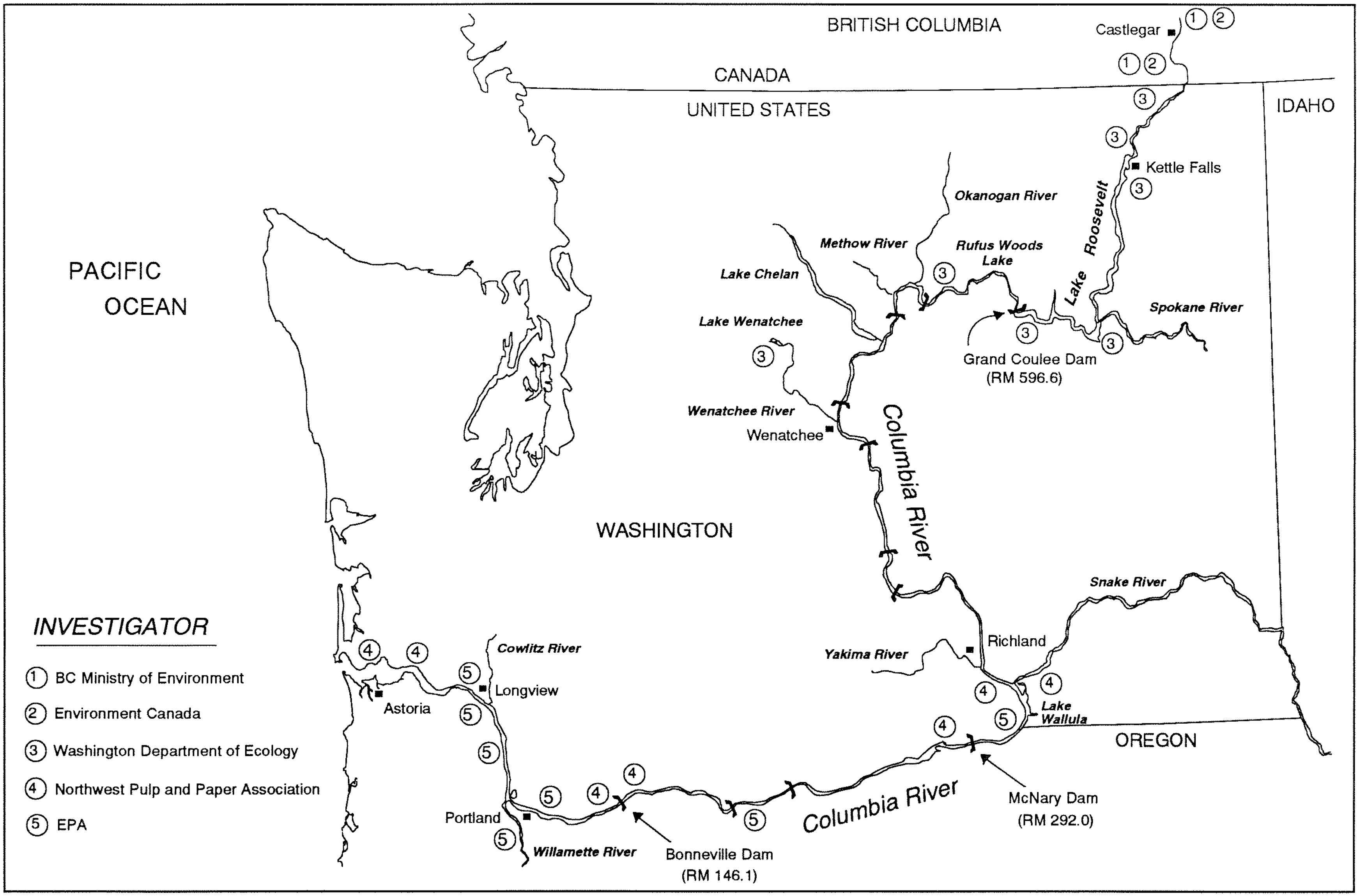


Figure 9. Sites in Columbia River Drainage where Data are Available on PCDDs and PCDFs in Muscle Tissue of Resident Fish Species (as of January, 1991)

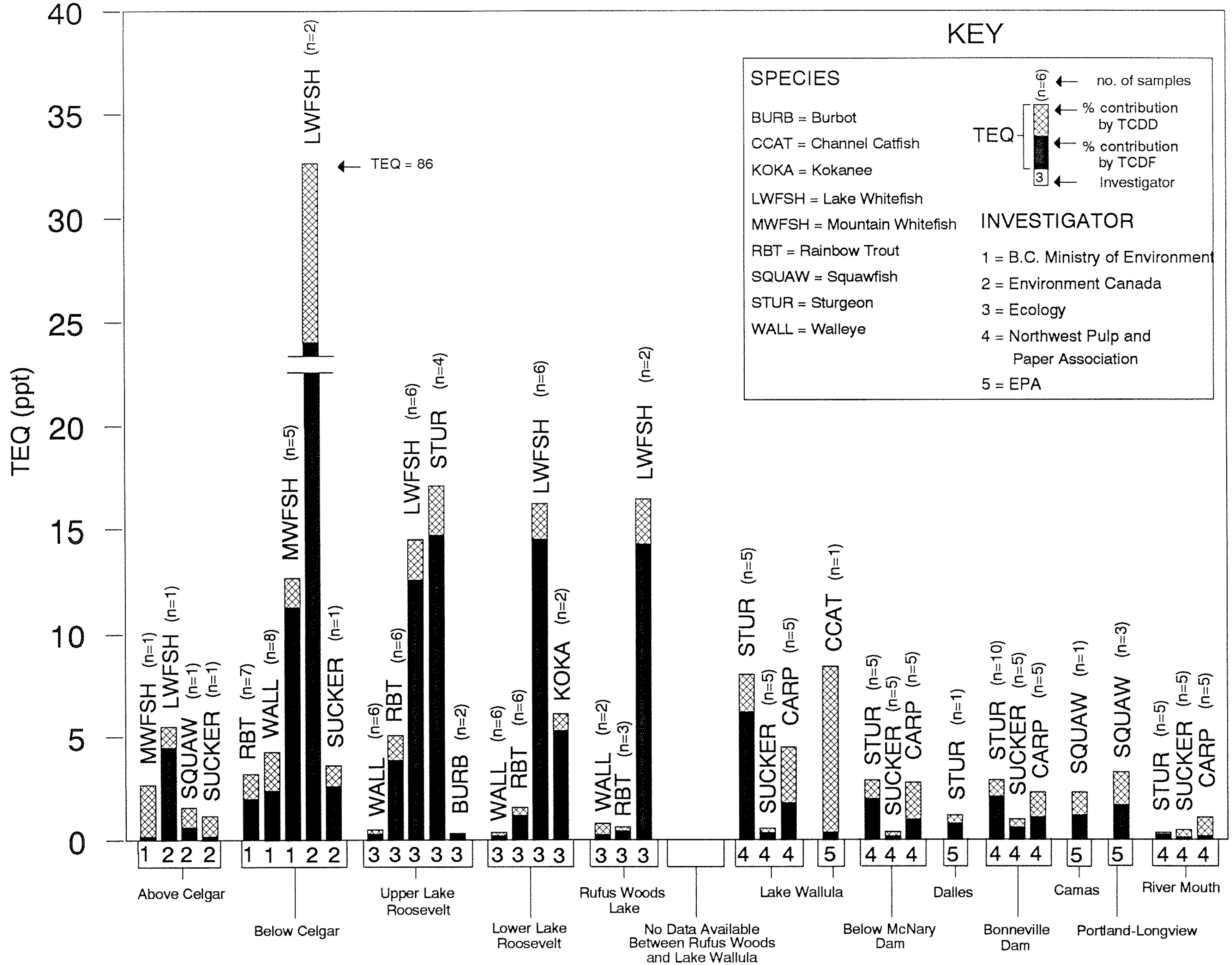


Figure 10. TEQs in Muscle Tissue of Resident Columbia River Fish (See Figure 9 for Sample Locations)

dioxide substitution for chlorine in bleaching. The generator is scheduled for start-up in May 1991. (Houck, personal communication; Ross, personal communication.)

Comparison with EPA National Fish Survey

In 1986, EPA initiated a national screening survey for bioaccumulative pollutants in U.S. fish. Sixty chemicals were analyzed, including PCDDs and PCDFs. Three hundred eighty-eight stations were sampled nation-wide with sites near pulp mills (the lower Columbia mills being among these); sites near other industrial, urban, agricultural activities; and background sites. Because these sites were, for the most part, heavily weighted towards suspected problem areas, the results do not represent a totally unbiased sample.

The report of the EPA study (Tetra Tech, Inc., 1990 - draft) contains data on PCDD/PCDF concentrations in 255 muscle tissue samples, as well as whole fish data. The distributions of the data on TCDD and TCDF in edible tissues have been plotted by percentile in Figures 11a,b and compared to results for Lake Roosevelt. Data on other congeners were not used.

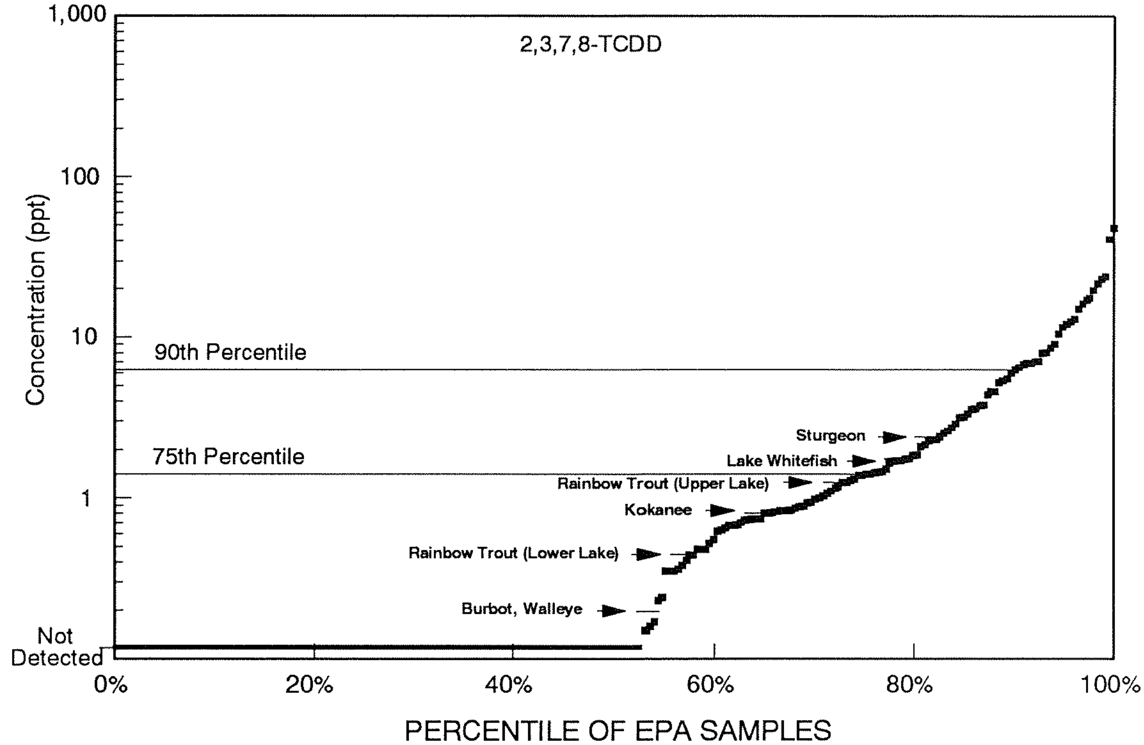
TCDD was not detected in approximately half the samples analyzed by EPA. Another 30% of the samples had between 0.1 - 2 ppt TCDD--the concentration range found in the majority of sturgeon, lake whitefish, kokanee, and upper lake rainbow trout samples from Lake Roosevelt. The most contaminated of the EPA samples (top 20%) had TCDD concentrations between 2 and 50 ppt, with about 10% over 5 ppt. No Lake Roosevelt samples exceeded 5 ppt TCDD.

While, in comparison to EPA's results, concentrations of TCDD in Lake Roosevelt fish are low to moderate, TCDF concentrations are high. All Lake Roosevelt species ranked among the upper 25% of the national results for TCDF. Lake whitefish and sturgeon from Lake Roosevelt generally had higher TCDF concentrations than found in EPA's national survey, with TEQs in the top ten percent of EPA samples.

Elevated TCDD/TCDF in Rufus Woods Whitefish

Although the present survey found low to non-detectable levels of TCDD and TCDF in walleye and rainbow trout from Rufus Woods Lake, the concentrations in lake whitefish were comparable to those in Lake Roosevelt whitefish. Possible explanations for this finding are: 1) movement of fish between reservoirs; 2) long-distance transport of TCDD/TCDF; and 3) additional TCDD/TCDF sources to lower Lake Roosevelt or Rufus Woods Lake.

All fish species in Lake Roosevelt get flushed downstream to some degree during spring draw-down of the reservoir (Beckman *et al.*, 1985; Scholz, personal communication). Although there have been no studies of lake whitefish movements, tag returns show that walleye and rainbow trout from Lake Roosevelt are commonly caught in Rufus Woods Lake (Scholz, personal communication). It is possible, therefore, that the whitefish collected in Rufus Woods Lake originated from and reflect the contamination in Lake Roosevelt.



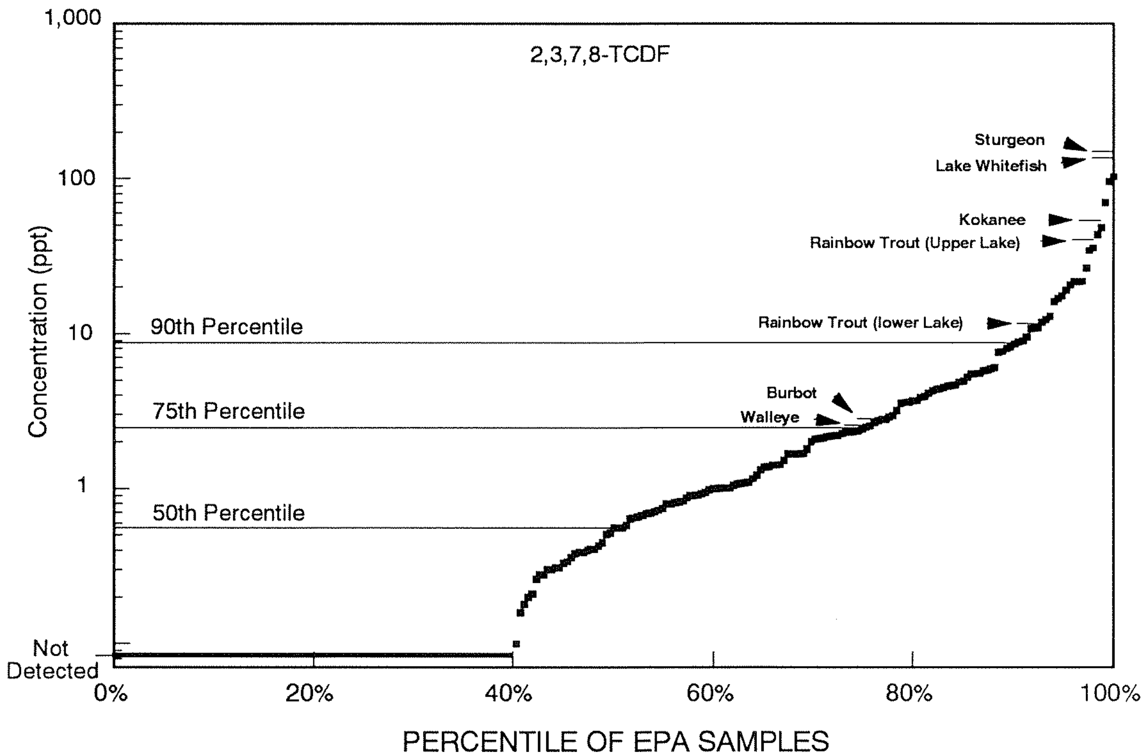


Figure 11a. Mean Concentrations of TCDD and TCDF in Muscle Tissue of Lake Roosevelt Sportfish Compared to Results of EPA National Fish Survey (modified from Tetra Tech, Inc., 1990)

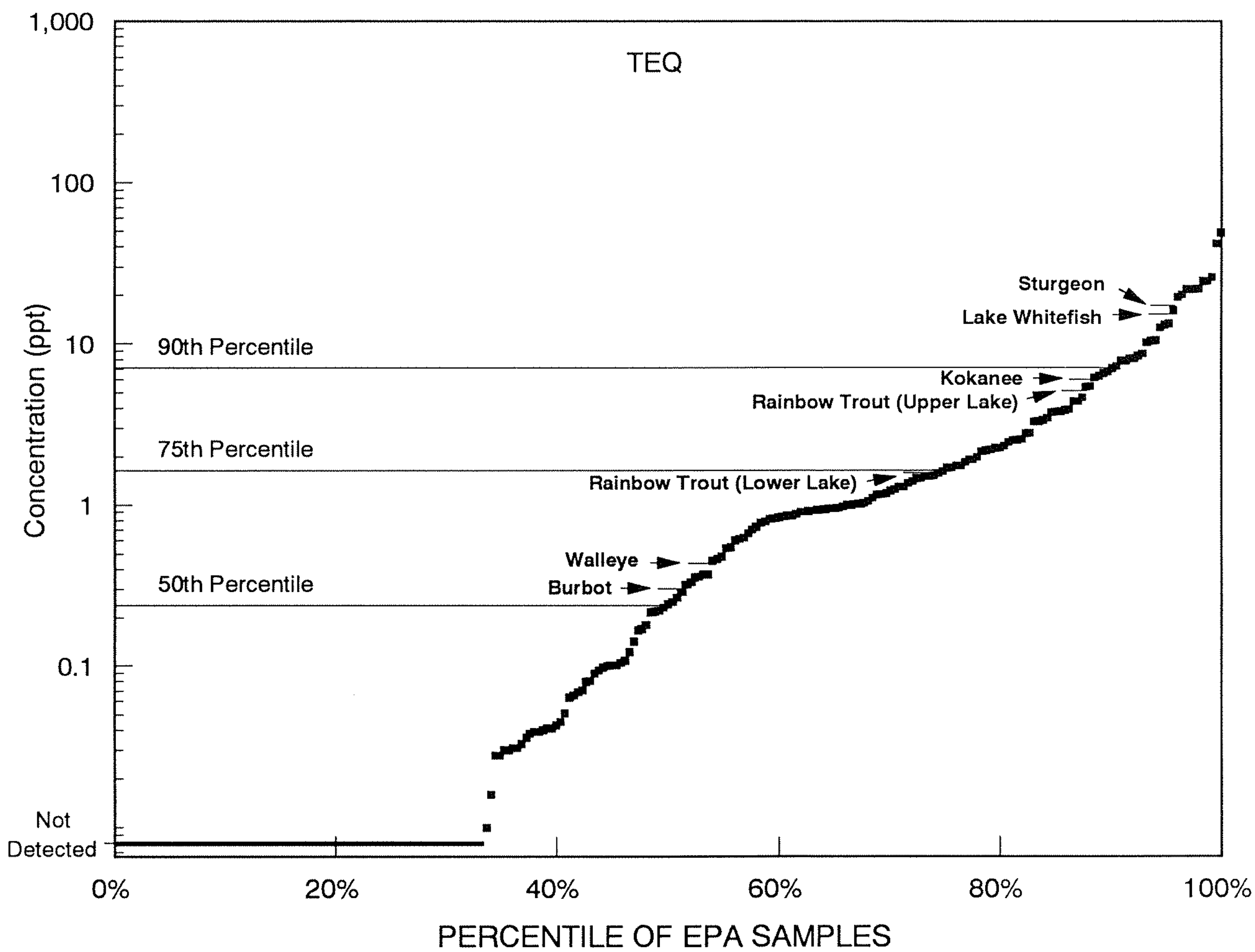


Figure 11b. Mean TEQs in Muscle Tissue of Lake Roosevelt Sportfish Compared to Results of EPA National Fish Survey (modified from Tetra Tech, Inc., 1990)

TCDD:TCDF ratios were similar in whitefish from both lakes. One of the Rufus Woods samples was re-analyzed for 2,3,7,8-substituted PCDDs/PCDFs to determine if the congener pattern differed from Lake Roosevelt. The results (Table 9) showed no additional congeners could be detected above 0.5 - 4.2 ppt. These observations suggest a common source of contamination.

As already mentioned, PCBs are potential sources of TCDF. Analyses conducted by the U.S. Fish and Wildlife Service (Schmitt *et al.*, 1990) and Ecology (Hopkins *et al.*, 1985) during the early 1980s indicate the levels of PCBs in Lake Roosevelt fish are relatively low. Not having similar data for Rufus Woods Lake and recognizing the potential for historical PCB inputs from Grand Coulee Dam and the greater Spokane urban/industrial area, lake whitefish samples were also analyzed for PCBs (EPA Method 680).

The results (Table 10) show low to moderate concentrations of PCBs. The whitefish sample analyzed from Rufus Woods Lake had a total PCB concentration of 82 parts per billion (ppb) which compares closely to the concentration of 72 ppb measured in lower Lake Roosevelt whitefish. The lowest concentration, 23 ppb, was in upper Lake Roosevelt whitefish. These concentrations are well below the geometric mean of 390 ppb total PCBs reported by the U.S. Fish and Wildlife Service (Schmitt *et al.*, 1990) for whole fish samples collected from 112 stations nation-wide in 1984 - 1985. Concentrations of total PCBs in the range of 3 - 2043 ppb occur in lower Columbia River fish (both edible and whole fish samples) and are associated with TCDF concentrations between 5.0 and 62 ppt (Tetra Tech, Inc., 1990 - draft).

Preliminary results on a series of bottom fish samples (largescale suckers, analyzed whole) collected by Ecology from Lake Roosevelt, Rufus Woods Lake, and the Spokane River in June 1990 suggest substantial attenuation of TCDD and TCDF between Lake Roosevelt and Rufus Woods Lake, and show no evidence that the Spokane River is a significant source of these compounds (Table 11). TCDD and TCDF levels in six Lake Roosevelt largescale sucker samples collected between the international border and Grand Coulee Dam were 0.92 - 2.60 ppt and 16.76 - 48.07 ppt, respectively. TCDD was below detection limits (0.68 ppt) in Rufus Woods Lake and the TCDF concentration (4.63 ppt) was 20-25% samples from lower Lake Roosevelt (18.85 -22.57 ppt). TCDD was also not detected in the Spokane River sample and the TCDF concentration was very low (0.58 ppt). (These data will be presented in more detail in a subsequent report scheduled to be completed in April 1991.)

Significance for Aquatic Life and Wildlife

At present, it is not known what levels of PCDDs/PCDFs in biological tissues pose a hazard to aquatic life or wildlife. Fish are among the most sensitive organisms to PCDDs and PCDFs (Kleeman *et al.*, 1988; Spitsbergen *et al.*, 1988). Adverse effects on survival, growth, and behavior have been observed in rainbow trout exposed to water concentrations of TCDD in the low parts per quadrillion range and TCDF in the low parts per trillion range - levels 1,000 to 10,000 times lower than those at which other organochlorine compounds produce similar effects (Mehrle *et al.*, 1988). There are few data, however, relating tissue concentrations to biological effects. Some research has shown that fish respond to tissue concentrations as low as 1 ppt TEQ.

Table 9. Comparison of PCDDs/PCDFs in Lake Whitefish from Rufus Woods Lake and Lake Roosevelt (parts per trillion, wet weight basis)

Location:	Rufus Woods Lake	Lower Lake Roosevelt	Upper Lake Roosevelt
Sample Number:	368108	188237	188243
PCDDs:			
2,3,7,8-TCDD	1.7 EMPC	1.2	1.4
1,2,3,7,8-PeCDD	ND(1.6)	ND(0.4)	0.1
1,2,3,4,7,8-HxCDD	ND(1.0)	ND(0.4)	ND(0.2)
1,2,3,6,7,8-HxCDD	ND(1.0)	ND(0.4)	0.2
1,2,3,7,8,9-HxCDD	ND(1.1)	ND(0.5)	ND(0.2)
1,2,3,4,6,7,8-HpCDD	ND(1.5)	ND(0.7)	0.3
OCDD	ND(4.2)	3.5	3.7
PCDFs:			
2,3,7,8-TCDF	176	150	155
1,2,3,7,8-PeCDF	ND(1.0)	ND(0.4)	0.4
2,3,4,7,8-PeCDF	ND(1.1)	0.9	1.1
1,2,3,4,7,8-HxCDF	ND(0.5)	ND(0.3)	ND(0.1)
1,2,3,6,7,8-HxCDF	ND(0.5)	ND(0.3)	ND(0.1)
2,3,4,6,7,8-HxCDF	ND(0.6)	ND(0.4)	0.4 EMPC
1,2,3,7,8,9-HxCDF	ND(0.8)	ND(0.5)	ND(0.2)
1,2,3,4,6,7,8-HpCDF	ND(0.6)	ND(0.2)	ND(0.2)
1,2,3,4,7,8,9-HpCDF	ND(1.0)	ND(0.4)	ND(0.4)
OCDF	ND(3.6)	ND(1.3)	ND(0.5)

ND = not detected; detection limit shown in parenthesis
EMPC = estimated maximum possible concentration

Table 10. PCB Analysis of Lake Whitefish Muscle Tissue
(parts per billion; wet weight basis)

Location:	Rufus Woods Lake	Lower Lake Roosevelt	Upper Lake Roosevelt
Sample Number:	368108	188237	188243
monochlorobiphenyls	ND	ND	ND
dichlorobiphenyls	0.02	0.20	0.08
trichlorobiphenyls	1.0	9.9	0.14
tetrachlorobiphenyls	13	26	1.6
pentachlorobiphenyls	26	23	7.5
hexachlorobiphenyls	25	7.7	9.3
heptachlorobiphenyls	12	5.0	3.9
octachlorobiphenyls	5.1	0.55	0.64
nonachlorobiphenyls	0.17	0.06	0.13
decachlorobiphenyl	0.01	ND	0.01
total PCBs	82	72	23

ND = not detected
EMPC = estimated maximum possible concentration

Table 11. 2,3,7,8-substituted PCDDs /PCDFs in Whole Largescale Suckers collected from Lake Roosevelt, Rufus Woods Lake, and Spokane River, June 1990 (parts per trillion, wet weight basis; each sample a five fish composite)

Sample Location	Approximate River Mile	2,3,7,8-TCDD	2,3,7,8-TCDF
	Lake Roosevelt		
Northport	733	1.69	33.43
" " (duplicate)		1.49	30.33
China Bend	722	1.12	16.76
Marcus Island	709	2.60	48.07
French Point	697	2.31	36.79
" " (duplicate)		2.22	36.01
Hunters	661	0.93	18.85
Grand Coulee	600	0.92	22.57
	Rufus Woods Lake		
Bridgeport State Park	546	ND (0.68)	4.63
	Spokane River		
Long Lake	37	ND (0.67)	0.58

ND = not detected; detection limit in parenthesis

Wisk and Cooper (1990) found a tissue concentration of 240 ppt TCDD caused lesions in fish embryos. Lake trout (*Salvelinus namaycush*) eggs with as low as 55 ppt TCDD experienced increased mortality; accumulation of 65 ppt TCDD resulted in 50% morality above controls at the swim-up stage (Walker *et al.*, 1991-in press). Other experiments with lake trout (Spitsbergen *et al.*, 1991) have shown increased embryo and sac fry mortality beginning at 40 ppt TCDD in eggs. All sac fry with 400 ppt TCDD died between hatching and swim-up. Bioaccumulation experiments with TCDD indicate that tissue concentrations at 1,000 - 2,000 ppt in young rainbow trout and carp are associated with 50% lethality (Cook *et al.*, 1991-draft).

Muir *et al.* (1990) fed rainbow trout diets treated with 2,3,4,7,8-PeCDD and found the threshold for induction of the liver enzyme ethoxyresorufin-O-deethylase (EROD) occurred at tissue concentrations of 200 ppt (equivalent to a TEQ of 100 ppt). EROD is one of a group of enzymes involved in metabolism of organic pollutants, as well as the synthesis and degradation of steroid hormones. Carp exposed to contaminated sediments exhibited significant increases in EROD activity and liver weight when the total 2,3,7,8-substituted tetra-through-octa PCDF concentration in liver was approximately 350 ppt (van der Weiden *et al.*, 1989).

Recent experiments on Fraser River chinook salmon smolts conducted by the Canadian Department of Fisheries & Oceans show a threshold of EROD activity at body burdens of 1 - 10 ppt TEQ (Servizi, unpublished data). A threshold of 10 ppt TCDD has also been observed for another de-toxifying liver enzyme, aryl hydrocarbon hydroxylase (AHH), in white suckers (*Catostomus commersoni*) (Hodson, unpublished data).

PCDDs and PCDFs have been linked to reproductive failures of birds on the West Coast and Great Lakes, but the co-occurrence of other contaminants at these sites prevented establishing a cause-effect relationship (Nordstrom *et al.*, 1985; Peakall and Fox, 1987; Elliot *et al.*, 1989; Kubiak, *et al.*, 1989). Eisler (1986) conducted a review of TCDD for the U.S. Fish and Wildlife Service. Based on results of laboratory experiments with birds and mammals, and in consideration of recommendations for human health protection, he concluded that TCDD concentrations in food items should not exceed 10 to 12 ppt to protect birds and other wildlife.

There are few data on the levels of PCDDs/PCDFs in sensitive organs or early life stages of Lake Roosevelt fish, and no data on the diets of birds and other wildlife. Results of the present survey suggest TEQs in excess 10 ppt may be found in fatty organs of several fish species. The single analysis conducted on lake whitefish eggs (Table 5) shows a TEQ concentration that was reported to cause significant mortality in lake trout.

Impact of Process Changes at Celgar

Celgar Pulp Co. is proposing to expand and modernize its Castlegar mill. Pulp production would double under the current plan. The latest available technology would be used to improve effluent quality and reduce the discharge of PCDDs and PCDFs to the Columbia River. A detailed description of the proposal and related environmental issues can be found in Bodkin *et al.*, (1991) The proposed process would employ extended delignification, oxygen delignification, 70% chlorine dioxide substitution of chlorine in bleaching, and oxygen/hydrogen peroxide in the extraction stage. The effluent would receive secondary biological treatment. These steps are in line with the dioxin control strategy proposed for Washington pulp and paper mills (Burkhalter, personal communication). It is the opinion of the Canadian Department of Fisheries & Oceans and Department of Environment (1990) that the "levels of dioxins and furans in the effluent from the modernized mill would not be expected to contribute significantly to the present body burdens in fish... downstream of the mill".

It is unlikely, however, that the present level of contamination will decrease rapidly. Although Celgar's proposal to modernize received approval in December 1990 (Bodkin *et al.*, 1990) implementation of process changes and installation of treatment facilities are at least two to three years away. Furthermore, by reason of half-lives in sediment on the order of one to ten years (Callahan *et al.*, 1979; Eisler, 1986; CCREM, 1987), in-place pollution may contribute to accumulation of PCDDs and PCDFs in Lake Roosevelt fish for some years to follow.

CONCLUSIONS

Muscle tissues of Lake Roosevelt sportfish contain elevated concentrations of TCDF and, to a lesser degree, TCDD. There are wide differences in concentrations between species. This appears to be primarily a function of lipid content, with low to nondetectable concentrations in walleye and burbot, moderately elevated concentrations in rainbow trout and kokanee, and high concentrations in lake whitefish and sturgeon.

Large concentration differences were generally not seen between the same species in the upper and lower lake. Walleye and rainbow trout collected below Lake Roosevelt in Rufus Woods Lake showed little or no evidence of contamination. Although elevated concentrations of TCDD and TCDF were found in lake whitefish from Rufus Woods, these fish may have originated in Lake Roosevelt. The weight of evidence from presently available data suggests Rufus Woods Lake is not substantially contaminated.

Most of the potential toxicity (i.e., TEQ) associated with the concentrations found in Lake Roosevelt fish is contributed by TCDF rather than TCDD. The level of contamination observed in lake whitefish and sturgeon from Lake Roosevelt is very high when compared to similar data on fish from the lower Columbia River and other U.S. freshwaters. This may be of biological significance.

RECOMMENDATIONS

1. Encourage the earliest possible installation of wastewater treatment and implementation of PCDD/PCDF control at Celgar.

2. Establish a sampling program to monitor time-trends in TCDD/TCDF contamination of Lake Roosevelt. This would be most easily accomplished by analyzing fish tissue, probably focusing on lake whitefish and rainbow trout in the upper lake. Composite samples of a size similar to that used in the present survey appear to be appropriate for

long-term monitoring. Muscle would be the tissue of choice for human health concerns, although analysis of eggs or other fatty tissue may be a more sensitive indicator for these compounds. Sampling should be conducted on a yearly basis and begin prior to process changes at Celgar.

3. Undertake studies to determine if adverse biological effects are occurring in the lake. The high TEQs in whitefish and sturgeon, and potential for elevated TEQs in fatty organs of kokanee and upper lake rainbow trout, suggests these species may be worth study. Additional data should be gathered on levels of PCDDs/PCDFs in eggs of Lake Roosevelt fish.

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APPENDIX A
Biological Data on Fish Samples

APPENDIX A - Biological Data on Fish Samples

Upper Lake Roosevelt

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Burbot	Kettle Falls	10/5/90	600	1458	N/A
448080	Burbot	Gifford	10/5/90	473	443	N/A
	Burbot	Gifford	10/5/90	675	1060	N/A
	Burbot	Gifford	10/5/90	644	890	N/A
			mean =	598	963	N/A
	Burbot	Kettle Falls	5/18/90	595	1041	N/A
448081	Burbot	Kettle Falls	5/18/90	498	958	N/A
	Burbot	Off Sherman Cr.	10/10/90	655	984	N/A
	Burbot	Off Onion Cr.	10/12/90	485	671	N/A
			mean =	558	914	N/A
	Walleye	Off Colville R.	5/1/90	475	1040	4
	Walleye	Off Colville R.	5/1/90	403	510	3
188234	Walleye	Off Colville R.	5/1/90	471	860	4
	Walleye	Off Colville R.	5/1/90	410	600	4
	Walleye	Off Colville R.	5/1/90	380	456	N/A
			mean =	428	693	4
	Walleye	Off Colville R.	5/1/90	490	1020	3
	Walleye	Off Colville R.	5/1/90	411	545	3
188235	Walleye	Off Colville R.	5/1/90	420	785	3
	Walleye	Off Colville R.	5/1/90	440	615	4
	Walleye	Off Colville R.	5/1/90	407	465	3
			mean =	434	686	3
	Walleye	Off Colville R.	5/1/90	461	930	4
	Walleye	Off Colville R.	5/1/90	450	750	4
188236	Walleye	Off Colville R.	5/1/90	423	650	4
	Walleye	Off Colville R.	5/1/90	406	480	3
	Walleye	Off Colville R.	5/1/90	398	580	3
			mean =	428	678	4
	Walleye	Off Colville R.	8/4/90	430	641	4
	Walleye	Off Colville R.	8/4/90	380	474	2
328083	Walleye	Off Colville R.	8/4/90	445	753	4
	Walleye	Off Colville R.	8/4/90	480	925	4
	Walleye	Off Colville R.	8/4/90	404	573	3
			mean =	428	673	3
	Walleye	Off Colville R.	8/4/90	440	925	4
	Walleye	Off Colville R.	8/4/90	451	733	4
328084	Walleye	Off Colville R.	8/4/90	364	366	2
	Walleye	Off Colville R.	8/4/90	422	656	4
	Walleye	Off Colville R.	8/4/90	414	607	3
			mean =	418	657	3
	Walleye	Off Colville R.	8/4/90	470	908	3
	Walleye	Off Colville R.	8/4/90	435	723	3
328085	Walleye	Off Colville R.	8/4/90	425	622	3
	Walleye	Off Colville R.	8/4/90	434	668	4
	Walleye	Off Colville R.	8/4/90	408	554	3
			mean =	434	695	3

APPENDIX A (continued)

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Rainbow Trout	Little Dalles	6/25/90	376	591	3
	Rainbow Trout	Off Sherman Cr.	6/25/90	500	1583	4
328086	Rainbow Trout	Off Sherman Cr.	6/25/90	236	189	1
	Rainbow Trout	Off Colville R.	5/2/90	394	758	2
	Rainbow Trout	Off Kettle R.	5/2/90	265	208	1
			mean =	354	666	2
	Rainbow Trout	Little Dalles	6/25/90	226	202	1
	Rainbow Trout	Little Dalles	6/25/90	423	498	3
328087	Rainbow Trout	Little Dalles	6/25/90	409	633	3
	Rainbow Trout	Off Colville R.	5/1/90	502	1450	4
	Rainbow Trout	Off Colville R.	5/2/90	316	390	1
			mean =	375	635	2
	Rainbow Trout	Off Colville R.	10/10/90	552	1463	4
	Rainbow Trout	Northport	10/11/90	321	317	1
428105	Rainbow Trout	Northport	10/11/90	302	266	<1
	Rainbow Trout	Northport	10/11/90	422	666	4
	Rainbow Trout	Off Onion Cr.	10/12/90	390	613	5
			mean =	397	665	3
	Rainbow Trout	Northport	10/10/90	496	1441	4
	Rainbow Trout	Northport	10/10/90	423	851	4
428106	Rainbow Trout	little Dalles	10/10/90	342	465	3
	Rainbow Trout	little Dalles	10/10/90	292	268	3
	Rainbow Trout	Northport	10/11/90	316	355	<1
			mean =	374	676	3
	Rainbow Trout	Northport	10/11/90	348	422	3
	Rainbow Trout	Northport	10/11/90	334	363	1
428107	Rainbow Trout	Northport	10/11/90	293	271	<1
	Rainbow Trout	Northport	10/11/90	425	869	3
	Rainbow Trout	Northport	10/11/90	481	1064	3
			mean =	376	598	2
	Rainbow Trout	Northport	10/10/90	330	394	4
	Rainbow Trout	Little Dalles	10/11/90	461	974	4
428108	Rainbow Trout	Northport	10/11/90	333	381	1
	Rainbow Trout	Northport	10/11/90	306	316	<1
	Rainbow Trout	Northport	10/11/90	463	917	4
			mean =	379	596	3
	Lk. Whitefish	Off Colville R.	5/1/90	400	650	3
	Lk. Whitefish	Off Colville R.	5/1/90	467	1035	5
188243	Lk. Whitefish	Off Sherman Cr.	5/2/90	494	1291	5
	Lk. Whitefish	Off Sherman Cr.	5/2/90	387	707	4
	Lk. Whitefish	Off Colville R.	5/2/90	502	1565	5
			mean =	450	1050	4
	Lk. Whitefish	Off Colville R.	5/1/90	408	685	4
	Lk. Whitefish	Off Sherman Cr.	5/2/90	495	1484	4
188244	Lk. Whitefish	Off Colville R.	5/2/90	406	816	4
	Lk. Whitefish	Off Colville R.	5/2/90	461	1059	5
	Lk. Whitefish	Off Colville R.	5/2/90	518	1285	5
			mean =	458	1066	4

APPENDIX A (continued)

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Lk. Whitefish	Off Colville R.	5/1/90	466	1455	5
	Lk. Whitefish	Off Sherman Cr.	5/2/90	393	693	3
188245	Lk. Whitefish	Off Sherman Cr.	5/2/90	466	1179	5
	Lk. Whitefish	Off Sherman Cr.	5/2/90	448	1121	5
	Lk. Whitefish	Off Colville R.	5/2/90	404	853	4
			mean =	435	1060	4
	Lk. Whitefish	Off Sherman Cr.	8/4/90	429	901	3
	Lk. Whitefish	Off Colville R.	10/11/90	535	2099	5
428109	Lk. Whitefish	Off Colville R.	10/11/90	498	1408	5
	Lk. Whitefish	Off Colville R.	10/11/90	455	1126	4
	Lk. Whitefish	Kettle Falls	N/A	467	N/A	N/A
			mean =	477	1384	4
	Lk. Whitefish	Off Sherman Cr.	8/4/90	450	983	4
	Lk. Whitefish	Off Sherman Cr.	8/4/90	525	1618	4
428110	Lk. Whitefish	Off Sherman Cr.	8/4/90	411	728	4
	Lk. Whitefish	Off Colville R.	8/5/90	495	1408	N/A
	Lk. Whitefish	Off Colville R.	10/11/90	496	1368	4
			mean =	475	1221	4
	Lk. Whitefish	Off Sherman Cr.	8/4/90	521	1555	4
	Lk. Whitefish	Off Colville R.	8/4/90	433	821	4
428111	Lk. Whitefish	Off Colville R.	8/4/90	460	1102	4
	Lk. Whitefish	Off Colville R.	8/5/90	510	1404	4
	Lk. Whitefish	Off Colville R.	10/11/90	467	1257	3
			mean =	478	1228	4
	White Sturgeon	Marcus Flats	7/25/90	1435	N/A	14
	White Sturgeon	Marcus Flats	7/25/90	1664	N/A	18
328088	White Sturgeon	Kettle Falls	7/7/90	1575	N/A	17
	White Sturgeon	Marcus Is.	5/19/90	1346	N/A	17
	White Sturgeon	Marcus Is. Area	N/A	N/A	N/A	16
			mean =	1505	N/A	16
	White Sturgeon	Marcus Flats	7/25/90	1232	N/A	13
	White Sturgeon	Marcus Flats	7/25/90	1346	N/A	16
328089	White Sturgeon	Kettle Falls	7/7/90	1473	N/A	12
	White Sturgeon	Kettle Falls	7/7/90	1575	N/A	16
	White Sturgeon	Marcus Is.	5/28/90	1651	N/A	13
			mean =	1455	N/A	14
	White Sturgeon	Marcus Flats	7/25/90	1283	N/A	16
	White Sturgeon	Kettle Falls	7/7/90	1549	N/A	13
328090	White Sturgeon	Marcus Is. Area	6/14/90	1473	N/A	15
	White Sturgeon	Marcus Is. Area	6/3/90	1600	N/A	15
	White Sturgeon	Marcus Is. Area	6/6/90	1372	N/A	14
			mean =	1455	N/A	15
	White Sturgeon	North Gorge	9/27/90	1346	N/A	N/A
	White Sturgeon	Kettle Falls	9/15/90	1372	N/A	16
448083	White Sturgeon	Kettle Falls	9/15/90	1232	N/A	14
	White Sturgeon	Kettle Falls	9/16/90	1422	N/A	14
	White Sturgeon	Marcus Is. Area	10/16/90	1499	N/A	14
			mean =	1374	N/A	14

APPENDIX A (continued)

Lower Lake Roosevelt

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Walleye	Seven Bays	5/2/90	497	876	4
	Walleye	Seven Bays	5/3/90	400	519	4
188240	Walleye	Seven Bays	5/3/90	380	439	3
	Walleye	Off Hawk Cr.	5/3/90	575	1523	5
	Walleye	Off Hawk Cr.	5/3/90	405	585	3
			mean =	451	788	4
	Walleye	Seven Bays	5/2/90	487	1179	4
	Walleye	Seven Bays	5/3/90	423	590	4
188241	Walleye	Seven Bays	5/3/90	406	528	3
	Walleye	Off Hawk Cr.	5/3/90	442	687	4
	Walleye	Off Hawk Cr.	5/3/90	372	440	4
			mean =	426	685	4
	Walleye	Seven Bays	5/2/90	509	1130	4
	Walleye	Seven Bays	5/3/90	405	542	4
188242	Walleye	Seven Bays	5/3/90	385	465	3
	Walleye	Off Hawk Cr.	5/3/90	430	640	4
	Walleye	Off Hawk Cr.	5/3/90	412	614	3
			mean =	428	678	4
	Walleye	Off Hawk Cr.	8/3/90	455	694	4
	Walleye	Sanpoil Arm	8/7/90	365	N/A	N/A
448084	Walleye	Sanpoil Arm	8/7/90	565	1580	4
	Walleye	Off Hawk Cr.	10/3/90	584	1901	5
	Walleye	Seven Bays	10/4/90	280	166	1
			mean =	450	1085	4
	Walleye	Sanpoil Arm	8/7/90	495	1094	4
	Walleye	Sanpoil Arm	8/7/90	389	447	3
448085	Walleye	Spring Canyon	8/?/90	536	1640	7
	Walleye	Off Hawk Cr.	10/3/90	280	205	1
	Walleye	Off Hawk Cr.	10/4/90	443	680	4
			mean =	429	813	4
	Walleye	Off Hawk Cr.	8/3/90	380	445	2
	Walleye	Sanpoil Arm	8/7/90	410	620	3
448086	Walleye	Sanpoil Arm	8/7/90	460	878	3
	Walleye	Sanpoil Arm	8/7/90	555	1390	4
	Walleye	Seven Bays	10/4/90	406	503	4
			mean =	442	767	3
	Rainbow Trout	Seven Bays	5/2/90	471	1460	3
	Rainbow Trout	Seven Bays	5/2/90	386	669	1
188230	Rainbow Trout	Keller Ferry	5/12/90	348	511	3
	Rainbow Trout	Keller Ferry	5/12/90	490	931	N/A
	Rainbow Trout	Keller Ferry	5/12/90	413	894	3
			mean =	422	893	2
	Rainbow Trout	Seven Bays	5/2/90	360	497	1
	Rainbow Trout	Keller Ferry	5/12/90	452	1100	4
188231	Rainbow Trout	Keller Ferry	5/12/90	426	647	3
	Rainbow Trout	Keller Ferry	5/12/90	414	825	3
	Rainbow Trout	Keller Ferry	5/12/90	443	934	4
			mean =	419	801	3

APPENDIX A (continued)

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Rainbow Trout	Seven Bays	5/2/90	425	1033	3
	Rainbow Trout	Keller Ferry	5/12/90	535	1028	4
188232	Rainbow Trout	Keller Ferry	5/12/90	325	399	2
	Rainbow Trout	Keller Ferry	5/12/90	445	716	3
	Rainbow Trout	Keller Ferry	5/12/90	420	818	4
			mean =	430	799	3
	Rainbow Trout	Seven Bays	8/3/90	410	727	N/A
	Rainbow Trout	Seven Bays	8/3/90	303	323	<1
328080	Rainbow Trout	Seven Bays	8/3/90	543	1747	2
	Rainbow Trout	Seven Bays	8/3/90	321	383	3
	Rainbow Trout	Seven Bays	8/3/90	305	337	<1
			mean =	376	703	2
	Rainbow Trout	Seven Bays	8/3/90	312	343	N/A
	Rainbow Trout	Seven Bays	8/3/90	305	335	N/A
328081	Rainbow Trout	Seven Bays	8/3/90	375	563	2
	Rainbow Trout	Seven Bays	8/3/90	314	388	2
	Rainbow Trout	Seven Bays	8/3/90	461	1003	4
			mean =	353	526	3
	Rainbow Trout	Off Hawk Cr.	8/3/90	414	891	1
	Rainbow Trout	Off Hawk Cr.	8/3/90	322	356	<1
328082	Rainbow Trout	Seven Bays	8/3/90	220	394	<1
	Rainbow Trout	Seven Bays	8/3/90	330	433	<1
	Rainbow Trout	Seven Bays	8/3/90	312	336	<1
			mean =	320	382	1
	Kokanee	Spring Canyon	5/10/90	411	710	3
	Kokanee	Spring Canyon	5/10/90	440	760	3
188233	Kokanee	Spring Canyon	5/10/90	382	548	2
	Kokanee	Spring Canyon	5/10/90	465	846	3
	Kokanee	Spring Canyon	5/10/90	405	735	3
			mean =	421	720	3
	Kokanee	Off Hawk Cr.	8/3/90	500	1334	3
	Kokanee	Keller Ferry	8/7/90	334	476	2
448082	Kokanee	Off Hawk Cr.	10/3/90	319	333	1
	Kokanee	Off Hawk Cr.	10/3/90	356	461	N/A
	Kokanee	Seven Bays	10/4/90	491	1210	2
			mean =	400	763	2
	Lk. Whitefish	Seven Bays	5/3/90	417	774	3
	Lk. Whitefish	Seven Bays	5/3/90	541	1795	5
188237	Lk. Whitefish	Seven Bays	5/3/90	517	1453	5
	Lk. Whitefish	Seven Bays	5/3/90	440	1066	5
	Lk. Whitefish	Off Hawk Cr.	5/3/90	375	489	5
			mean =	458	1115	5
	Lk. Whitefish	Seven Bays	5/3/90	386	574	3
	Lk. Whitefish	Seven Bays	5/3/90	454	890	4
188238	Lk. Whitefish	Seven Bays	5/3/90	555	1770	6
	Lk. Whitefish	Seven Bays	5/3/90	516	1291	5
	Lk. Whitefish	Seven Bays	5/3/90	495	1164	5
			mean =	481	1138	5

APPENDIX A (continued)

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Lk. Whitefish	Seven Bays	5/3/90	520	1626	6
	Lk. Whitefish	Seven Bays	5/3/90	380	668	3
188239	Lk. Whitefish	Seven Bays	5/3/90	502	1166	5
	Lk. Whitefish	Seven Bays	5/3/90	481	1034	5
	Lk. Whitefish	Seven Bays	5/3/90	510	1197	6
			mean =	479	1138	5
	Lk. Whitefish	Off Hawk Cr.	10/3/90	580	2060	7
	Lk. Whitefish	Off Hawk Cr.	10/3/90	520	1673	7
448087	Lk. Whitefish	Off Hawk Cr.	10/3/90	360	578	3
	Lk. Whitefish	Off Hawk Cr.	10/3/90	536	1486	6
	Lk. Whitefish	Off Hawk Cr.	10/3/90	549	858	5
			mean =	509	1331	6
	Lk. Whitefish	Off Hawk Cr.	8/3/90	374	613	3
	Lk. Whitefish	Seven Bays	8/3/90	505	1580	4
448088	Lk. Whitefish	Seven Bays	8/3/90	500	1165	4
	Lk. Whitefish	Off Hawk Cr.	10/3/90	518	1649	6
	Lk. Whitefish	Seven Bays	10/4/90	553	1720	7
			mean =	490	1345	5
	Lk. Whitefish	Seven Bays	8/3/90	354	557	3
	Lk. Whitefish	Seven Bays	8/3/90	505	1234	4
448089	Lk. Whitefish	Off Hawk Cr.	10/3/90	544	1679	6
	Lk. Whitefish	Off Hawk Cr.	10/3/90	372	636	4
	Lk. Whitefish	Seven Bays	10/4/90	613	2643	7
			mean =	478	1350	5

APPENDIX A (continued)

Rufus Woods Lake

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Walleye	Bridgeport S.P.	8/22/90	655	2763	7
	Walleye	Bridgeport S.P.	8/22/90	414	611	3
368110	Walleye	Bridgeport S.P.	8/22/90	417	672	4
	Walleye	Bridgeport S.P.	8/22/90	456	1043	4
	Walleye	Bridgeport S.P.	8/22/90	429	754	4
			mean =	474	1169	4
	Walleye	Bridgeport S.P.	8/22/90	432	723	3
	Walleye	Bridgeport S.P.	8/22/90	401	615	3
368111	Walleye	Bridgeport S.P.	8/22/90	466	977	3
	Walleye	Bridgeport S.P.	8/22/90	434	909	3
	Walleye	Bridgeport S.P.	8/22/90	491	1268	3
			mean =	445	898	3
	Rainbow Trout	Bridgeport S.P.	8/21/90	309	365	1
	Rainbow Trout	Bridgeport S.P.	8/22/90	406	779	3
368105	Rainbow Trout	Bridgeport S.P.	8/21/90	292	304	<1
	Rainbow Trout	Bridgeport S.P.	8/21/90	303	317	1
	Rainbow Trout	Bridgeport S.P.	8/22/90	334	369	<1
			mean =	329	427	1
	Rainbow Trout	Bridgeport S.P.	8/21/90	328	352	<1
	Rainbow Trout	Bridgeport S.P.	8/21/90	295	271	1
368106	Rainbow Trout	Bridgeport S.P.	8/21/90	310	370	1
	Rainbow Trout	Bridgeport S.P.	8/21/90	303	325	<1
	Rainbow Trout	Bridgeport S.P.	8/22/90	350	460	<1
			mean =	317	356	1
	Rainbow Trout	Bridgeport S.P.	8/21/90	320	365	1
	Rainbow Trout	Bridgeport S.P.	8/21/90	305	315	1
368107	Rainbow Trout	Bridgeport S.P.	8/21/90	334	382	1
	Rainbow Trout	Bridgeport S.P.	8/21/90	296	322	<1
	Rainbow Trout	Bridgeport S.P.	8/22/90	321	381	3
			mean =	315	353	1
	Lake Whitefish	Bridgeport S.P.	8/22/90	525	1724	5
	Lake Whitefish	Bridgeport S.P.	8/22/90	494	1448	5
368108	Lake Whitefish	Bridgeport S.P.	8/22/90	509	1362	5
	Lake Whitefish	Bridgeport S.P.	8/22/90	511	1944	8
	Lake Whitefish	Bridgeport S.P.	8/22/90	461	1413	6
			mean =	500	1578	6
	Lake Whitefish	Bridgeport S.P.	8/22/90	551	1658	4
	Lake Whitefish	Bridgeport S.P.	8/22/90	531	1794	6
368109	Lake Whitefish	Bridgeport S.P.	8/22/90	520	1613	6
	Lake Whitefish	Bridgeport S.P.	8/22/90	496	1436	4
	Lake Whitefish	Bridgeport S.P.	8/22/90	501	1409	5
			mean =	520	1582	5

APPENDIX A (continued)

Lake Wenatchee

ECOLOGY SAMPLE NO.	SPECIES	LOCATION	DATE	TOTAL LENGTH (mm)	WEIGHT (g)	EST. AGE (yrs)
	Mt. Whitefish	Little Wen. R.	9/12/90	413	905	N/A
	Mt. Whitefish	Little Wen. R.	9/12/90	361	508	N/A
398185	Mt. Whitefish	Near Inlet	9/12/90	287	225	N/A
	Mt. Whitefish	Near Inlet	9/12/90	273	182	N/A
	Mt. Whitefish	Near Inlet	9/12/90	261	140	N/A
			mean =	319	392	N/A
	Mt. Whitefish	Little Wen. R.	9/12/90	371	548	N/A
	Mt. Whitefish	Near Inlet	9/12/90	273	236	N/A
398186	Mt. Whitefish	Near Inlet	9/12/90	305	314	N/A
	Mt. Whitefish	Near Inlet	9/12/90	273	194	N/A
	Mt. Whitefish	Near Inlet	9/12/90	261	145	N/A
			mean =	297	287	N/A
	Mt. Whitefish	Little Wen. R.	9/12/90	371	530	N/A
	Mt. Whitefish	Little Wen. R.	9/12/90	300	245	N/A
398187	Mt. Whitefish	Little Wen. R.	9/12/90	276	179	N/A
	Mt. Whitefish	Near Inlet	9/12/90	304	270	N/A
	Mt. Whitefish	Near Inlet	9/12/90	275	197	N/A
			mean =	305	284	N/A

N/A = Not Available