Monitoring of Mountain Whitefish, *Prosopium williamsoni*, from the Columbia River System near Castlegar, British Columbia: Fish Health Assessment and Contaminants in 1994

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MONITORING OF MOUNTAIN WHITEFISH, *Prosopium williamsoni*, FROM THE COLUMBIA RIVER SYSTEM NEAR CASTLEGAR, BRITISH COLUMBIA: FISH HEALTH ASSESSMENT AND CONTAMINANTS IN 1994

by

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ABSTRACT

In July 1994 adult mountain whitefish (*Prosopium williamsoni*) were sampled from two reaches of the Columbia River near Castlegar, B.C.: at Genelle, downstream of a bleached kraft pulp mill, and at Beaver Creek, downstream of a lead/zinc smelter. Fish were also sampled from a reference site on the Slocan River. Fish health was assessed using a Cumulative Disease Severity (CDS) approach, which accounts for the prevalence and severity of gross external and internal abnormalities, histopathological analyses of several tissues/organs, and bacteriology. Fish were also examined for feeding habitats, organic contaminants and metals in muscle tissue, metals in liver, hepatic mixed function oxidase activity, and metallothioneins. This study represents the second of three sampling programs (in July of 1992, 1994, and 1996), designed to examine the health and chemical contamination of Columbia River mountain whitefish following upgrading and modernization of the pulp mill and smelter. This study is a follow-up to a preliminary study conducted in 1991, prior to the upgrade of the pulp mill.

Mountain whitefish sampled from the Genelle and Beaver Creek reaches of the Columbia River had significantly higher condition factors, growth (size-at-age), gonad weight, and gonadosomatic index (GSI) than similarly-aged fish of the same sex from the reference site, suggesting no adverse effects of effluent from the pulp mill or smelter on these variables. Liversomatic index (relative liver weight) was higher in female fish at Genelle (downstream of the pulp mill); this effect has previously been associated with exposure to pulp mill effluent. The presence of loose eggs in the body cavity of several fish from Beaver Creek and Genelle may indicate nonspawning with resorption of mature oocytes, possibly in response to stress. Increased feeding and condition factor observed in fish below the pulp mill from 1992 to 1994 may reflect increased availability of benthic prey items as a result of secondary treatment and 100% chlorine dioxide substitution for elemental chlorine in the bleaching process.

Genelle whitefish had a significantly higher prevalence of external, internal, gill, and liver abnormalities as compared to Slocan River fish, and a significantly higher prevalence of liver abnormalities as compared to Beaver Creek fish. Genelle fish also had a significantly higher severity of external, internal, gill, and liver abnormalities than Slocan River fish, and Beaver Creek fish had significantly higher severity of gill abnormalities compared to the reference fish. CDS was significantly higher in fish from Genelle compared to the other two sites, and CDS in fish from Beaver Creek was significantly higher than that for fish from the reference site. This pattern of differences held even when the effects of natural ageing were removed from the data. Gross external signs of gas supersaturation were not observed in fish from any sampling location. Results were similar to those found in 1992.

Polychlorinated dibenzodioxin (PCDD) and dibenzofuran (PCDF) concentrations in muscle tissue declined substantially at the two Columbia River sites compared with 1991 data, while polychlorinated biphenyl (PCB) congeners remained stable. The consumption advisory for Columbia River mountain whitefish was lifted in March 1995, given the low levels of PCDDs and PCDFs measured in this (July 1994) study. The contribution of PCBs to toxicity equivalents was almost equal to that from dioxin sources.

Monoxygenase enzyme (MFO) activity in mountain whitefish sampled from the Columbia River below the pulp mill declined from very high levels in 1991 (prior to upgrading), to levels similar to those found at the reference site by 1994 (approximately one year following completion of secondary treatment at the pulp mill and 100% chlorine dioxide substitution). The apparent induction seen in the 1994 samples at Genelle is consistent with more transient induction seen around non-bleaching mills, which suggests that organochlorines are probably a contributing factor rather than the exclusive cause of MFO induction.

Metal concentrations in fish muscle tissue remained low at all sampling locations. Copper (Cu) and cadmium (Cd) increased in liver tissue in fish caught below the smelter between 1992 and 1994. Consistent with the 1992 study, metallothionein (MBP) correlated strongly with liver metals in fish from the site below the smelter, suggesting active metal uptake. Unlike 1992, there was also a significant

relationship shown for MBP and Cd in Slocan fish in 1994. This may suggest that there is some unidentified source of Cd near the reference site. Metallothionein concentration was lower in 1994 compared with 1992 at all sampling locations.

The first two sampling phases of this study document a decline in PCDDs and PCDFs in muscle tissue and hepatic MFO activities in Columbia River mountain whitefish following secondary treatment and 100% chlorine dioxide substitution at the pulp mill. The consistently higher mean severity of abnormalities and CDS in fish from Genelle and Beaver Creek compared to the reference site indicate that Columbia River fish may experience a decreased quality of environment. However, abnormalities commonly associated with exposure to pulp mill effluent or metal contamination were observed at low levels in fish sampled from the Columbia River. Several abnormalities appeared to be stress-related. CDS was also not correlated with organic contaminants or MFO activity. Results suggest that the CDS rating likely reflects the cumulative effect of all stressors on the system, including effluent discharge from the pulp mill and smelter, and flow regulation.

Results may also indicate that although Columbia River fish appear to be stressed, the stressors have not resulted in reduced growth (size-at-age), condition factor, or relative gonad size, compared to the Slocan River reference site. Further research is required to determine whether stress from flow regulation or other sources can effect non-spawning and resorption of mature oocytes.

RÉSUMÉ

En juillet 1994, on a prélevé des ménominis de montagnes (*Prosopium williamsoni)* adultes dans deux biefs du fleuve Columbia près de Castlegar, en C.-B., soit à Genelle, en aval d'une usine de pâte kraft blanchie et à Beaver Creek, en aval d'une fonderie de plomb et de zinc. On a aussi prélevé des poissons à un site de référence sur la rivière Slocan. On a évalué la santé des poissons au moyen d'un indice de gravité cumulative des maladies, qui tient compte de la prévalence et de la gravité des anomalies internes et externes manifestes, des analyses histopathologiques de plusieurs tissus et organes et des analyses bactériologiques. Les analyses ont aussi porté sur les habitats d'alimentation, les contaminants organiques et les métaux dans les tissus musculaires, les métaux dans le foie, l'activité hépatique OFM et les métallothionéines. Cette étude constitue le deuxième programme d'échantillonnage d'une série de trois (en juillet 1992, 1994 et 1996), conçue pour évaluer la santé et la contamination chimique du ménomini de montagnes du fleuve Columbia suite à la modernisation de la fonderie et de l'usine de pâtes. Cette étude vient compléter une étude préliminaire réalisée en 1991 avant la modernisation de l'usine de pâtes.

Les ménominis de montagnes prélevés près de Genelle et de Beaver Creek dans le fleuve Columbia présentaient des coefficients de condition, une croissance (taille selon l'âge), un poids des gonades et un indice gonadosomatique significativement plus élevés que les poissons de même sexe et d'âge semblable provenant du site de référence. Il ne semble donc pas y avoir d'effets néfastes liés aux effluents de l'usine de pâtes ou de la fonderie sur ces variables. L'indice hépatosomatique (poids relatif du foie) était toutefois plus élevé chez des poissons femelles prélevés à Genelle (en aval de l'usine de pâtes); cet effet a déjà été associé à l'exposition aux effluents d'usine de pâtes. La présence d'oeufs libres dans la cavité abdominale de plusiers poissons de Beaver Creek et du bief de Genelle pourrait indiquer une absence de reproduction accompagnée d'une résorption des ovocytes matures, peut-être en réaction au stress. L'augmentation de l'alimentation et du coefficient de condition des poissons prélevés en aval de l'usine de pâtes entre 1992 et 1994 pourrait refléter une hausse de la disponibilité des proies benthiques résultant du traitement secondaire et du remplacement à 100 % du chlore élémentaire atomique par du dioxyde de chlore dans le procédé de blanchiment.

Les ménominis de montagnes de Genelle présentaient une prévalence significativement plus élevée des anomalies externes, internes, branchiales et hépatiques par rapport aux poissons de la rivière Slocan, ainsi qu'une prévalence significativement plus élevée des anomalies hépatiques par rapport aux poissons de Beaver Creek. Pour les poissons de Genelle, la gravité des anomalies externes, internes, branchiales et hépatiques était significativement plus élevée que pour les poissons de la rivière Slocan; la gravité des anomalies branchiales était significativement plus élevée pour les poissons de Beaver Creek que pour les poissons du site de référence. L'indice de gravité cumulative des maladies était significativement plus élevé chez les poissons de Genelle que chez les poissons provenant des deux autres points d'échantillonnage; cet indice était aussi plus élevé chez les poissons de Beaver Creek que chez les poissons du site de référence. Cette distinction demeurait vraie, même lorsqu'on éliminait des données du vieillissement naturel. On n'a observé aucun signe externe manifeste d'une supersaturation gazeuse. Les résultats étaient semblables aux résultats obtenus en 1992.

Les concentrations de dibenzodioxines polychlorées (PCDD) et de dibenzofuranes polychlorés (PCDF) dans les tissus musculaires ont diminué de beaucoup par rapport aux données obtenues en 1991 pour les deux points de prélèvement du fleuve Columbia, tandis que les concentrations de congénères de biphényles polychlorés (BPC) sont demeurées stables. L'interdiction de consommation du ménomini de montagnes du fleuve Columbia a été levée en mars 1995, étant donné les faibles concentrations de PCDD et de PCDF mesurées lors de l'étude (juillet 1994). La contribution des BPC à la toxicité globale était presque égale à celle provenant des autres sources de dioxine.

L'activité des mono-oxygénases dans les ménominis de montagnes prélevés dans le Columbia en aval de l'usine de pâtes a diminué; elle atteignait des niveaux très élevés en 1991, avant la modernisation, et s'est abaissée à des concentrations semblables à celles mesurées au site de référence en 1994 (à peu près un an après la mise en marche du traitement secondaire à l'usine de pâtes et le remplacement complet du chlore élémentaire par du dioxyde de chlore). L'induction apparente observée dans les échantillons de Genelle de 1994 est conforme à une induction plus transitoire observée près des usines qui ne pratiquent pas le blanchiment, ce qui semble indiquer que les composés organochlorés constituent probablement un facteur contribuant à l'induction des mono-oxygénases mais n'en sont pas la seule cause.

Les concentrations de métaux dans les tissus musculaires des poissons sont demeurées faibles pour tous les points d'échantillonnage. Les concentrations de cuivre (Cu) et de cadmium (Cd) ont toutefois augmenté dans les tissus hépatiques de poissons capturés en aval de la fonderie en 1992 et 1994. Conformément à l'étude de 1992, les teneurs en métallothionéines étaient en étroite corrélation avec celles des métaux dans le foie des poissons prélevés en aval de la fonderie, ce qui indique une absorption active des métaux. Contrairement à 1992 toutefois, on a aussi noté un lien important entre les métallothionéines et le Cd chez les poissons capturés à Slocan en 1994. Il se pourrait donc qu'il y ait une source non identifiée de Cd près du site de référence. Les concentrations de métallothionéines étaient plus faibles en 1994 qu'en 1992 pour tous les points d'échantillonnage.

Les deux premières phases d'échantillonnage de l'étude montrent clairement une diminution des PCDD et des PCDF dans les tissus musculaires et de l'activité des mono-oxygénases dans le foie chez le ménomini de montagnes du Columbia après la mise en marche du traitement secondaire et l'utilisation du dioxyde de chlore à l'usine de pâtes. Les valeurs régulièrement plus élevées observées dans la gravité des anomalies et la gravité cumulative des maladies chez les poissons provenant de Genelle et de Beaver Creek par rapport à celles du site de référence pourraient refléter une diminution de la qualité du milieu aquatique. Toutefois, les anomalies fréquemment associées à l'exposition aux effluents d'usines de pâtes ou à la contamination métallique étaient peu élevées chez les poissons provenant du fleuve Columbia. Plusieurs anomalies sembleraient plutôt liées au stress. De même, la gravité cumulative des maladies n'était pas corrélée avec les contaminants organiques ni avec l'activité des mono-oxygénases. Les résultats donnent à penser que l'indice de gravité cumulative des maladies reflète probablement l'effet cumulé de tous les agents de stress sur le système, y compris celui des effluents de l'usine de pâtes et de la fonderie et l'effet de la régularisation des débits.

Les résultats pourraient aussi indiquer que, même si les poissons du fleuve Columbia semblent soumis à des agents de stress, ceux-ci ne semblent toutefois pas avoir entraîné une diminution de la croissance (taille selon l'âge), des coefficients de condition ou de la taille relative des gonades par rapport aux poissons du site de référence de la rivière Slocan. D'autres études devraient permettre de déterminer si le stress causé par la régularisation des débits ou par d'autres facteurs peut influer sur l'absence de reproduction et sur la résorption des ovocytes matures.

INTRODUCTION

The Department of Fisheries and Oceans (DFO) initiated a five year study under the Green Plan Toxic Chemicals Program to examine mountain whitefish, *Prosopium williamsoni*, from the Columbia River between the Hugh Keenleyside Dam and the international border. The study consisted of three sampling phases, in July of 1992, 1994, and 1996. The purpose was to monitor fish health and chemical contamination following the expansion and upgrading of Celgar's bleached kraft pulp mill near Castlegar, B.C., and modernization of Cominco's lead/zinc smelter and fertilizer complex located at Trail, B.C. Improvements at the pulp mill included an air-activated sludge secondary treatment system, 100% chlorine dioxide substitution for elemental chlorine in the bleaching process, and use of hydrogen peroxide in the delignification process. Production capacity of the mill also doubled. These changes were completed by June 1993. The modernization of the smelter included a number of projects, which reduced the concentration, and loading of metals released to the Columbia River. This study is a follow-up to a preliminary study in January 1991 (Boyle *et al.* 1992), which documents the health of mountain whitefish prior to the planned expansion of the pulp mill.

The first sampling phase of this study took place from July 6 to 13, 1992 (Nener *et al.* 1995). Adult mountain whitefish were sampled from two reaches within the Columbia River: at Genelle, downstream of the pulp mill; and at Beaver Creek, downstream of the smelter. Mountain whitefish were also sampled from a reference site within the Slocan River. Fish were analyzed for wet weight, fork length, age, histopathology, gut contents, organic contaminants in muscle tissue, mixed function oxidase activities (MFOs), metals in muscle and liver tissue, and metallothioneins (MBP).

In July 1992, fish sampled downstream of the pulp mill at Genelle exhibited consistently greater disease prevalence and severity than fish from Beaver Creek or the Slocan River reference site (Nener *et al.* 1995). Genelle fish were also significantly older than fish from the other two sites, and a significant relationship between age and cumulative disease severity (CDS) was found at both Genelle and Beaver Creek. A statistical comparison of the prevalence and severity of abnormalities after eliminating the effect of age was not performed due to the lack of older fish at the reference site. This made it difficult to assess whether the differences in CDS among sampling locations were related to natural ageing or adverse environmental conditions.

Lawrence (1996) reassessed the 1992 data using general linear modelling (ANCOVA) to separate the effect of age from intersite differences in CDS for Columbia River fish. Genelle fish had significantly greater mean CDS than Beaver Creek fish, after eliminating the age effect. Although Slocan River fish were not included in this analysis, mean age did not differ significantly between fish from Beaver Creek and the Slocan River in 1992. Lawrence (1996) also compared CDS among the three sampling locations for fish less than twelve years of age and found that CDS was significantly higher for Genelle fish compared to fish from the reference site ($p<0.001$), and CDS for Beaver Creek fish did not differ significantly from the other two sites. Lawrence (1996) also revealed that the relationship between CDS and age in 1992 might be non-linear.

Polychlorinated dibenzodioxin (PCDD) and dibenzofuran (PCDF) concentrations in muscle tissue of Columbia River whitefish have declined since the preliminary study in January 1991. Fish from the Columbia River had significantly higher polychlorinated biphenyl (PCB) concentrations in muscle tissue compared with fish from the Slocan River reference site in 1992. Comparisons of PCB concentrations between the 1991 and 1992 studies were limited as only Aroclor 1254/1260 was measured in the earlier study. Fish collected below the pulp mill at Genelle in 1992 had significantly higher muscle concentrations of mercury than fish from either Beaver Creek or the Slocan River, but all concentrations were below the federal human health consumption guideline of 0.5 μg/g (wet weight).

The second sampling phase of the Columbia River fish health and chemical contamination study was conducted in July 1994. All sampling locations remained the same as in the July 1992 study and the sampling program differed in only three areas. First, a slightly larger sample size was used in the disease survey to overcome the difficulties experienced in 1992 due to uneven age distributions among sampling locations. Second, viral pathogens were not included because the 1992 samples tested negative for filtrable infectious agents. Third, the method of fish capture differed slightly between studies; fish were collected by angling and electroshocking in 1992 and by electroshocking only in 1994. It is unlikely that these differences would confound interpretation of results because the majority of fish were caught by electroshocking in 1992, and analysis of the 1992 data showed no significant effect of capture method on fish health variables.

The purpose of this report is to present methods and results for the July 1994 sampling program. Raw data and summary statistics can be found in Lawrence (1996). Results of the two previous studies are provided in Boyle *et al.* (1992) and Nener *et al.* (1995).

METHODS

FISH COLLECTION

Sampling for mountain whitefish (*Prosopium williamsoni*) took place from July 4 to 15, 1994 at the same three reaches that were sampled in the July 1992 study (Fig. 1). The Genelle reach of the Columbia River was approximately 20 km downstream of the Celgar pulp mill. The Beaver Creek reach was approximately 10 km downstream of the smelter and fertilizer complex at Trail. The reference reach on the Slocan River, a tributary to the Kootenay River, was approximately 2 km downstream from Slocan Lake, near Passmore Bridge. Fish were generally collected over a reach of about 5 km in length at all sampling locations.

The two main hydroelectric facilities in the immediate vicinity of the study area are the Hugh Keenleyside Dam, approximately 4 km upstream of the pulp mill, and the Brilliant Dam on the Kootenay River, just upstream of the confluence of the Columbia River. The Brilliant Dam has no fish passage facilities, and hence there is no possibility of upstream movement from the Columbia River to the reference site on the Slocan River. There are no fish passage facilities at Keenleyside, and entrainment of adult mountain whitefish through the dam is likely low.

All fish were caught by electroshocking using a boom-mounted unit on a jet boat with a low voltage setting of 2.5 to 4 amperes. Electroshocking was conducted over two nights at each site, usually between 19:00 and 23:00 h, with the exception of the Genelle site, where the second day of electroshocking occurred between 14:00 and 17:00 h. Adult mountain whitefish between approximately 25 and 45 cm in fork length were selected in order to obtain a similar age distribution among sites. Once captured, fish were held in live tanks on the boat until they were transported to holding pens near the river bank.

Individual fish were taken from the holding pens and pithed. Fork length was recorded and fish were towel-dried in a consistent manner prior to being weighed on a Mettler PL300 electronic balance. Fish were then examined externally and internally using the disease survey procedures described below. For the subset of fish selected for MFO or metallothionein analyses, the livers were removed, weighed, and frozen between flat sections of dry ice within approximately 2 minutes of death. A small section of the liver was removed for histology before the sample was placed in a whirl-pack bag for freezing. Upon completion of the disease survey and preparation of liver samples for biochemical analysis, the remaining internal organs were removed and weighed, and gutted weight was recorded. Whitefish stomachs were preserved by placing the complete digestive track in a glass jar containing 10% (v/v) formalin. Mesenteric fat and gonad development were estimated qualitatively. Otoliths were removed for ageing. For the subset of fish selected for contaminant analyses, the muscle tissue was preserved according to the procedures described below for organic contaminants or metals.

The total number of fish retained for analyses was 83 at the Slocan River reference area, 80 at Genelle, and 83 at Beaver Creek. All but ten fish collected at each site were examined for disease survey. The remaining ten fish per site were examined for parasitology only. A subset of the total number of fish examined for disease survey were also analyzed for organic contaminants (10 fish per site) and MFO activities (20 fish per site). Another subset of fish were analyzed for metals in muscle tissue (15 fish per site) and metallothionein (15 fish per site). The stomachs from all fish analyzed for organics/MFO and metals/metallothionein were preserved for stomach content analyses. This equalled thirty-five stomachs from each sampling reach.

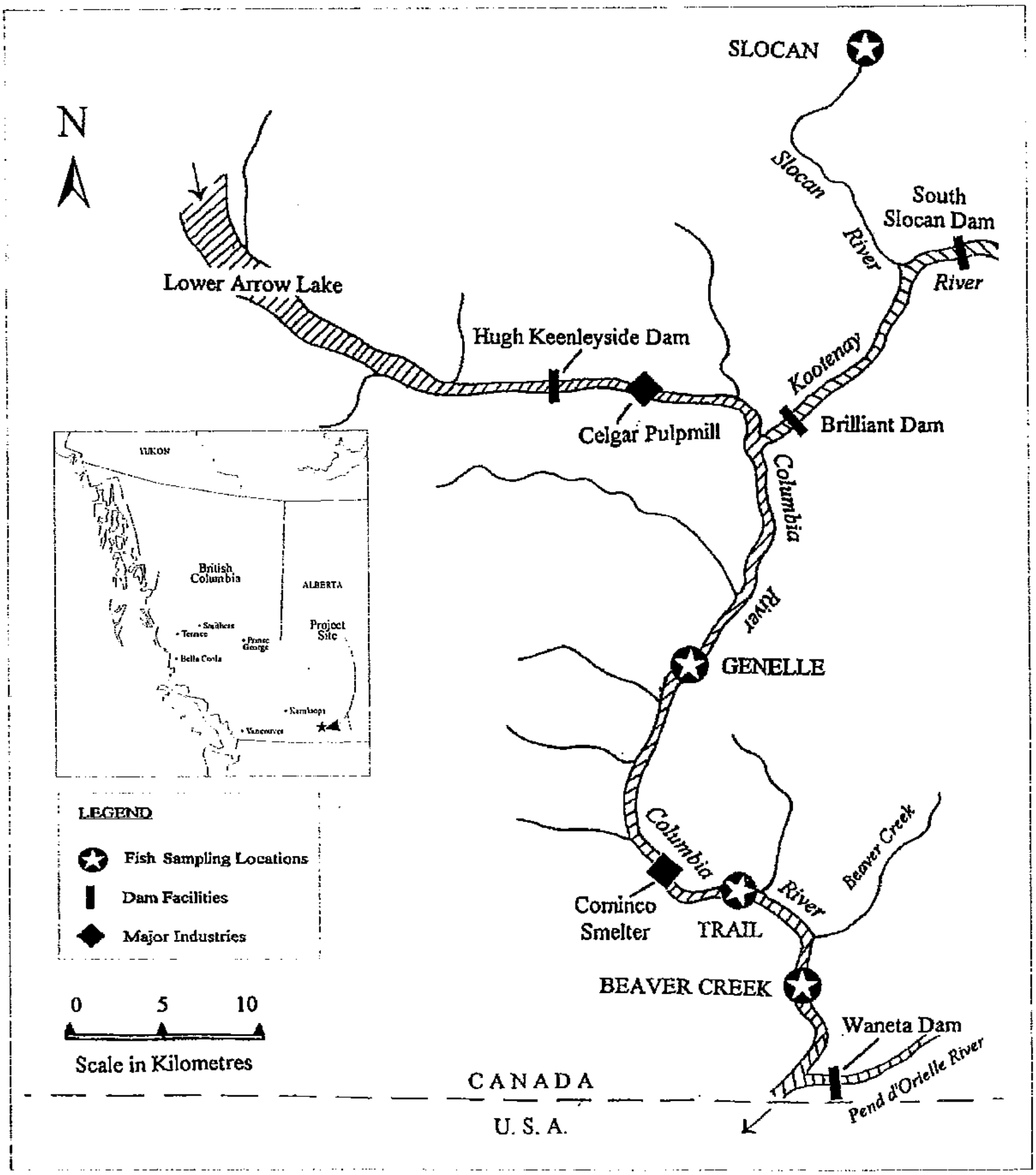


Figure 1. Study area and sampling sites for mountain whitefish collected from the Columbia and Slocan Rivers, July 1994.

AGE DETERMINATION

Ages of sampled fish were determined through otolith analysis at the Pacific Biological Station, Nanaimo, B.C. Ages (whole years of growth) were determined with random precision checks, but no validation with fish of known ages was done. Other biologists working on this stretch of the Columbia River have rarely observed mountain whitefish over 9 years of age (Larry Hildebrand, R.L. and L. Environmental Services Ltd., Castlegar, BC, V1N 3K3, pers. comm.). These biologists have also found that ageing of mountain whitefish by otoliths gives consistently higher ages than ageing by scales. This study may therefore overestimate age, however, all samples in the July 1994 and July 1992 study were aged in a consistent manner.

STOMACH CONTENT ANALYSES

The preserved whitefish stomachs were shipped to Applied Technical Services (Saanichton, B.C.) for analyses of the diet of mountain whitefish from the Columbia and Slocan Rivers. The total contents of each stomach were removed from the jar and blotted on filter paper to remove excess moisture prior to weighing to the nearest milligram (mg) on an electronic balance. The contents were then sorted and identified to the lowest practical taxonomic level. Organisms were categorised according to life history stage and habitat of origin. Individual diet items were measured, counted, and weighed by whole animal or body parts. Relative stomach fullness was estimated as an indication of the extent of feeding. Percent digestion of ingested prey was also estimated, as it can influence the level of identification and the lengths and weights of individual organisms.

The level of identification and identification criteria for each species or group of prey items followed that used in the July 1992 study (Nener *et al.* 1995). The level of identification was usually genus (and species if possible), and in some cases subfamily, family or suborder. Identification criteria included head, gills, wings, exuviae, legs, shell, and other parts. Identifications were performed using a Wild M5A binocular dissecting microscope (X 6 to X 25 magnification). If necessary, wet mounts were prepared for smaller organisms or parts and these were examined on a Wild M12 Binocular compound microscope (X 10 to X 400 magnification). In some cases, the whole animal or particular body parts where too badly damaged for reliable identification to the lowest desired level.

The following list of taxonomic keys was used to identify the stomach contents: Allen and Edmunds 1961, 1962, 1965; Borror and White 1970; Clarke 1981; Edmunds 1959; Edmunds *et al.* 1976; Imms 1957; Merritt and Cummins 1984; Pennak 1989; Scott and Crossman 1973; Wiggins 1977.

The length of each organism was measured to the nearest millimetre (mm), or less in smaller organisms, using the micrometer eyepiece of the microscope. Measurements were generally taken from the front of the head to the end of the body, not including antennae, setae, hooks, or other projections. When the whole animal was not present, it was placed in a 3 mm length category, length was estimated based on the parts present or by extrapolation from measured organisms present in the same sample. Individual prey items were assigned to a taxon-specific length strata for enumeration and measurements of wet weight.

Whole animals and parts of organisms were counted using the enumeration criteria in Nener *et al.* (1995). The part used depended on the level of digestion (e.g., bodies, heads, eyes, wings, thorax, bones, shell). In some samples, separate counts of each part were made and the highest count used. Where the numbers of a particular organism were larger than 100, a subsample of about 100 organisms was measured and counted, and remaining individuals of that species were counted, and length categories were assigned by extrapolation. The enumeration did not include parasites of either the fish (trematodes, nematodes, cestodes) or the diet items (nematodes). Fish scales and eggs were also not counted, as these are rarely found when the preserved stomach is unbroken, and they are often found loose in the sample jar as contaminants from the fish dissection.

Each organism or length group was weighed to the nearest mg. The weight was estimated from known weights of a large number of a particular length group when the organism or length group present weighed less than 1 mg. The items were blotted on filter paper in a consistent manner prior to weighing to remove excess surface water. The total weight of the stomach contents, recorded at the start of the procedure, was usually equal to the sum of the contents. However, when the contents were heavily digested, the estimated weights exceeded the original weight (e.g., the empty exuviae of a *Drunella* sp. may only weigh 10 mg, whereas the entire nymph would weigh 150 mg).

The following categories were assigned to each diet item: benthic (B), surface or drift (D), water column (C), or other (e.g., case materials and mucus). Benthic organisms include nymphs, larva and pupae of aquatic insects that are buried in or closely associated with the bottom, and sculpins. Organisms found on the surface include terrestrial organisms that accidentally fall into the water, or adults of aquatic insects that live on the surface film or are laying their eggs or mating at the surface. Those organisms that are under the water (e.g., emerging adults of Trichoptera or Ephemeroptera) are counted as drift. Organisms present in the water column include corixids and cladocerans.

DISEASE SURVEY

The numbers of fish sampled and disease testing methods followed protocols outlined in the Fish Health Protection Regulations: Manual of Compliance (Department of Fisheries and Oceans 1984).

Gross Examination

Fish were examined externally and internally for gross abnormalities, including signs of gas supersaturation. Where present, abnormal tissue was preserved in Davidson's solution for histological evaluation.

Bacteriology

Kidney tissue from each fish was cultured on tryptic soy agar plates for a minimum of five days. Selected colonies were chosen for identification using API 20E strips (API, St. Laurent. P.Q.) or using slide agglutination tests with commercially prepared antisera (Micrologix Inc., Victoria, B.C.), with standard cytochrome oxidase tests, motility tests, and Gram stains of the colonies.

To detect mycobacteria, kidney tissue from fish numbers 1 to 11 and 25 to 34 from the Slocan River, 106 to 115 and 123 to 132 from Beaver Creek, and 205 to 214 and 222 to 231 from the Genelle site of the Columbia River, was cultured individually on commercially prepared Lowenstein-Jensen (PML Microbiologicals, Richmond, B.C.) medium at 20 °C for at least six weeks.

Two smears of kidney were prepared. One smear was microscopically examined for bacterial and protozoal agents after Gram staining. The other smear was acid-fast stained to test for the presence of mycobacteria.

Parasitology

Ten whole fish from each site were collected and frozen, and submitted to the Parasitology Laboratory at the Pacific Biological Station for evaluation. Tissues examined were: fins, heart, head, eyes, viscera, swimbladder, branchial cavity, musculature, and brain. The prevalence of gill parasites could not be determined as the gills had been removed from the samples provided. Wet mounts of liver, intestine, kidney, gall bladder, and urinary bladder were prepared and 50 fields were examined at 350x magnification to detect protozoan parasites. Helminths were identified after removal from the tissues by the bicarbonate separation technique.

Histology

For each fish sampled, pieces of gill, liver, kidney, spleen, pyloric caeca/pancreas, and posterior gut were preserved in Davidson's solution. Material from abnormalities of interest (e.g., tumours) was also preserved. Haematoxylin-eosin stained sections of each tissue were prepared and evaluated using standard histological techniques (Humason 1979).

ORGANIC CONTAMINANTS

The heads and tails of each fish to be analyzed for organic contaminants were removed and the gutted carcass (with skin in tact) was placed inside a contaminant-free plastic bag. The bag was sealed, placed on dry ice, and transported to the Institute of Ocean Sciences' (IOS) Ultra Trace Contaminants laboratory in Sidney, B.C. for storage at -20°C.

Fish muscle tissue was dissected and homogenised by AXYS Analytical Laboratories. The skin and bones were removed during the dissection and the tissue was homogenised using a commercial meat grinder. All dissection and homogenisation equipment was cleaned and solvent-rinsed prior to use and after each sample, and polyethylene gloves were worn while handling the samples. After samples were homogenised, they were subsampled for PCDD/PCDF and PCB analyses and for percent moisture and lipid content.

AXYS analyzed the tissue using high resolution gas chromatography (HRGC) with high resolution mass spectrometric detection (HRMS) for dioxins and furans and non-ortho-substituted PCB congeners, and HRGC with low resolution mass spectrometric detection for all other PCB congeners and Aroclors. Analytical procedures for PCDDs and PCDFs were identical to those used in the 1992 study. The PCB methods differed slightly from those used in 1992, however, the variations in methods do not compromise the comparability of the two data sets or the continuity of the study. Quality control and quality assurance (QA/QC) measures included blank samples, duplicates, and certified reference standards. As an additional QA/QC check, twelve duplicates were prepared by AXYS and a random selection of five of these blind duplicates were analyzed by IOS for inter-lab comparisons.

Toxicity equivalents (TEQs) were calculated for the PCDD and PCDF congeners using the internationally accepted toxicity equivalency factors (TEFs) from NATO (1988). As there are no internationally accepted TEF values for PCB compounds, TEQs were calculated using two common TEF schemes (see Table 1); the World Health Organisation/International Programme on Safety (WHO/IPCS) interim TEF system (Ahlborg *et al.* 1994), and the system suggested by Safe (1994). The TEFs for some compounds can vary by an order of magnitude or more between these two systems, as a result of the uncertainty in chemical toxicity for these substances. Two PCB compounds that have been assigned TEF values (PCB 123 and PCB 167) were not analyzed by AXYS, and hence they were not included in the PCB TEQ calculations. Total TEQs, which included the contribution from PCDDs/PCDFs and PCBs, were calculated by summing the 2,3,7,8-TCDD TEQs for the PCDD/PCDF congeners with the 2,3,7,8-TCDD TEQs for the PCB compounds. TEQs for both PCDDs/PCDFs and PCBs are in units of pg 2,3,7,8-TCDD/g tissue.

All TEQs were calculated based on three methods: the Environment Canada method, where all non-detected values are given a concentration of zero; the B.C. Ministry of Environment method, which uses one-half the detection limit as the concentration; and a conservative approach where all non-detected values are replaced with the detection limit.

Table 1. Toxicity equivalency factors for polychlorinated biphenyls (PCBs). Source: Ahlborg *et al.* (1994).

Mono- and Di- Ortho Substituted PCBs:	WHO/IPCS Interim TEF:	Safe (1994) Suggested TEF:
PCB 105	0.0001	0.001
PCB 114	0.0005	0.0002
PCB 118	0.0001	0.0001
PCB 123*	0.0001	0.0001
PCB 156	0.0005	0.0004
PCB 157	0.0005	0.0003
PCB 167*	0.00001	0
PCB 189	0.0001	0
PCB 170	0.0001	0
PCB 180	0.00001	0
Non-Ortho Substituted (Coplanar) PCBs:	**WHO/IPCS Interim TEF:**	**Safe (1994) Suggested TEF:**
PCB 77	0.0005	0.01
PCB 126	0.1	0.1
PCB 169	0.01	0.05

MIXED FUNCTION OXIDASES

Samples of liver were frozen on dry ice in the field and shipped to the Freshwater Institute in Winnipeg where they were stored at –80°C until analysis. Samples were analyzed for ethoxyresorufin O-deethylase (EROD), aryl hydrocarbon hydroxylase (AHH), also referred to as benzopyrene hydroxylase and cytochrome P-450 using methods described elsewhere (Boyle *et al.* 1992; Hodson *et al.* 1991).

TRACE METALS AND METALLOTHIONEINS

Muscle Tissue

Tissues from 45 mountain whitefish were analyzed for trace metals. Fish carcasses were shipped to the contracting laboratory (Quanta Trace Laboratories, Burnaby, B.C.), and samples of muscle were removed from the right side equidistant from the anterior and posterior borders. Portions were trimmed so that no exposed flesh was included in the analysis. The entire sample was oven dried (55°C) and percent moisture determined. Dried samples were ground and portions (approx. 0.5 g) were weighed and transferred to Teflon vessels for microwave-enhanced digestion in nitric acid. Thirty-four elements were determined by inductively coupled plasma spectrometry. Mercury was determined by cold-vapor atomic absorption spectrometry.

Liver Tissue

Four trace metals (Cd, Cu, Zn, and Hg) and metal-binding proteins or metallothioneins (MBP) were determined in livers from the same 45 fish analyzed for trace metals in muscle tissue. Tissues were split into two portions, one to be shipped to Quanta Trace Ltd., Burnaby for mercury determination. The other portion was lyophilized and pulverized (agate mortar and pestle) for metal and metal-binding protein (metallothionein) assays of the cytosolic fraction. Metals (cadmium, copper and zinc) in liver tissue were determined by flameless atomic absorption spectrometry after microwave-enhanced, concentrated nitric acid digestion of tissue homogenates and cytosols.

A second portion of dried tissue was homogenized in chilled Tris-buffer (50 mM, pH 7.5, 1 mM dithiothreitol as an antioxidant, 0.05% sodium azide) and centrifuged 24 h later. An aliquot of the supernatant cytosol was removed for total protein determination (Bradford 1976). The remaining cytosol was subjected to heat denaturation (90°C for 5 min) and centrifugation (47 000 xg) at 5°C. Metallothioneins, or metal binding proteins (MBP) were determined in the heat denatured pool (HD) cytosols by the differential pulse polarographic (DPP) method of Thompson and Cosson (1984) with the following modifications: 1. cell temperature was maintained at 5.0 ± 0.5 °C; and 2. the concentration of the hexamminecobalt catalyst in the electrolytic buffer was increased to 80 $mg.L^{-1}$. The HD pool was also assayed for the metals Cd, Cu and Zn by graphite furnace AAS after digestion in concentrated nitric acid.

All chemicals used for reagent preparation were ACS reagent grade or better. In addition, the TRIS buffer was purified further by batch extraction over Chelex-100 ion exchange resin. Water used in the preparation of solutions was doubly deionized (Milli-Q).

For QA/QC of the liver analysis the following measures were taken: Three samples (S54, T127 and G226) were chosen for replicate analysis, wherein the entire procedure was triplicated, starting with the initial sample preparation. Four blank aliquots of the homogenization buffer were treated identically to the samples, to provide a check on possible contamination of the cytosol. Twelve reagent (tissue) blanks were also run on the concentrated HNO_3. Tissue blanks were also used as matrix in the preparation of the metal standards for calibration of the spectrometer. Detection limits for each analyte were determined as $3\sigma_b$, where σ_b is the standard deviation of the blank determinations.

Average coefficients of variation (CV) for the replicate analysis of liver cytosols for Cd, Cu and Zn were 6.35, 12.4 and 17.8% respectively; while the values for the tissue homogenates were 8.35, 8.14 and 6.30%. For cytosolic total protein and MBP the average CV values were 3.70% and 3.46%, respectively.

Accuracy was determined by analyzing ten samples of dogfish liver certified reference material ('DORT-1', NRC, Canada). Recoveries for Cd, Cu and Zn were 91.8, 88.5 and 91.0%, respectively. Data were not corrected for these recovery values.

For chemical and statistical purposes, data for metals and proteins in cytosols and the cellular fraction are reported in $\mu moles.kg^{-1}$.

RESULTS AND DISCUSSION

LIFE HISTORY DATA

Life history data (e.g., age, wet weight, fork length, liver weight, stomach weight, gonad weight, condition factor, gonadosomatic index, liversomatic index, and sex ratio) for each sampling location are summarized in Table 2. Raw data are provided in Appendix 1.

Mean age was 8 years for Genelle fish, 9 years for Beaver Creek fish, and 8 years for fish from the Slocan River (Table 2). There was no significant difference in mean age among sampling location ($p=0.116$) (Lawrence 1996). Mean age did not differ significantly among sampling location for male fish only ($p=0.122$), or for female fish only ($p=0.052$). At two sites, the Slocan River and Genelle, mean age did not differ significantly between males and females, while females were significantly older than males at Beaver Creek ($p<0.02$). The majority of fish sampled from the Slocan River site were between 5 and 10 years of age, while the fish from the Columbia River sites had a higher percentage of fish less than 5 years and greater than 12 years of age (Fig. 2).

Slocan River fish were significantly shorter, on average, than fish sampled from the Genelle and Beaver Creek reaches of the Columbia River, which did not differ significantly ($p<0.001$) (Lawrence 1996). When only male fish were considered, Slocan River fish were significantly shorter than Beaver Creek fish ($p=0.037$). For females, Beaver Creek fish were longest, followed by Genelle and then Slocan River fish. At each sampling location, males and females had similar fork length.

Slocan River fish weighed significantly less than Genelle or Beaver Creek fish, which did not differ significantly in mean wet weight (total body weight) ($p<0.001$) (Lawrence 1996). This same pattern of differences held when fish were separated into sex. At individual reaches, some differences among sexes were observed; females from Genelle ($p<0.02$) and Beaver Creek ($p<0.05$) were heavier than males.

The relationship between fork length and wet weight was examined for both sexes using linear regression. Results indicate that for each sex, Slocan fish weighed significantly less than fish from the two reaches of the Columbia River, for a given fork length (Fig. 3). Although the slope of the regression line for Slocan River fish was greater than that for the other two sites, there were few Slocan River fish older than 13 years.

The relationship between fish age and fork length was found to be non-linear for males and females from all sampling locations (Fig. 4). To account for this non-linearity, the independent variable (age) was log transformed; no transformation of the dependent variable was required. Linear regression of log transformed data indicated that male fish from the Slocan River were significantly shorter than male fish from either site on the Columbia River, after the effect of age was taken into account. This same conclusion held for female fish, however, the slopes of the regression lines were not equal and there were no female fish from the Slocan River greater than 13 years of age. Hence, this conclusion may not apply to female fish from the Slocan River older than 13 years. Analysis of the relationship between age and wet weight provided similar results. Males from the Slocan River weighed significantly less than males from the two Columbia River reaches, after accounting for age. This conclusion also applied to females, aged 13 years or less. Overall, results indicate that growth, measured by size-at-age (length or weight), was higher for Columbia River fish than for fish from the Slocan River reference site.

Table 2. Life history data for mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Variable		SLOCAN Mean (± S. D.*)	GENELLE Mean (± S. D.)	BEAVER CREEK Mean (± S. D.)
Age (years)	*All fish:*	8 ± 3	8 ± 6	9 ± 6
	Females:	8	8	10
	Males:	9	8	7
Wet Weight (g)	*All fish:*	363.3 ± 208.2	482.2 ± 146.2	521.7 ± 136.7
	Females:	372.0	516.2	546.3
	Males:	351.4	434.2	473.4
Fork Length (cm)	*All fish:*	30.9 ± 4.6	33.4 ± 3.8	34.4 ± 3.0
	Females:	30.8	33.9	35.1
	Males:	31.0	32.6	33.1
Liver Weight (g)	*All fish:*	3.6 ± 2.4	4.6 ± 1.8	4.5 ± 1.4
	Females:	3.7	5.4	5.0
	Males:	3.4	3.6	3.7
Stomach Weight (g)	*All fish:*	29.2 ± 27.2	25.0 ± 12.0	24.84 ± 6.0
	Females:	31.0	28.7	26.3
	Males:	26.8	19.8	22.3
Gonad Weight (g)	*All fish:*	5.7 ± 6.4	12.4 ± 11.1	13.0 ± 10.1
	Females:	7.8	12.7	13.3
	Males:	2.7	11.93	12.2
Condition Factor	*All fish:*	1.15 ± 0.10	1.28 ± 0.21	1.28 ± 0.24
	Females:	1.16	1.31	1.26
	Males:	1.15	1.25	1.29
Gonadosomatic Index (GSI)	*All fish:*	1.49 ± 0.91	2.39 ± 1.93	2.38 ± 1.68
	Females:	1.95	2.35	2.34
	Males:	0.80	2.44	2.38
Liversomatic Index (LSI)	*All fish:*	0.98 ± 0.45	0.97 ± 0.27	0.87 ± 0.16
	Females:	0.98	1.06	0.92
	Males:	0.98	0.84	0.79
Sex Ratio	*(male:female)*	1 : 1.4	1 : 1.5	1 : 1.9

* S.D. = Standard Deviation

Slocan River whitefish had significantly lower gutted weight, on average, than Columbia River whitefish, which did not differ significantly between the two reaches sampled ($p<0.001$) (Lawrence 1996).

There was no significant difference in mean stomach weight (whole, intact stomachs) among sampling location for all fish (both sexes combined)($p=0.116$), for male fish only ($p=0.161$), or for females ($p=0.090$). At the two Columbia River sites, stomach weights for females were significantly larger than those for males (Lawrence 1996). A summary of visceral fat levels, where noted is given in Table 3. The majority of fish from the Slocan River had moderate to heavy fat levels, while few fish from Beaver Creek exhibited heavy fat.

Table 3. Visceral fat where noted, in mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Visceral fat	Slocan (n=63)	Genelle (n=50)	Beaver Creek (n=64)
light	5 (7.9 %)	10 (20.0 %)	23 (35.9 %)
moderate	31 (49.2 %)	13 (26.0 %)	31 (48.4 %)
heavy	27 (42.9 %)	27 (54.0 %)	10 (15.6 %)

Slocan River whitefish had significantly lower liver weight, on average, than Columbia River whitefish, which were not significantly different ($p<0.001$) (Lawrence 1996). This same conclusion held when only female fish were compared among sampling location ($p<0.001$). When only male fish were considered, mean liver weight did not differ significantly among sampling location ($p=0.196$). At all sampling locations liver weights were greater for females than males, however, these differences were significant only at the two Columbia River sites.

Slocan River whitefish also had significantly lower gonad weight, on average, than Columbia River whitefish, which were not significantly different ($p<0.001$) (Lawrence 1996). This conclusion also held for female fish only ($p<0.001$). Male fish from the Slocan River had significantly lower mean gonad weight than male fish from Genelle or Beaver Creek ($p=0.026$), which did not differ significantly. When individual sampling locations were considered, gonad weight was significantly larger for females compared to males at the reference site only.

A summary of gonad development, where noted in the field, is given in Table 4. Several mountain whitefish sampled from the Columbia River contained loose eggs in the body cavity, in addition to the next set of developing eggs. Five fish from Genelle (7.2 %) and 21 fish from Beaver Creek (28.8 %) were observed to have loose eggs in the body cavity. No fish from the Slocan River had loose eggs in the body cavity, however, one fish had developing, semi-loose eggs.

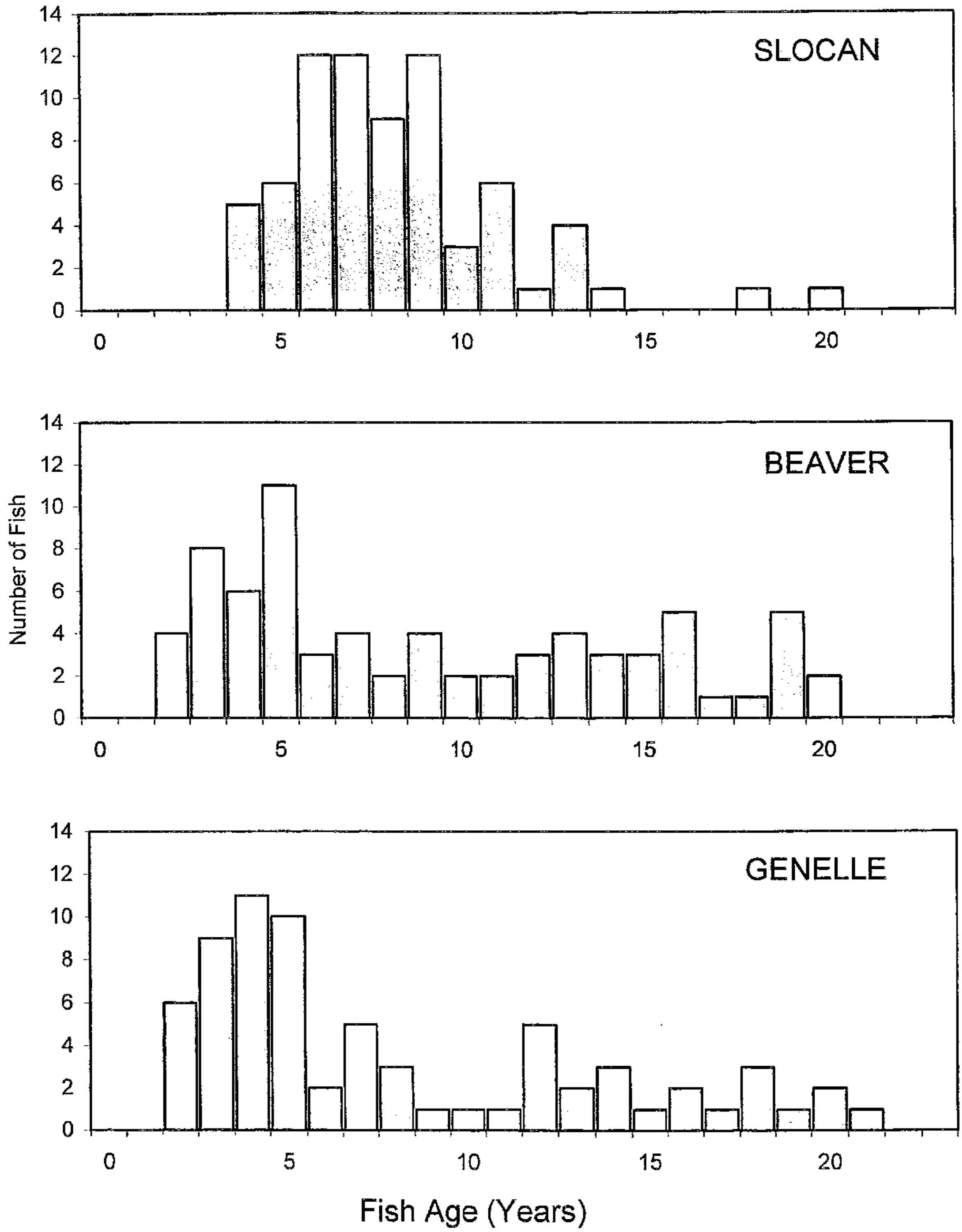
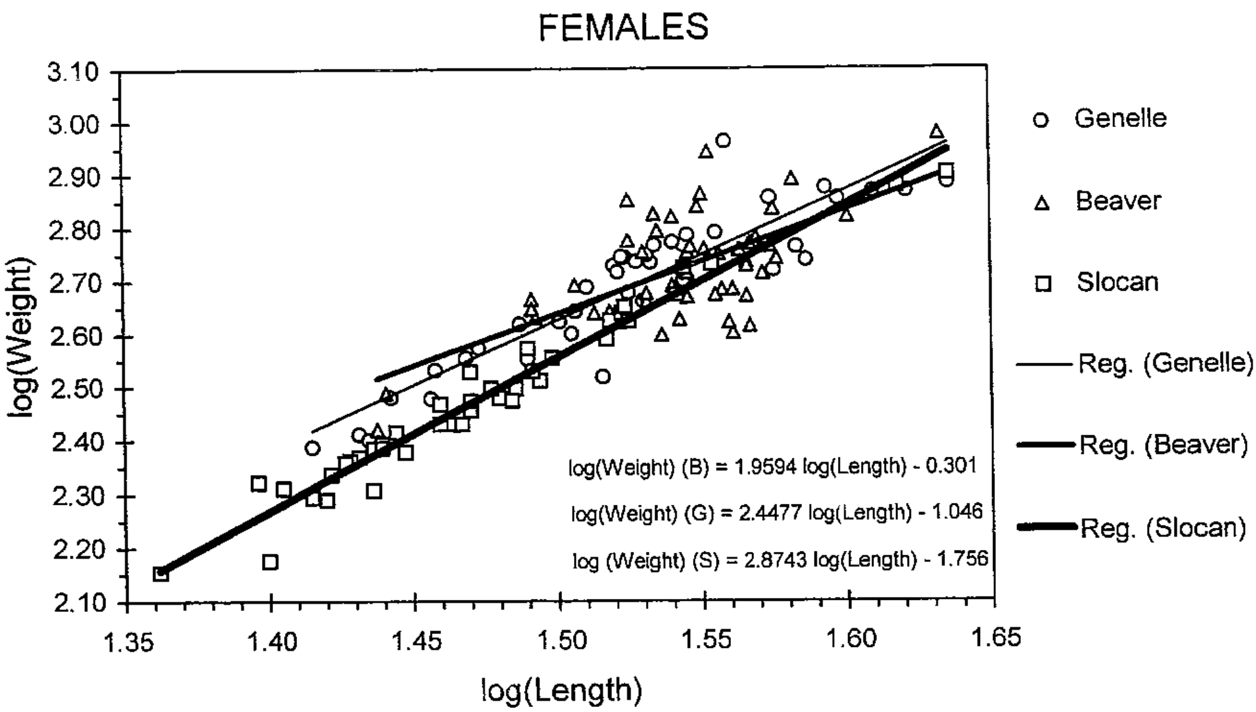


Figure 2. Age distributions of fish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.



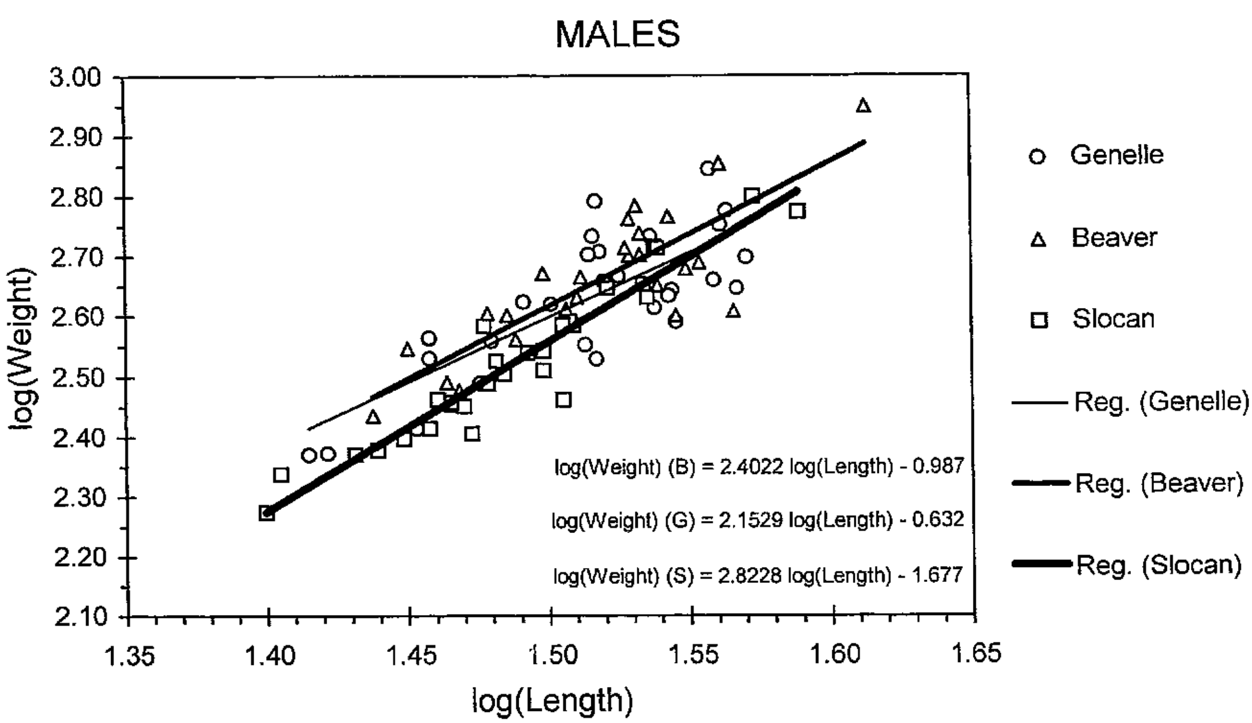


Figure 3. Logarithmic regression of wet weight versus fork length by sampling location.

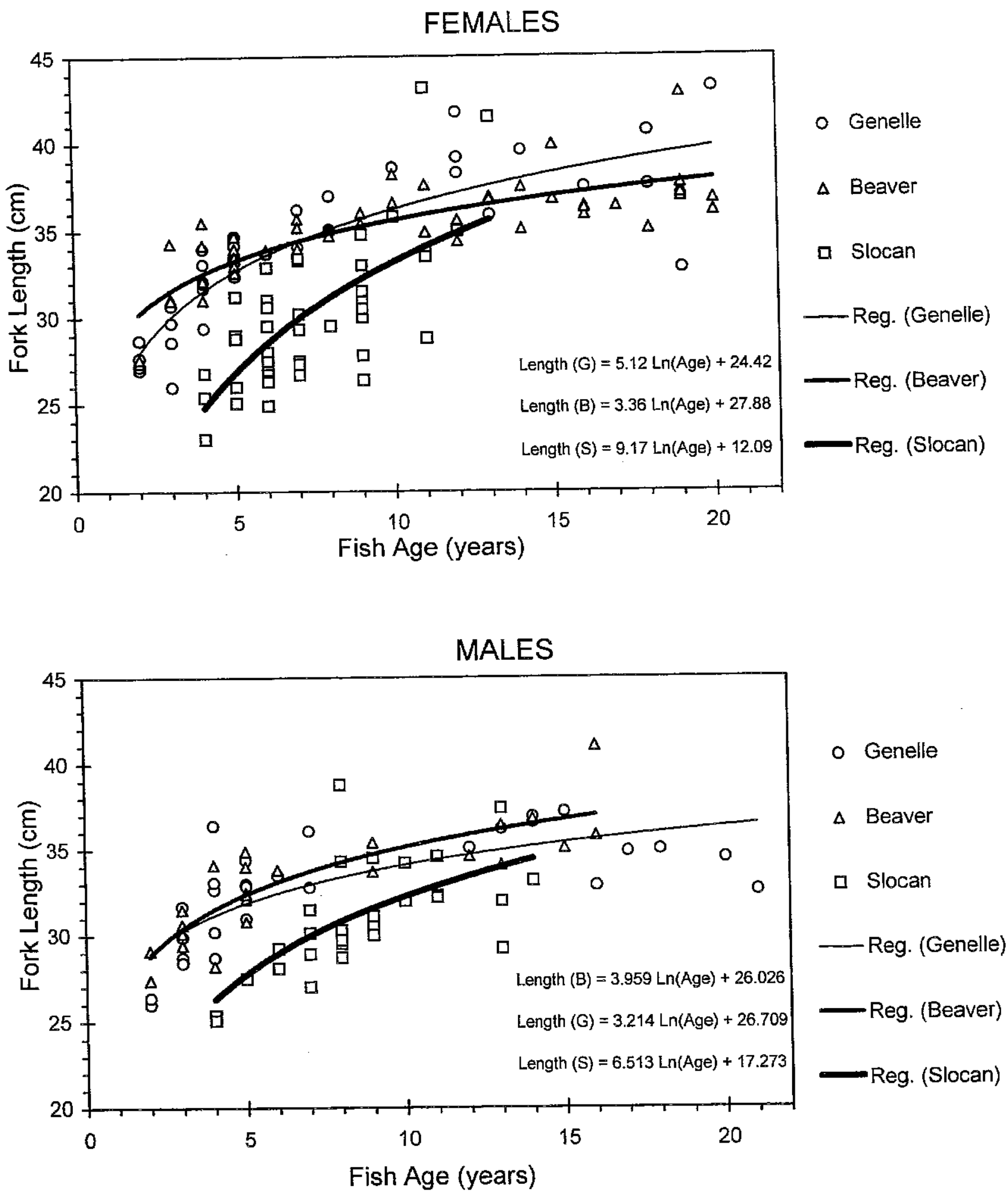


Figure 4. Logarithmic regression of fork length versus fish age by sampling location.

Table 4. Gonad development in mountain whitefish sampled from two reaches within the Columbia River, and a reference site within the Slocan River, in July 1994.

Gonad Development	**Slocan (n=22)**	**Genelle (n=24)**	**Beaver Creek (n=31)**
light	7 (31.8 %)	7 (29.2 %)	2 (6.5 %)
moderate	13 (59.1 %)	11 (45.8 %)	23 (74.2 %)
Well developed or ripe	2 (9.1 %)	6 (25.0 %)	6 (19.4 %)

The ratio of males to females was 1:1.4 at Slocan, 1:1.5 at Genelle, and 1:1.9 at Beaver Creek. 39.7 % of the mountain whitefish collected at the Slocan River were male and 58.9 % were female (one fish had indeterminate sex), 34.2 % of the fish from the Beaver Creek reach of the Columbia River were male while 64.4 % were female (one had indeterminate sex), and 41.4 % of the fish from Genelle male and 58.6 % were female. Sex ratio did not differ significantly among sampling locations (p=0.679) (Lawrence 1996).

Condition Factor

Condition factor was calculated as Weight (g) x Fork Length^{-3} (mm) x 10^5. The mean condition factor was 1.15 for fish from the Slocan River, and 1.28 for fish sampled at each site of the Columbia River. Condition factors were significantly higher for fish from Genelle and Beaver Creek compared to fish from the reference site (p<0.001) (Lawrence 1996). This same pattern of differences held when male and female fish were considered separately. Condition factor did not differ significantly among males or females at any sampling location (Lawrence 1996).

Liversomatic Index

The liversomatic index (LSI), calculated as a ratio of liver weight to total body weight (Poels *et al.* 1980), was 0.98 for Slocan River fish, and 0.97 and 0.87 for fish from Genelle and Beaver Creek, respectively. No significant differences in LSI were found among the three locations for males (Lawrence 1996). For females, LSI was significantly higher for Genelle fish compared to Beaver Creek fish, while Slocan River fish did not differ significantly from Genelle or Beaver Creek fish. When individual sampling locations were considered, females had significantly higher LSI than males at the two Columbia River reaches.

The LSI assumes that the relationship between wet weight and liver weight is linear, and that all fish are similar in size. The 1994 data were linear over the range of data sampled, however, the variance of liver weight was not homoscedastic. The independent and dependent variables were therefore logarithmic transformed and analyzed using regression analysis. Results for female fish showed that liver weights at the Genelle site were significantly greater than liver weights at the Beaver Creek site, after the effect of total body weight was taken into account (p=0.036), while liver weights for Slocan River fish did not differ significantly from fish at Genelle or Beaver Creek. Liver weights for male fish did not differ significantly among sampling location, after the effect of total body weight was considered. This analysis confirmed the comparison of LSI among sampling location.

Gonadosomatic Index

The gonadosomatic index (GSI), calculated as the ratio of gonad weight to total body weight (Poels *et al.* 1980), averaged 1.49 for Slocan River fish, compared to 2.39 for Genelle fish and 2.38 for Beaver Creek fish. For female fish, the GSI was significantly higher in fish sampled from the Columbia River than in fish from the Slocan River ($p<0.001$) (Lawrence 1996). For male fish only, the mean GSI was higher at the two Columbia River reaches compared to the reference site, however, this difference was not significant, probably due to high variability and a smaller sample size. This is a reflection of the higher number of Columbia River fish with well-developed gonads. There was little difference in GSI among sexes at the two Columbia River sites, but at Slocan females had significantly higher GSI than males ($p<0.001$).

The relationship between gonad weight and body weight was non-linear for both male and female fish. The dependent variable was therefore log-transformed and analyzed using regression analysis. Results showed that, for female fish only, gonad weight did not differ significantly among sampling location, after the effect of total body weight was taken into account ($p=0.764$). Results were similar for male fish only ($p=0.240$). Although these findings differ slightly from the GSI scores, both analyses indicate that there was no reduction in gonad size in fish collected downstream of the pulp mill.

Discussion of Life History Data

The Slocan River fish were of a similar age to the Columbia River fish, however, they were significantly shorter, lighter, and had lower condition factors than the Columbia River fish. Lipid levels were also higher in fish from Genelle and Beaver Creek, however, these differences were not significant, possibly due to the small sample size of 10 fish per site.

Fish from the two reaches of the Columbia River were similar. There were no significant differences between Genelle and Beaver Creek in any of the biological variables in Table 2, with the exception of liver weight for females (higher at Genelle compared to Beaver Creek), and fork length for females (higher at Beaver Creek compared to Genelle). Although tagging studies indicate that mountain whitefish from this stretch of the Columbia River are relatively non-migratory, it is possible that fish from the Genelle and Beaver Creek reaches of the Columbia River represent the same population.

The higher condition factors observed for Columbia River whitefish, compared to Slocan River fish, may be related to organic enrichment in the receiving environment downstream of the pulp mill. Although the Slocan River reference site represents an oligotrophic, less productive system than the Columbia River, the Cycle One Environmental Effects Monitoring (EEM) Program for the Castlegar pulp mill also documented organic enrichment effects downstream of the mill. These effects included growth stimulation in the *Selanastrum capricornutum* sublethal toxicity tests, the presence of richer, more diverse, and more equitable benthic macroinvertebrate communities below the mill, and higher condition factors in mountain whitefish sampled below the pulp mill (Hatfield Consultants Ltd. 1995). The reference site for the EEM study was the Columbia River upstream of pulp mill and the Hugh Keenleyside Dam.

A number of studies have documented the effects of pulp mill effluent on wild fish exposed to dilute concentrations (less than 2%) in the receiving environment (e.g., Munkittrick *et al.* 1994). These effects include reduced sex hormone levels, induction of liver enzymes, increased liver size, reduced secondary sex characteristics, increased age-at-maturity, delayed spawning, reduced fecundity, smaller egg size, and reduced gonad size. In this study, condition factor, gonad weight, GSI, and growth (size-at-age) were higher for Columbia River fish compared to similarly aged fish, of the same sex, from the Slocan River reference site. These findings suggest that there were no adverse effects of pulp mill effluent, or metal contamination, on these variables. However, LSI and relative liver weight (assessed by linear regression of liver weight and total body weight) were higher for female fish from Genelle compared to Beaver

Creek fish, while LSI and relative liver weight for female fish from the reference site did not differ significantly from the other two sites. LSI did not differ significantly among sampling location for male fish. Increased liver size in females from Genelle and not Beaver Creek might be related to exposure to pulp mill effluent.

The Genelle sampling site was located approximately 20 km below the pulp mill, where the dilution of effluent is typically less than 0.2 %. Hatfield Consultants Ltd. (1994) examined the effect of effluent from the Celgar pulp mill on adult mountain whitefish in the near-field zone immediately below the diffuser, where effluent concentration was about 0.54 to 1.03 %. Their results were similar in that condition factor was higher for fish sampled downstream of the mill, and there was no evidence of reduced gonad size or GSI in male or female fish captured below the mill. Fecundity was also significantly higher at the near-field zone compared to the reference site (6335 vs. 2900 eggs per female), while egg size did not differ significantly among sites. Ford *et al.* (1995) report that range of fecundity for mountain whitefish ranges from 5000 to 7700 eggs per female, with 5000 being the more realistic number. Relative fecundity (number of eggs/ per kilogram of female) averaged 15,905 at the near-field site and 10,522 at the reference site below Revelstoke Dam. The reference site for this study was the Columbia River upstream of the pulp mill but below the Revelstoke Dam, a peaking power plant facility which leads to daily fluctuations in discharge. The near-field zone was also located below a dam, however, the Hugh Keenleyside Dam is a storage facility, and discharges do not fluctuate on a daily basis to meet power demands. Fish from the reference site might have been stressed due to operation of the Revelstoke Dam, however, it is unknown whether this type of stress would influence gonad size, condition factor, and fecundity.

Several mountain whitefish sampled from the Columbia River in the July 1994 study contained free or loose eggs in the body cavity, in addition to the eggs developing for the next spawning season. This was observed in 7 % of fish from Genelle, 29 % of Beaver Creek, and zero % of fish from the Slocan River reference site. Several fish were egg bound (i.e., the body cavity was essentially full of ripe eggs), while others contained a much smaller number of loose eggs scattered throughout the body cavity. Unfortunately, it was not possible to separate out these two conditions from the field notes. Mountain whitefish in the Columbia River system are known to spawn every year, usually from October through to February when temperature declines below 5°C. Mountain whitefish are broadcast spawners (i.e., they do not dig reds), and there is no evidence to suggest that spawning habitat is limited. The presence of loose, ripe eggs in the body cavity of Columbia River fish may indicate non-spawning with resorption of loose eggs, possibly in response to stress. The higher prevalence of non-spawning at Beaver Creek compared to Genelle is difficult to explain. It might be related to regulation of the Pend d'Oreille River, which may cause additional stress for fish that utilize the lower reach of the Columbia River. The three dams on the Pend d'Oreille River (Boundary, Seven Mile and Waneta) operate as peaking power plant facilities, resulting in daily flow fluctuations in the Columbia River below the confluence of the Pend d'Oreille River. Tagging studies, however, have shown that mountain whitefish are relatively non-migratory in this part of the Columbia River, and few fish are found below the Canada-U.S. border.

Shikshabekov (1971) examined lake whitefish trapped in an area of sluice flows and also found that spawning did not occur, and mature oocytes were resorbed. The presence of free eggs in Columbia River whitefish could also indicate delayed spawning, however, this is unlikely as there is no evidence to suggest that mountain whitefish have spawned in late summer in the Columbia River system.

Population estimates for mountain whitefish in the Columbia River system below the Keenleyside Dam indicate that the population size has increased from 1990 to 1994, while catch per unit effort has decreased (Larry Hildebrand, R.L. and L. Environmental Services Ltd., Castlegar, BC, V1N 3K3, pers. comm.).

Comparison of 1992 and 1994 Life history Data

Some of the biological variables measured in the 1994 study differed from those found in the 1992 study. The most striking difference was for whole stomach weights, for male fish and for female fish, which were approximately three times higher in 1994 than in 1992 at all sampling locations. Relative stomach weights (whole stomach weight/total body weight) also increased significantly at each sampling location between 1992 and 1994. Condition factor for each sex also increased significantly between 1992 and 1994 at Genelle and Slocan, but not at Beaver Creek. Condition factor in fish from Genelle was similar between the preliminary 1991 study and the 1992 study. Increased feeding and condition factor between 1992 and 1994 at Genelle might reflect increased availability of benthic prey items. Hatfield Consultants Ltd. (1995) found that the number of benthic invertebrate taxa and percentage of more pollution-sensitive organisms were higher in the fall of 1994, compared to surveys conducted from 1980 to 1988 at Robson and Birchbank. These changes might be associated with improvements at the pulp mill (secondary treatment and 100 % chlorine dioxide substitution), and removal of the fibre mat below the mill, all of which occurred between January 1991 and June 1993.

Liver weight, LSI, gonad weight, and GSI also increased significantly between 1992 and 1994 at Genelle and Slocan, but not at Beaver Creek, with the exception of liver weight for females, which also increased at Beaver Creek in 1994. An increase in liver weight often accompanies an increase in MFO activity, however, in this case MFO activity declined between 1992 and 1994 at the Columbia River sites. The fact that feeding (stomach weight) was higher for Beaver Creek fish in 1994 compared to 1992 but condition factor, liver weight (males only), LSI, gonad weight, and GSI did not increase might indicate a difference in energy storage for Beaver Creek fish. More energy may be diverted into coping with stress and other needs, as opposed to being stored in lipid, muscle, liver, or gonad tissue. Beaver Creek fish also had the highest incidence of mature oocyte resorption suggesting additional stress at this reach. This issue will be further examined following analysis of 1996 data.

The mean age of Beaver Creek fish did not differ significantly between 1992 and 1994, while fish from Genelle were significantly younger in 1994 (8.0 years) compared with 1992 (13.6 years), and fish from the Slocan River were significantly older in 1994 (8.2 years) compared to 1992 (6.3 years). These differences are considered later in the comparison of disease severity results from 1992 and 1994.

STOMACH CONTENT ANALYSES

Appendix 2A summarizes the types of prey items found in mountain whitefish stomachs. The numbers of prey items, sorted by origin and prey groups, are shown in Appendix 2B. Raw data for total number and weight of species or groups, stage (i.e., adult, nymph, larvae, pupae, remains), actual and estimated length and weight of individual prey items, and origin of prey items (i.e., benthic, surface or drift, water column) are reported in Stallard (1994). Table 5 presents summary data for stomach contents weight, percent fullness, and level of digestion, and diet diversity index.

For the subset of mountain whitefish analyzed for stomach contents, mean age did not differ significantly among sampling locations ($p=0.16$), while mean fork length and wet weight were significantly lower for Slocan River fish compared to fish from the two reaches of the Columbia River, which did not differ significantly from one another ($p<0.001$)(Lawrence 1996). The mean condition factor for Slocan River fish was significantly lower than that for fish from Genelle or Beaver Creek ($p=0.002$)(Lawrence 1996).

Food was found in the stomachs of all fish sampled. The mean percent fullness was high at all reaches (Table 5), and percent fullness did not differ significantly among reaches ($p=0.206$)(Lawrence 1996). Only a few fish from each site had stomachs less than 50 percent full. These results indicate that fish were feeding at all reaches sampled. The mean level of digestion was significantly lower at the Slocan River site (63 %), compared with the site sampled at Genelle (78 %) and Beaver Creek (83 %)($p=0.005$) (Lawrence 1996).

Table 5. Stomach contents weight, fullness, level of digestion, and diet diversity index for mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Variable		SLOCAN (n=35)	GENELLE (n=35)	BEAVER (n=35)
Stomach Contents	*Mean:*	4037.97	2495.83	2593.54
Weight (mg)	*St. Dev.:*	3756.02	2083.19	1340.77
Stomach Fullness	*Mean:*	78.57	69.0	71.86
(%)	*St. Dev.:*	19.35	25.2	23.92
Level of Digestion	*Mean:*	63.00	77.97	83.29
(%)	*St. Dev.:*	30.68	19.72	15.53
Diet Diversity Index	*Mean:*	5.86	5.86	5.86
	St. Dev.:	2.26	2.43	2.26

Mean weight of the total gut contents was significantly higher in Slocan River fish compared to fish from Genelle and Beaver Creek ($p=0.022$), even though fish from the Slocan River weighed less, on average, than fish from the Columbia River (Table 5).

The most notable difference in diet among the three sampling locations was the number of prey organisms found in the whitefish stomachs (Appendix 2A). Fewer species or groups of prey organisms were found in the stomachs of whitefish from the two reaches on the Columbia River, compared to the Slocan River. At the Slocan River site, a total of 52 different species or groups of prey organisms were consumed, while only 31 and 26 prey items were consumed by fish from Genelle and Beaver Creek, respectively. Almost all species/groups found in stomachs of fish from the two Columbia River sites were also found at the Slocan site, with the exception of *Ceraclea*, *Brachycentrus occidentalis*, and *Psycohomyia*, which were found at Beaver Creek and Genelle only, and Cladocera, *Eukiefferiella* and *Chalocidea*, found at Genelle only.

To test whether the greater diversity of prey items for Slocan River fish was an artifact of a few fish with a large number of prey groups, a diet diversity index was calculated as the number of prey species or groups per fish (Table 5). This index did not include non-food items or unspecified insect remains. The diet diversity index was significantly greater for fish from the Slocan River (mean of 8.5 prey types per fish) compared with fish from Genelle and Beaver Creek, which both had a mean diet diversity of 5.9 prey types per sample ($p<0.001$)(Lawrence 1996). This suggests that the greater diet diversity at the Slocan River site is representative of the feeding habitats of the majority of fish from this location. The greater diet diversity for Slocan River fish is likely related to food availability.

Fig. 5 shows the mean weight of stomach contents sorted by prey origin for each sampling location. Benthic food items comprise the majority of the diet at all sampling locations. Surface or drift prey items were very rare at the two sites on the Columbia River, where they comprised less than 1 % by weight of the total gut content. Surface or drift items were slightly more common at the Slocan River site, where they comprised 1.5 % of the diet. Prey items from the water column were rarely observed at any of the sampling reaches. The amount of non-food material in the gut, which consisted primarily of case materials, pebbles, mucus, and fish scales, differed substantially among locations. Whitefish stomachs from Beaver Creek contained very little non-food matter (less than 4 %), while Genelle fish stomachs contained about 27 % non-food matter. Fish from the Slocan River had the highest proportion of non-food items in their stomachs (over 40 %), contributing to a higher overall gut content weight compared to the other two locations on the Columbia River.

The composition of benthic food items, by weight, found in the whitefish stomachs are shown in Fig. 6. The two most dominant benthic prey items at three sampling locations were *Ephemeroptera* (mayflies) and *Trichoptera* (caddisflies). The proportion of all other benthic food items was small. The composition of *Plecoptera* by weight was 0.2 % at Beaver Creek and Genelle, and 8.2 % at the Slocan River reference site. The percentage of insect remains by weight was 7.4 % at Beaver Creek, 5.9 % at Genelle, and 4.6 % at the Slocan River location.

The number of fish analyzed for stomach contents that had thin body form were 7 out of 35 fish from Genelle, 9 out of 35 fish from Beaver Creek, and 0 out of 35 fish from the Slocan River. In order to make statistical comparisons of stomach contents between normal fish and fish with a "thin" body form, the samples from the Columbia River were pooled. This provided a sample size of 16 thin and 54 normal fish from the Columbia River. Statistical analyses indicated there were no significant differences in stomach fullness, level of digestion, or stomach content weight between thin and normal fish (Lawrence 1996). These results suggest that feeding patterns are similar for thin and non-thin body forms.

As in the July 1992 study, material that appeared like slag was found in the stomachs of fish from Beaver Creek. Slag is a black, glassy, sand-like material that was historically discharged from the lead-zinc smelter at Trail, B.C. into the Columbia River. The slag material was also wrapped around caddisflies, indicating that the slag particles may be ingested as part of invertebrate cases. Observations made during stomach content analyses also indicated that the Hydropsychidae did not seem to be making cases, possibly as a result of the lack of pebbles or other material to make cases from.

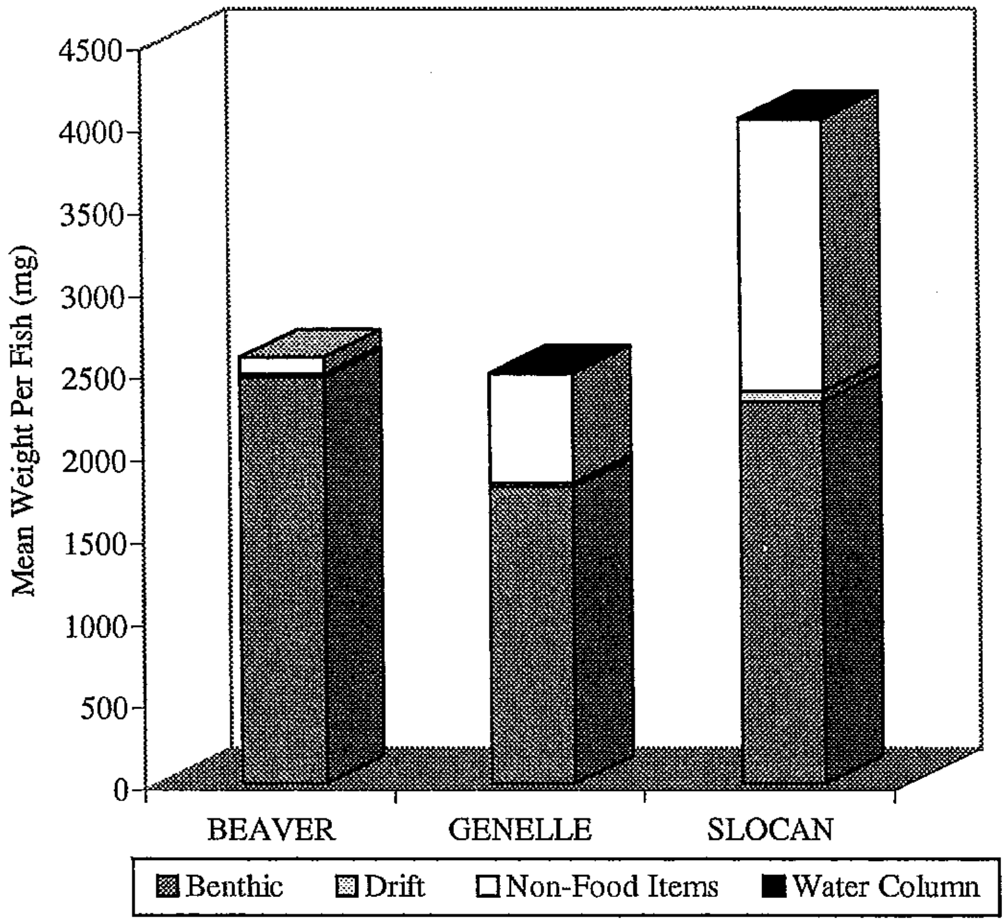


Figure 5. Mean weight of stomach contents, sorted by prey origin, found in mountain whitefish stomachs in July 1994.

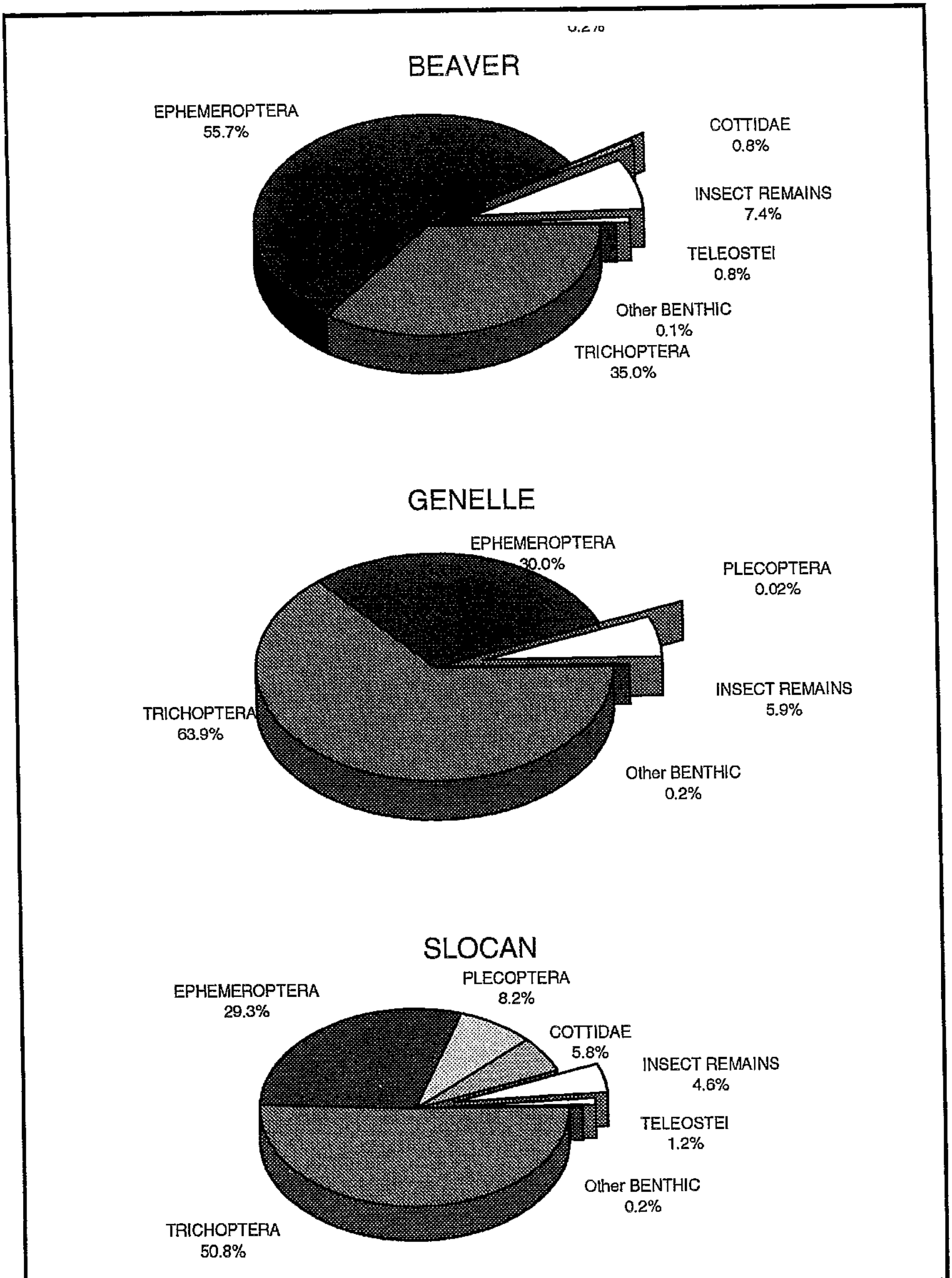


Figure 6. Composition of benthic food items (by weight) found in mountain whitefish stomachs in July 1994.

DISEASE SURVEY

To interpret the fish health significance of the abnormalities and quantify the cumulative effect of all abnormalities present in one fish, a coding system was developed which subjectively rated the abnormalities as to their potential impact on fish health. The coding system is similar to, but more comprehensive than, other quantitative autopsy-based systems of fish health assessment (e.g., Adams *et al.* 1993; Goede and Barton 1990). An abnormality such as a parasite cyst was rated light (1), reflecting the impact it is likely to have on fish health. The impact of causative organisms such as myxobacteria was considered to be moderate (2), while the finding of mycobacteria is considered more damaging, and was rated as severe (3). The normal condition, as well as any artifacts of sampling or slide preparation, were given a rating of (0). The total numerical value of all abnormalities found in one fish at a given location was used to indicate the cumulative disease severity (CDS) rating (overall health status) of each fish. The CDS rating includes results from the gross external and internal examination, histopathology of six differences tissues (gill, liver, kidney, spleen, hind gut, and pyloric cacea), and bacteriology. Parasitology results for the 10 individual fish examined per site were not included in the CDS rating. In cases where parasites were encountered during the histopathological analysis of individual tissues or organs, such as helminths in gill tissue, they were included in the CDS rating.

The coding system, summary of total number of abnormalities found at each sampling location, and the CDS rating is provided in Appendix 3. The CDS rating for each individual fish is provided in Appendix 1.

Fish that did not have a complete histological evaluation of all tissues (gill, liver, kidney, spleen, pyloric caeca/pancreas/posterior-gut) were not used in the disease survey, in order to prevent a lowering of the CDS rating. These were fish numbers: 8, 11, 13, 14, 35, 41, 51, 52, 64, and 68 from the Slocan River site, and numbers 256 and 257 from the Genelle reach of the Columbia River. All 73 fish sampled from the Beaver Creek reach of the Columbia River had complete health summaries. Adjusted sampled sizes for the disease survey were: n = 63 from the Slocan River; n = 73 from Beaver Creek; n = 68 from Genelle.

Gross Examination

External Abnormalities

External lesions, discolouration, and thin body form were found in mountain whitefish sampled from the Columbia River in October 1990. Baseline monitoring of Columbia River mountain whitefish in January 1991 indicated that a few of the fish collected downstream of the pulp mill had these external abnormalities (Boyle *et al.* 1992). Mountain whitefish collected during the first (1992) and second (1994) phase of this study did not exhibit external discolouration as observed in 1990. In 1992 no external lesions were observed, and in 1994 very few external lesions were observed (1.5 % of Genelle fish and 2.7 % of Beaver Creek fish). The incidence of external lesions and injuries in mountain whitefish sampled downstream of a biologically treated bleached-kraft pulp mill in the Wapiti/Smoky River system below Grande Prairie, Alberta, was 6.1 %, compared to 2.9 % at a reference site on the North Saskatchewan River (Kloepper-Sams *et al.* 1994). The kraft pulp mill at Grande Prairie has operated at 100 % chlorine dioxide substitution since July 1992.

In July 1994 thin fish were found in 16.2 % of mountain whitefish sampled from the Genelle reach and 26 % of fish sampled from the Beaver Creek reach, compared with no thin fish observed at the Slocan River site (n=63). Thin body form was significantly more prevalent at the two Columbia River reaches than at the Slocan River site ($p<0.001$) (Lawrence 1996). Over both Columbia River reaches (n=141), 21.3 % of the fish sampled had thin body form in July 1994 (n=141), and 27.3 % of Columbia River whitefish were described as thin (n=121).

Of the whitefish described as having a thin or 'snake' body shape in 1994, 50 % of Genelle and 65 % of Beaver Creek fish had low levels of visceral fat. Moderate fat levels were noted in a few cases where the slender body was also described, however high fat levels were never associated with this body shape. Of Slocan River fish sampled in July 1994, 8.9 % had low levels of visceral fat and none were described as thin. Although body fat levels were lowest for fish from the two reaches of the Columbia River, fish from these sites also had significantly higher condition factor than Slocan River fish. This suggests that the thin condition might not be a reflection of reduced health. The consistent prevalence of this body shape might indicate different morphologies in Columbia River whitefish or different maturation patterns.

The evidence for rating thin condition as an abnormality with moderate severity in the 1992 study was the field observation that thin fish generally had emptier stomachs compared to 'plumper' fish (Nener *et al.* 1995). The 1994 data showed that stomach fullness, level of digestion, and stomach content weight were similar for thin and normal body forms. Thus, for the 1994 study, the severity of external abnormalities and the cumulative disease severity were calculated with and without thin condition as an abnormality.

In 1994 fin erosion was found in two fish sampled from Beaver Creek (n=73), and no fish sampled from Genelle (n=68) or the Slocan River (n=63). No fin erosion was found in whitefish sampled from all locations in 1992. In a similar river system near Grande Prairie, Alberta, the incidence of fin erosion in mountain whitefish sampled downstream of a biologically treated bleached-kraft pulp mill was 4.5 % from 1990 to 1992 (Kloepper-Sams *et al.* 1994). Fin erosion is a consistently described effect of decreased environmental quality due to metal contamination and effluent from bleached kraft pulp mills (Couillard *et al.* 1988; Lindesjöö and Thulin 1990; Sindermann 1979).

In 1994 fungus on the gills or other external surfaces was found in five whitefish sampled from the reference site (n=63), but these external abnormalities were not found in any of the whitefish sampled from Genelle (n=68) or Beaver Creek (n=73).

Prevalence of some external abnormalities increased in the 1994 study compared to the July 1992 study. Hemorrhaging at the base of the fins increased at all sites, with the greatest increase at the Genelle reach. The incidence of this abnormality at the Genelle reach rose from zero in 1992 to 23.5 % in 1994, and from 1.7 % in 1992 to 4.1 % in 1994 for Beaver Creek fish. At the Slocan River reference site, hemorrhaging at the base of the fins also rose from 5.8 % in 1992 to 12.7 % in 1994. This abnormality could indicate clinical signs of systemic bacterial infection, however bacteriology results do not indicate significant bacterial problems. The increase in prevalence of external abnormalities, such as hemorrhaging at the base of fins, at all sites could also be a sampling artifact, possibly due to small differences in electrofishing voltage.

Prevalence of other external abnormalities that increased between July 1994 and July 1992 included: pale gills, mechanical damage, and deformities. In 1994, pale gills were found in 20.6 % of the Genelle fish, 12.3 % of the Beaver Creek fish, and 12.7 % of the Slocan River fish, compared with 1.6 % of Genelle, 5.0 % of Beaver Creek, and 1.4 % of Slocan River fish in 1992. In 1994, mechanical damage, which included scarring and split or abraded fins, was noted in 16.2 % of Genelle fish, 5.5 % of Beaver Creek fish, and 9.5 % of Slocan River fish, compared with 1.6 % of Genelle, 1.7 % of Beaver Creek, and 0 % of Slocan River in 1992. Incidence of mechanical damage in 1994 did not differ significantly among sampling locations ($p=0.11$)(Lawrence 1996).

Deformities, such as scoliosis, were found in 5.9 % and 5.5 % of fish sampled from Genelle and Beaver Creek, respectively, in 1994. No deformities were observed in the July 1992 study. Skeletal deformities in fish have been associated with exposure to pulp mill effluent (e.g., Lindesjöö and Thulin 1990), heavy metals, selenium, vitamin C deficiency, and organo-phosphates and insecticides (Trent Bollinger, Canadian Cooperative Wildlife Health Centre, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 0W0, pers. comm.). In 1992, the production of both ammonium phosphate and ammonium sulphate fertilizers at the smelter/fertilizer plant in Trail used to result in a discharge of approximately 300 to 4,000 kg/day total phosphate to the Columbia River. This range represents a steady decline from a high of 6,700 kg/day in 1988. The phosphate portion of the fertilizer plant was closed in July 1994, and by September 1994 total phosphate in the effluent has been reduced to low levels.

Fish sampled from the Genelle site had a significantly higher proportion of external abnormalities compared to Slocan River whitefish (p=0.014) (Lawrence 1996). Beaver Creek whitefish were not significantly different in proportion of external abnormalities compared to Genelle or Slocan River fish (Lawrence 1996). The mean severity of gross external abnormalities, based on the cumulative disease severity rating system, was 1.51 at the Genelle reach of the Columbia River, and 1.04 at the Beaver Creek reach. The mean severity of external abnormalities in whitefish sampled from the Slocan River was 0.78. Mean severity of external abnormalities was significantly higher in Genelle whitefish than in Slocan River whitefish (p=0.013) (Lawrence 1996). Beaver Creek whitefish were not significantly different than Genelle or Slocan River whitefish in severity of external abnormalities (Lawrence 1996). If thin fish was rated as a normal condition (Table 6), fish sampled from the Genelle reach still have the highest mean severity of external abnormalities, but the reference site had a higher severity than Beaver Creek (p=0.001) (Lawrence 1996).

Internal Abnormalities

Upon gross internal examination, 10.3 % of Genelle and 8.2 % of Beaver Creek fish had an enlarged spleen, compared with 3.2 % of Slocan River fish. This is a decrease in prevalence of this abnormality compared with the July 1992 study, in which 16.4 % of Genelle, 11.7 % of Beaver Creek, and 5.8 % of Slocan River fish had enlarged spleens. In 1994, the prevalence of enlarged spleen did not differ significantly among reaches (p=0.278) (Lawrence 1996).

In 1994 parasite lesions or cysts were found in 13.2 % of Genelle, 6.8 % of Beaver Creek, and 4.8 % of Slocan River fish, and these differences were not significant (p=0.183) (Lawrence 1996). In 1992, only one whitefish sampled from the reference site had this abnormality (n=69).

The incidence of internal abnormalities such as dark or discoloured livers also increased between 1992 and 1994. In 1992, brown livers were found in two whitefish sampled from the Genelle reach (n=61), compared with 14.7 % of Genelle fish having dark livers in 1994. No fish from Beaver Creek fish dark livers in 1992, compared with 8.2 % in 1994. In 1992, no fish had discoloured livers, while 2.9 % of Genelle and 12.3 % of Beaver Creek fish had discoloured livers in 1994. None of the fish sampled from the Slocan River in 1994 had either dark or discoloured livers. None of the fish sampled from the Slocan River in 1992 had the "brown" liver abnormality.

Cysts in the liver were found in 2.9 % of Genelle, 5.5 % of Beaver Creek, and 1.6 % of Slocan River fish. Adhesions were noted in 5.5 % of Beaver Creek fish, and none of Slocan River or Genelle fish. Other gross internal abnormalities noted in less than five percent of fish sampled from all sites in 1994 included: enlarged kidney, pale liver, grey liver, discoloured spleen, pale spleen, nodules in kidney, and cysts in the spleen. One fish sampled from the Beaver Creek site had a soft liver, and one had abnormal internal pigmentation (n=73). Abnormalities found in 1994 which were not described in fish sampled in July 1992 included: enlarged kidney, discoloured spleen, and pale spleen. Abnormalities described in 1992 in less than five percent of fish sampled, and not noted in 1994 included: small liver, cysts in the ovary, and hemorrhagic areas. Upon gross internal examination, liver lesions were found in 6.6 % of fish from Genelle and 1.4 % of fish from the reference site in 1992, and they were not found in any fish in July 1994.

Table 6. The frequency of fish with at least one abnormality and mean severity of abnormalities found in mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994, with without "thin" fish included as an abnormality.

Parameter:	SLOCAN (n=63)			GENELLE (n=68)			BEAVER (n=73)		
	Frequency (%)	Severity Mean	Severity Std. Dev.	Frequency (%)	Severity Mean	Severity Std. Dev.	Frequency (%)	Severity Mean	Severity Std. Dev.
With "thin" fish									
External	34.9	0.78	1.2	60.3	1.51	1.7	50.7	1.04	1.18
Internal	17.5	0.25	0.59	41.2	0.74	1.11	43.8	0.66	0.9
Gill	38.1	0.49	0.78	67.6	1.81	1.42	57.5	1.44	1.43
Liver	3.2	0.05	0.28	25	0.37	0.79	4.1	0.05	0.28
Kidney	0	0	0	2.9	0.04	0.27	0	0	0
Spleen	0	0	0	1.5	0.03	0.24	1.4	0	0
Pyloric caeca/ Hind-gut	0	0	0	2.9	0.03	0.17	6.9	0.07	0.25
Other	3.2	0.06	0.4	1.5	0.01	0.12	5.5	0.08	0.4
Myxobacteria	6.4	0.13	0.49	4.4	0.09	0.41	2.7	0.05	0.33
Other Bacteria	1.6	0.03	0.25	1.5	0.03	0.24	0	0	0
Mycobacteria	1.6	0.05	0.38	1.5	0.04	0.36	1.4	0.04	0.35
CDS	N/A	1.84	2.03	N/A	4.71	2.9	N/A	3.44	2.08
Without "thin" fish									
External	34.9	0.78	1.2	60.3	1.19	1.2	31.5	0.52	0.85
CDS	N/A	1.84	2.03	N/A	4.38	2.47	N/A	2.92	1.79

A significantly higher proportion of whitefish with internal abnormalities were found at Genelle and Beaver Creek, as compared to the Slocan River (p=0.002) (Lawrence 1996). The mean severity of gross internal abnormalities was 0.74 in fish sampled from Genelle, 0.66 in fish sampled from Beaver Creek, and 0.25 in fish sampled from the reference site. This represented a significantly higher severity of internal abnormalities in Genelle and Beaver Creek whitefish, as compared to whitefish sampled from the Slocan River (p=0.003) (Lawrence 1996).

Bacteriology

The bacteriological results for all whitefish sampled from the three sites (n=73 at Slocan, n=70 at Genelle, and n=73 at Beaver Creek) are shown in Appendix 3. Myxobacteria were found (by Gram stain of kidney tissue) in 3 fish from Genelle (4.3 %), 2 fish from Beaver Creek (2.7 %), and 4 fish from the Slocan River (5.5 %). This is a decrease from the 9.8 % of Genelle, and 7.2 % of Slocan fish with myxobacteria in July 1992. No Beaver Creek fish had myxobacteria in 1992. In January 1991, 17.7 % of Columbia River fish, and 5 % of reference fish had myxobacteria. Myxobacterial infections tend to be seasonal, with the highest frequency of outbreaks occurring during the colder winter months.

Mycobacteria were found (by acid-fast staining of kidney tissue) in one fish (1.4 %) from each site. This is a decrease at all sites from 1992, in which 14.8 % of Genelle, 6.7 % of Beaver Creek, and 7.2 % of Slocan River fish had mycobacteria. In 1991, 5.9 % of Columbia River whitefish sampled had mycobacteria.

Renibacterium salmoninarum, the causative agent of Bacterial Kidney Disease (BKD), was found in one fish from the Slocan River (1.4 %) and one fish from Genelle (1.4 %). One fish sampled from the Columbia River in January 1991 was found to have this Gram-positive bacteria, however it was not found in fish sampled in July 1992. *Yersinia ruckeri*, the causative agent of enteric redmouth disease (ERM), was not isolated in the 1994 or 1991 studies, but was isolated in one fish sampled from the Slocan River in 1992. No bacterial colonies were isolated on tryptic soy agar or Lowenstein-Jensen media from fish sampled in 1994.

No significant difference in proportion of whitefish with myxobacteria, mycobacteria, or other bacteria was found between fish sampled from the Columbia River or the Slocan River (p=0.452) (Lawrence 1996). As insufficient frequencies of bacterial abnormalities did not allow for chi-square tests comparing proportion of each category of bacteria across sites, an "overall bacteria" category was formed by pooling the incidence of myxobacteria, mycobacteria, and other bacterial problems (Lawrence 1996). No significant difference in proportion of overall bacterial problems were found among fish sampled from all locations (p=0.452) (Lawrence 1996). The mean severity of all bacterial problems was 0.16 at Genelle, 0.10 at Beaver Creek, and 0.21 at the Slocan River site. No significant difference in mean severity of overall bacterial problems was found (p=0.462) (Lawrence 1996).

Parasitology

Table 7 summarizes the 1994 results of the examination for selected parasites. Of the parasites found in fish sampled from the Slocan River, the eye-fluke *Diplostomum sp.* and the larval nematode *Eustrongylides sp.* have the potential to cause problems. Of the parasites found in fish sampled from the Beaver Creek reach of the Columbia River, only *Henneguya* in the musculature has the potential to cause problems. None of the parasites found in the fish sampled from the Genelle reach of the Columbia River has the potential to cause problems. The rest of the helminths and the *Chloromyxum* are usual freshwater salmonid parasites.

The 1994 results are similar to those found in July 1992. *Eustrongylides sp.* was the only parasite found in the July 1992 study with the potential to cause problems. Consistent with 1992, no microsporidian or myxosporean parasites were found in any fish sampled in 1994.

There were some differences in parasite distribution among sampling location. In 1992, a larval nematode *(Eustrongylides sp.)* was found in 3 of 10 fish examined from the Slocan River, and it was not found in fish examined from the Columbia River sites. In 1992 and 1994, the trematode *Plagioporus shawi* was not found in fish sampled from the Slocan River, but it was found in all fish sampled from the Genelle and Beaver Creek sites. These results provide evidence that there is a difference between the Slocan River and Columbia River in parasite distribution.

Histology

Results for the histological evaluation of 5 tissues (gill, liver, spleen, kidney, pyloric caeca/hindgut) from each fish are summarized in Appendix 3. A summary of the mean severity of abnormalities in each tissue is given in Table 6.

Gill

Histological evaluation of gill tissue revealed that 60.3 % of Genelle, and 52.1 % of Beaver Creek fish sampled had helminth in the gills compared with 23.8 % of Slocan River fish. Two types of parasites were identified: a trematode of the genus *Tetraonchus* (one to four parasites per infected fish, 5μm section); and a fluke in the larval form, most likely *Sanguinicola. Tetraonchus* was found external to the gill tissue and was not associated with damage to the tissue. The gill fluke, however, was internal to the tissue, and in cases where it was identified there was inflammatory activity in the tissue, causing severe clubbing of the gill lamellae in some cases. The gill fluke was found in 55.9 % of Genelle fish, and 41.1 % of Beaver Creek fish, compared with 1.6 % of Slocan fish. *Sanguinicola* is an important parasite in the culture of carp and salmonids. Heavy mortality in North American trout hatcheries has been attributed to *Sanguinicola.* Severe haemorrhage and necrosis of gill tissue may be seen when fluke eggs hatch and the miracidia burst out of the gills.

In July 1992 metazoan parasites were found in gill tissue in 2.9 % of Slocan, and 1.7 % of Beaver Creek fish, and lamellar clumping was found in only one fish from Beaver Creek (n=60). In January 1991, both metazoan parasites and inflammatory foci were found in the gills in 3.9 % of fish sampled from the Columbia River. No evidence of *Sanguinicola* was found by histological evaluation of gill tissue in the 1991 or 1992 studies, however parasitology results for the 1992 study found *Sanguinicola* in the gills of a single fish sampled from Beaver Creek.

In July 1994 aneurysm in the gill tissue was found in 8.8 % of Genelle fish, 9.6 % of Beaver Creek fish, and 17.5 % of Slocan River fish. The incidence of gill aneurysm in 1994 did not differ significantly among sampling locations (p=0.238)(Lawrence 1996). In July 1992, aneurysm was found in 8.2 % of Genelle, 3.3 % of Beaver Creek, and 8.7 % of Slocan River fish. In January 1991, aneurysm was found in 13.7 % of Genelle and Beaver Creek fish combined, and 17.6 % of the reference site fish (Brilliant Reservoir and Kootenay Lake). One fish sampled from the Beaver Creek reach (n=73) of the Columbia River in July 1994 had a tumour of the gill tissue, identified as a chondrosarcoma indicating a malignant tumour of cartilage cells.

Lamellar fusion and cellular hyperplasia are described effects of exposure to mill effluent or metal contaminants (Couillard *et al.* 1988; Skidmore 1970). These types of gill abnormalities were not found in any of the fish sampled from the Columbia River in 1994. This is consistent with results of the 1992 study. Inflammation of gill tissue was associated with parasitism in all cases in fish sampled in 1994.

A significantly higher proportion of Genelle fish had gill abnormalities as compared to Slocan River fish (p=0.003) (Lawrence 1996). Beaver Creek whitefish were not significantly different than Genelle or Slocan River fish in proportion of gill abnormalities (Lawrence 1996). The mean severity of gill abnormalities was 1.81 at Genelle, 1.44 at Beaver Creek, and 0.49 in Slocan River whitefish. Severity of gill abnormalities was significantly higher in Genelle and Beaver Creek whitefish than Slocan River whitefish ($p<0.001$) (Lawrence 1996).

Table 7. Mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994, examined for selected parasites.

Parasite	Prevalence		
	Slocan (n=10)	**Genelle (n=10)**	**Beaver (n=10)**
Henneguya in musculature	0	0	1
Diphyllobothrium in musculature	0	0	0
Myxobolus insidiosus in musculature	0	0	0
Myxidium in kidney	0	0	0
Myxidium in urinary bladder	0	0	0
Chloromyxum in gall bladder	2	0	1
Ceratomyxa in gall bladder	0	0	0
Myxidium in liver	0	0	0
Ceratomyxa in liver	0	0	0
Ceratomyxa in intestine	0	0	0
Eimeria in intestine	0	0	0
The following helminths were found in the viscera: TREMATODA:			
Crepidostomum farionis in gallbladder	7	0	1
Diplostomum sp. metacercaria in eyes	3	0	0
Plagioporus shawi in intestine	0	10	10
NEMATODA:			
Eustrongylides sp. larva on mesenteries	2	0	0
Rhabdochona sp. juveniles in stomach	5	0	0
Truttaedacnitis truttae in intestine	3	6	4

Liver

In 1994 helminth in the liver were found in 10.3 % of whitefish collected from Genelle, while no fish from Beaver Creek had helminth in the liver. In 1992 parasite cysts in the liver tissue were found in 11.5 % of Genelle whitefish, and in 6.7 % of Beaver Creek whitefish. No helminth in the liver were found in Slocan River whitefish in 1994 or 1992. Parasites in the liver were found in 3.9 % of Columbia River whitefish, and in 2 % of fish collected from the reference site in 1991.

Inflammatory response in a tissue can be caused by bacteria, viruses, fungi, parasites, and physical or chemical injuries (Thomson 1984). There was a decrease in the amount of inflammatory activity found in liver tissue at all sites in 1994, compared with 1992. Of fish sampled from the Genelle reach of the Columbia River in 1994, 4.4 % had this abnormality. No fish sampled from Beaver Creek or the Slocan River were found to have inflammatory activity in the liver in 1994. In July 1992, inflammatory foci in the liver was found in 42.6 % of Genelle, 18.3 % of Beaver Creek, and 7.2 % of reference fish. Of whitefish collected from the Columbia River in 1991, 3.9 % had inflammatory foci in liver tissue.

The abnormal accumulation of melanin in a tissue is termed melanosis (Thomson 1984). The prevalence of melanosis in the liver of fish sampled from the Columbia River decreased in the 1994 study as compared to that found in 1992. In 1994 only one fish sampled from Genelle (n=68) had melanosis, compared to 13.1 % of Genelle and 15 % of Beaver Creek fish in 1992. Melanosis in the liver was found in 5.9 % of Columbia River fish in January 1991. No melanosis was found in whitefish sampled from the Slocan River in 1994 or 1992. One fish sampled from the reference site had melanosis in 1991 (n=51).

Small or large liver lesions of unknown etiology were found in 10.3 % of Genelle, 5.5 % of Beaver Creek, and 1.6 % of Slocan River fish sampled in 1994. No liver lesions were reported in the July 1992 study.

No liver tumours were found in 1994, and liver tumour prevalence was low in July 1992 (3.3 %, or 2 of 61 fish from Genelle, and 0 % of Beaver Creek and Slocan River fish). The prevalence of liver neoplasia in white suckers sampled from the Great Lakes Region in Ontario between 1985 and 1990 ranged from 5 % to 9 % at five sites exposed to carcinogenic contaminants, and one site dominated by industrial and municipal discharges (Smith *et al.* 1995). No liver neoplasms were found at another site dominated by agricultural and municipal discharges. The prevalence of liver neoplasia was low at five reference sites (0 %, 0 %, 0 %, 0.4 %, 2.4 %) (n=572). Smith *et al.* (1995) suggest that liver neoplasms are a response to the presence of synthetic chemicals and liver parasites as co-carcinogens. Baumann *et al.* (1987) have shown that liver tumour prevalence to be correlated with age and season.

Granulomas, which can be caused by parasites or chronic bacterial infections, represent material, which cannot be easily, eliminated (Thomson 1984). Granulomas were found in one fish sampled from Genelle reach (n=68) in 1994, and three fish from Genelle (n=61) and seven fish from Beaver Creek (n=60) in 1992. In 1991 granulomas were found in 9.8 % of Columbia River fish, and in none of the fish sampled from the reference site.

Fatty infiltration in the liver was noted in one fish sampled from the Genelle reach in 1994. This liver abnormality was not found in any fish sampled in 1991 or 1992. A hemorrhagic area in the liver was found in one whitefish sampled from the Slocan River in 1994 (n=63).

Other liver abnormalities found in the July 1992 study which were not found in whitefish sampled in 1994 included foamy areas and cirrhosis.

A significantly higher proportion of Genelle whitefish had liver abnormalities than both Slocan River and Beaver Creek whitefish ($p<0.001$) (Lawrence 1996). The mean severity of liver abnormalities was 0.37 at Genelle, 0.05 at Beaver Creek, and 0.05 at the Slocan River. The mean severity of liver abnormalities was significantly higher in Genelle whitefish than in Slocan River and Beaver Creek whitefish ($p<0.001$) (Lawrence 1996).

Spleen

One fish sampled from Genelle in 1994 had melanosis in the spleen (n=68). Of Columbia River whitefish sampled in 1991, 5.9 % had hemorrhagic areas in the spleen, and 7.8 % had melanin accumulation. One fish each sampled from Genelle (n=61), and Beaver Creek (n=60), in July 1992, had melanin deposits in the spleen. Granulomas in the spleen were found in one fish sampled from the Genelle reach in 1992 (n=61), and were not found in any fish in 1994.

Insufficient frequencies of spleen abnormalities did not allow for chi-square tests to compare proportion of spleen abnormalities across sites (Lawrence 1996). The mean severity of spleen abnormalities was 0.03 in Genelle, and zero in Beaver Creek and Slocan River whitefish. No significant difference in severity of spleen abnormalities were found among fish sampled from all locations (p=0.368) (Lawrence 1996).

Kidney

Histologically, only two kidney abnormalities were found in whitefish sampled in July 1994. At Genelle (n=68), one fish sampled had a granuloma of the kidney, and another fish had a kidney lesion of unknown etiology. This is consistent with the few kidney abnormalities found in July 1992. Granulomas in the kidney were found in 5.9 % of Columbia River fish in January 1991 (n=51), and 4.1 % of Columbia River fish in July 1992 (n=121). In January 1991, melanomacrophage activity in the kidney tissue was found in most fish sampled from the Columbia River sites as compared to none of the reference fish. In July 1992, only one fish sampled from the Beaver Creek reach (n=60) had this abnormality. No fish sampled in 1994 had melanomacrophage activity in the kidney.

Insufficient frequencies of kidney abnormalities did not allow for chi-square tests to compare proportion of kidney abnormalities across sites (Lawrence 1996). The mean severity of kidney abnormalities was 0.04 at Genelle, and 0 at Beaver Creek and Slocan River reaches. No significant difference in severity of kidney abnormalities was found among whitefish sampled from all locations (p=0.134) (Lawrence 1996).

Pyloric Caeca/Hindgut

In 1994 helminth in the pyloric caeca/pancreas or posterior gut were found in 2.9 % of Genelle and 6.8 % of Beaver Creek fish. Abnormalities not found in 1994 but present in 1992 at Genelle and Beaver Creek included: hypercellular submucosa, granulomas in mesentery, foamy lesion in pancreas, and tumour of the pyloric caeca/pancreas. Inflammatory foci and leukocyte proliferation, which were found in a few Columbia River fish in January 1991, were not found in any fish sampled in July 1994.

A large (approximately 3.5 cm diameter) benign tumour of the testes was identified in one fish sampled from Beaver Creek in 1994. Histologically the tissue appeared to have normal development, with some focal necrosis. Abnormal gonads were found in 4.1 % of Beaver Creek and 15 % of Genelle fish.

Insufficient frequencies of pyloric caeca/hindgut or other abnormalities did not allow for chi-square tests to compare proportions of these abnormalities across sites, therefore a miscellaneous category was formed by pooling the incidence of spleen, kidney, pyloric caeca/hindgut, and other abnormalities. No significant difference in proportions of whitefish with pooled spleen, kidney, pyloric caeca/hindgut, or other abnormalities was found between Columbia River and Slocan River fish (p=0.098). The mean severity of pyloric caeca/hindgut abnormalities was 0.03 at Genelle, 0.07 at Beaver Creek, and zero at the Slocan River. No significant difference in severity of pyloric caeca/hindgut abnormalities was found among whitefish sampled from all locations (p=0.089). The mean severity of "other" abnormalities was 0.01 at Genelle, 0.08 at Beaver Creek, and 0.06 at the Slocan River. No significant difference in severity of other abnormalities was found among whitefish sampled from all locations (p=0.423) (Lawrence 1996).

Summary and Overview of Cumulative Disease Severity

If all types of abnormalities are included, the Columbia River sites had higher proportions of whitefish with at least one abnormality of any type, compared to the reference site (Table 8). No abnormalities of any kind were found in 1.5 % of fish from Genelle and 6.8 % of fish from Beaver Creek, compared to 28.6 % of fish from the Slocan River reference site. A significantly higher proportion of Columbia River whitefish (from Genelle and Beaver Creek) had at least one abnormality, compared to Slocan River fish ($p<0.001$) (Lawrence 1996).

Genelle whitefish had a significantly higher prevalence of external, internal, gill, and liver abnormalities than Slocan River fish. Beaver Creek whitefish had significantly higher prevalence of internal abnormalities than Slocan River fish. No significant differences in prevalence of bacterial and pooled miscellaneous abnormalities (consisting of spleen, kidney, pyloric caeca/hindgut, and other abnormalities) were found among reaches (Lawrence 1996). The prevalence of abnormalities did not differ significantly between the two Columbia River sites, with the exception of the prevalence of abnormalities in liver tissue, which was higher at Genelle (Lawrence 1996).

Severity of external, internal, and gill abnormalities were significantly higher in Genelle fish as compared to Slocan River fish. Severity of liver abnormalities was significantly higher in Genelle fish as compared to both Beaver Creek and Slocan River fish. The mean severity of internal and gill abnormalities were significantly higher in Beaver Creek fish compared to Slocan River fish. No significant differences in mean severity of bacterial, spleen, kidney, pyloric caeca/hindgut, or other abnormalities, were found (Lawrence 1996).

The mean cumulative disease severity (CDS) was 4.7 at Genelle, 3.4 at Beaver Creek, and 1.8 at the Slocan River reference site. The mean CDS was significantly higher in Genelle fish than in Beaver Creek fish, and mean CDS in Beaver Creek fish was significantly higher than that for Slocan River fish ($p<0.001$) (Lawrence 1996). The frequency of the cumulative disease severity rating of whitefish by reach is given in Fig. 7. If "thin fish" condition was not rated as an abnormality, then the mean CDS was 4.4 at Genelle, 2.9 at Beaver Creek, and 1.8 at the Slocan River site (Table 6). The pattern of significant among-site differences in CDS - without thin fish rated as an abnormality - was the same as that for CDS - with thin fish rated as an abnormality. It was: CDS in Genelle fish > CDS in Beaver Creek fish > CDS in Slocan River fish ($p<0.001$) (Lawrence 1996).

The most significant contribution to the CDS at the two Columbia River sites was from gill abnormalities, followed by external abnormalities and then gross internal abnormalities (Table 6). The histology of liver, spleen, kidney, pyloric caeca/hind-gut, other abnormalities, myxobacteria, mycobacteria, other bacteria had lower severity scores, and hence a smaller contribution to the CDS. At the Slocan River site, external abnormalities had the highest severity scores, followed by gill and then internal abnormalities. In the July 1992 study, the severity of liver abnormalities had the greatest contribution to the CDS, followed by external and then gross internal abnormalities.

If "thin fish" condition was not counted as an abnormality, then the mean CDS was 4.4 at Genelle, 2.9 at Beaver Creek, and 1.8 at the Slocan River site (Table 6). The overall cumulative disease severity (without thin fish as an abnormality) still reflects the same pattern of significant among-site differences: CDS in Genelle fish > CDS in Beaver Creek fish > CDS in Slocan River fish ($p<0.001$) (Lawrence 1996).

Table 8. Percentage of whitefish sampled from two reaches withn the Columbia River at Genelle and Beaver Creek, and a reference site within the Slocan River, July 1994, with any type of abnormality, by age class.

Site	Percentage of Fish With Any Abnormality, by Age Class					
	1 - 5	6 - 10	11 - 15	16 - 20	21+	Total
Slocan	73 % (n=11)	70 % (n=43)	75 % (n=8)	100 % (n=1)	0 % (n=0)	71 % (n=63)
Genelle	97 % (n=35)	100 % (n=12)	100 % (n=11)	100 % (n=9)	100 % (n=1)	99 % (n=68)
Beaver	90 % (n=29)	93 % (n=15)	93 % (n=15)	100 % (n=14)	0 % (n=0)	93 % (n=73)

The contribution of various abnormality types to the CDS (all abnormality types combined) is shown in Table 6. The most significant contribution to the CDS at the two Columbia River sites was from gill abnormalities, (which had highest severity scores), followed by external abnormalities, and then gross internal abnormalities. The histology of liver, spleen, kidney, pyloric caeca/hind-gut, other abnormalities, myxobacteria, mycobacteria, other bacteria had lower severity scores, and hence a smaller contribution to the overall CDS. At the Slocan River site, external abnormalities had the highest severity scores, followed by gill and then internal abnormalities. In the July 1992 study, the severity of liver abnormalities had the greatest contribution to the CDS, followed by external and then gross internal abnormalities.

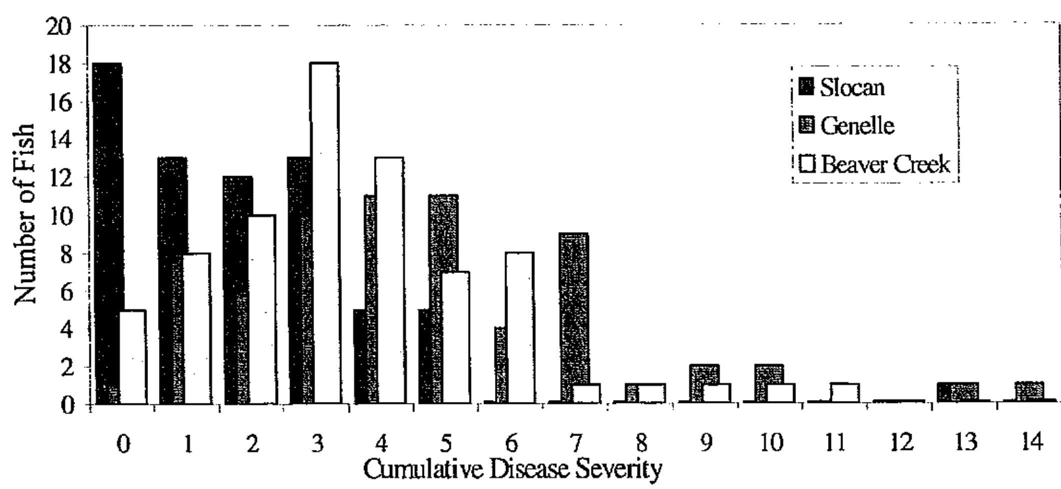


Figure 7. Frequency of Cumulative Disease Severity rating of mountain whitefish sampled from the Columbia and Slocan Rivers in July 1994.

Fish Age and Cumulative Disease Severity

The relationship between CDS and fish age was assessed initially using linear regression (Lawrence 1996). A significant positive correlation between CDS and fish age was found at Genelle ($p<0.001$) and Beaver Creek ($p=0.003$). The relationship between CDS and age for Slocan River fish was not significant ($p=0.777$), possibly due to low numbers of older fish collected from this site. A second-order polynomical regression was also fit to the data at each sampling location, as the data suggested a non-linear relationship between CDS and age (Fig. 8). CDS values remained fairly constant up to age 10 to 12 years, and increased after this age. The range of first age-at-maturity for mountain whitefish is 2 to 4 years (Ford *et al.* 1995).

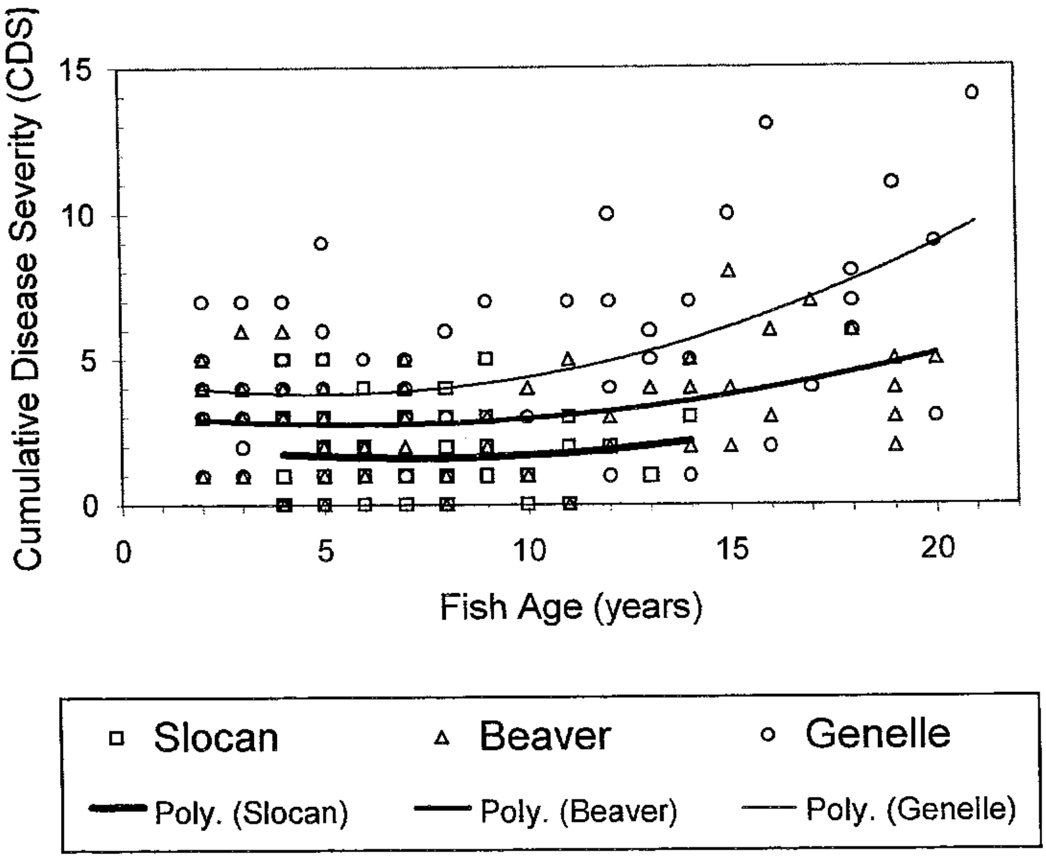


Fig. 8 Cumulative disease severity (CDS) as a function of whitefish age by sampling location; reaches smoothed by quadratic curves.

Analysis of covariance (ANCOVA) techniques were used to compare differences in CDS among sampling locations, after accounting for the effect of age on CDS. The ANCOVA revealed that there was a significant positive relationship between fish age and CDS ($p<0.001$), and CDS was significantly higher for Genelle fish compared to Beaver Creek fish, which was significantly higher than that for Slocan River fish ($p<0.001$) (Lawrence 1996). These results confirmed the simple ANOVA results, which did not account for the effects of age. ANCOVA tests also indicated that while CDS varied across sampling locations for fish less than 12 years of age (in the order Genelle > Beaver > Slocan), CDS no longer varied significantly with fish age when fish 12 years or greater were removed from the analysis ($p=0.680$) (Lawrence 1996). The differences in CDS among sampling locations are therefore not due to age.

Sex Differences in Histological Parameters

Sex differences were assessed to determine whether the severity of various abnormalities differed between males and females at each location (Lawrence 1996). The histological variables that were assessed included mean severity of abnormalities in the following areas/tissues: external, internal, gill, liver, spleen, kidney, pyloric caeca, myxobacteria, mycobacteria, and other bacteria. There were few significant differences in these variables between males and females at each location.

Time Trends

CDS did not differ significantly between 1992 and 1994 at any sampling location (Fig. 9). Lower mean CDS in 1994 at Genelle might be related to fact that fish sampled from Genelle were younger in 1994 (mean age was 8.0 years), compared with 1992 (mean age was 13.6 years). Slocan River fish were older in 1994 (8.2 years) compared to 1992 (6.3 years), and CDS was higher in 1994 compared to 1992 at this site.

The prevalence and severity of specific abnormalities did vary significantly between 1992 and 1994. The incidence and severity of gill abnormalities increased significantly between 1992 and 1994 at all locations. The gill fluke *Sanguinicola* was found with high prevalence in Columbia River whitefish in 1994, and was only found in one fish sampled from the Columbia River in 1992. This might account for the increase in severity of gill abnormalities between 1992 and 1994. The incidence of liver abnormalities (e.g., inflammatory foci, melanosis, granulomas, foamy areas, cirrhosis) decreased significantly from 1992 to 1994 in fish sampled from Genelle ($p=0.001$) and Beaver Creek ($p<0.001$) (Lawrence 1996). The severity of liver abnormalities decreased significantly at all locations between 1992 and 1994. The prevalence of kidney abnormalities (e.g., melanin, granulomas, tumours) also decreased significantly from 1992 to 1994 in fish sampled from Genelle ($p=0.003$) and Beaver Creek ($p<0.001$) (Lawrence 1996). The severity of kidney abnormalities also decreased at all locations between 1992 and 1994; this decline was significant at Genelle ($p<0.01$), and insufficient data were available to conduct statistical tests at the other two sites. The reduction in prevalence and severity of gill and liver abnormalities in 1994 was a significant finding, as PCDDs/PCDFs, MFO activity, concentrations of lead and mercury in muscle tissue also decreased during this time period. The change in field personnel performing gross external and internal examinations between the 1992 and 1994 studies may also account for some difference in prevalence of gross external and internal abnormalities between 1992 and 1994, due to subjectivity in observation. Laboratory personnel were consistent for both studies. The final sampling program in 1996 was conducted using the same field personnel as in 1994.

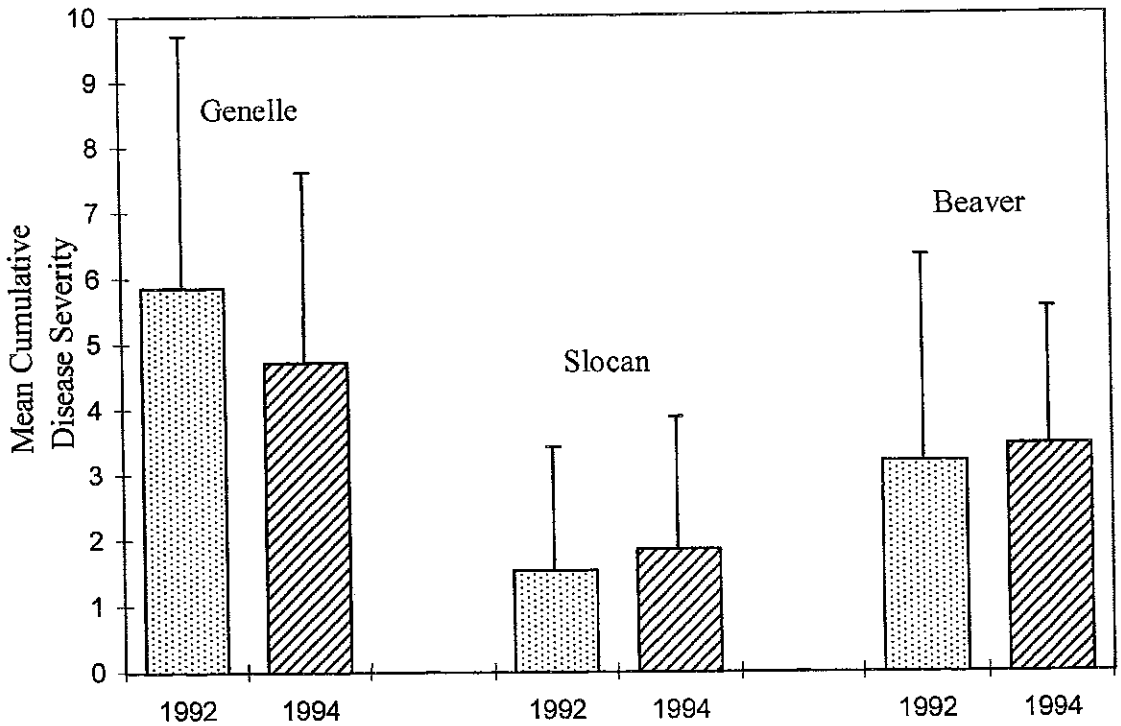


Figure 9. Mean Cumulative Disease Severity in 1992 and 1994, by reach.

ORGANIC CONTAMINANTS

Polychlorinated Dibenzodioxins (PCDDs) and Dibenzofurans (PCDFs)

Concentrations of PCDDs/PCDFs, lipid content, and toxic equivalencies (TEQs) are provided in Appendix 4A. Each batch of samples analyzed consisted of a maximum of nine samples plus one spiked tissue sample, one procedural blank, and one duplicate. Duplicates generally fell within the acceptable range of ± (20 % + Method Detection Limit), and procedural blanks had low background levels of the target compounds, indicating no sample contamination. The surrogate standard recoveries for most samples were within the acceptable range of 40-120 %, and in the few cases where this standard was not met the analyses were repeated. Recoveries for the spiked samples fell within the acceptable range of 70-130 %. Where duplicate analyses were performed on a single sample, the arithmetic mean of the two concentrations was used in the statistical analyses and the calculation of toxic equivalencies. The detection limits were very similar to those reported in the 1992 study (Nener *et al.* 1995).

Results of blind duplicate samples analyzed by AXYS and IOS (Appendix 4B) indicated that IOS provided higher concentrations and higher TEQs than those from AXYS for most congeners, however, these differences were generally small (less than ± 20 %). The IOS analyses also had lower detection limits than those of AXYS. The IOS data were used for QA/QC purposes; they were not averaged with the AXYS data to estimate the sample concentration. This approach is consistent with the July 1992 study.

The samples analyzed for organic contaminants did not differ significantly among sampling location in terms of fish age (p=0.644), fork length (p=0.118), condition factor (p=0.118), or percent lipid content (p=0.556) (Table 9) (Lawrence 1996). Mean wet weight of Slocan River fish was significantly less than that for Genelle fish (p=0.034), while mean wet weight of Beaver Creek fish did not differ significantly from that for Slocan River or Genelle fish (Lawrence 1996). Since organic contaminants are extremely lipophilic, and age and lipid content did not differ among sampling location, life history variables were not controlled for in the statistical analyses.

Concentrations of PCDDs and PCDFs in muscle tissue of whitefish from the Slocan River reference site were very low, and in most cases, all values were below analytical detection limits (Appendix 4A). These findings support the conclusion that the Slocan River, which has no known point sources of dioxins or furans, was an appropriate reference site for this component of the study. The predominant congeners detected in the muscle tissue of Columbia River fish were those in the T4CDF and T4CDD subgroups, specifically, 2,3,7,8-TCDF and 2,3,7,8-TCDD. Some congeners in the P5CDF subgroup (e.g., 2,3,4,7,8-PCDF) were also detected. Concentrations of the higher chlorinated congeners (i.e., HxCDDs, HxCDFs, HpCDDs, HpCDFs, OCDDs, OCDFs) were virtually non-detectable in Columbia River fish. These findings indicate that the source of dioxin contamination is of pulp mill origin, with little or no contribution from atmospheric sources. Historical use of pentachlorophenol at the sawmill near Castlegar might have contributed to body burdens of P5CDF in Columbia River fish.

Table 9. Summary of life history data for the subset of mountain whitefish collected in July 1994 and sampled for PCDDs, PCDFs and PCBs.

Variable:		SLOCAN (n=10)	GENELLE (n=10)	BEAVER (n=10)
Age (years)	Mean: St. Deviation:	9.10 (2.60)	8.70 (6.22)	9.80 (6.43)
Wet Weight (g)	Mean: St. Deviation:	389.90 (103.83)	519.10 (162.87)	576.00 (183.59)
Fork Length (cm)	Mean: St. Deviation:	32.14 (2.82)	34.00 (3.68)	35.08 (2.67)
Condition Index	Mean: St. Deviation:	1.15 (0.06)	1.29 (0.16)	1.33 (0.35)
Lipid Content (%)	Mean: St. Deviation:	4.85 (0.98)	5.55 (1.54)	5.71 (2.67)

Due to the low concentrations of many congeners, only a few were examined statistically using one-way analysis of variance (ANOVA). These congeners were: 2,3,7,8-TCDD, 2,3,7,8-TCDF, 1,2,3,7,8-PCDF, 2,3,4,7,8-PCDF, and all subgroup totals (e.g., total TCDD, total OCDF). For raw data (not lipid normalized), significant among location differences in mean concentrations were found for total TCDD ($p<0.001$), 2,3,7,8-TCDD ($p=0.001$), total TCDF ($p<0.001$), 2,3,7,8-TCDF ($p<0.001$), total PCDF ($p=0.001$), and 2,3,4,7,8-PCDF ($p<0.018$) (Lawrence 1996). For each of these significant results, the contaminant levels at the reference site on the Slocan River were significantly lower than those at Genelle or Beaver Creek. Concentrations of some congeners differed substantially between the two reaches of the Columbia River, however, these differences were not statistically significant due to extremely high variability and small sample sizes. For example, concentrations of 2,3,7,8-TCDD and total TCDD in fish from Genelle were almost twice those found in fish from Beaver Creek, and concentrations of 2,3,7,8-TCDF and total TCDF were approximately 1.3 times higher in fish from Beaver Creek compared with fish from Genelle.

ANOVA results for lipid normalized data were identical to those for raw data, with the exception of 2,3,4,7,8-PCDF, which did not differ significantly among reaches. This non-significant result was likely attributable to high variability, since the average concentration of 2,3,4,7,8-PCDF in fish from Genelle was 5 times higher than that for Slocan River fish. Results for raw and lipid corrected data were similar because percent lipid content was similar among sampling location (Appendix 4A).

The choice of method used to calculate the TEQs lead to only a small difference for the two Columbia River sites (Appendix 4A). This finding was not surprising, since the congeners with the highest TEFs had few observations below the detection limit. The difference between methods was greater for the Slocan samples, where most concentrations were below the detection limit. TEQs calculated based on the most conservative method were used for discussion, statistical analysis, and comparison with earlier studies.

The 2,3,7,8-TCDD TEQs averaged 0.36 pg/g at the Slocan River, 5.1 pg/g at Genelle, and 4.8 pg/g at Beaver Creek (Appendix 4A). Mean TEQs in Genelle and Beaver Creek fish did not differ significantly, and they were both significantly higher than the mean TEQ in Slocan River fish ($p<0.001$) (Lawrence 1996). At the two Columbia River sites, 2,3,7,8-TCDD and 2,3,7,8-TCDF contributed almost 100 % of the 2,3,7,8-TCDD TEQ. At Genelle, 2,3,7,8-TCDD and 2,3,7,8-TCDF contributed equally, on average, to the mean 2,3,7,8-TCDD TEQ. At Beaver Creek, 2,3,7,8-TCDF contributed almost three times as much toxicity as 2,3,7,8-TCDD, on average.

The 1994 PCDD/PCDF concentrations and TEQs were low at all three sampling locations. Health Canada assessed these data and concluded that the consumption of the fillet of mountain whitefish collected from the two reaches of the Columbia River or the reference site on the Slocan River would not pose a health hazard to humans. This assessment corroborates the British Columbia Ministry of Health's March 1995 decision to lift the dioxin and furan consumption advisory on mountain whitefish caught in the Columbia River between the Hugh Keenleyside Dam and the international border. Previous testing indicated low concentrations of PCDDs and PCDFs in muscle tissue of other Columbia River sport fish, including rainbow trout, burbot, kokanee, and white sturgeon. Low concentrations in these other species might be attributable to feeding trophic level and habitat preference.

A series of regressions were performed to examine the relationship between PCDDs/PCDFs and lipid content, age, PCBs, and cumulative disease severity (Table 10). To be consistent with the July 1992 study, total dioxin and furan concentration, calculated as the sum of concentrations for all PCDD and PCDF congeners, was used in the regression analysis. A significant positive relationship was found between total dioxin and furan concentration and percent lipid content at Beaver Creek ($p=0.004$) and the Slocan River ($p=0.007$), but not at Genelle ($p=0.103$). Regression analysis of 2,3,7,8-TCDD TEQs and lipid content provided a similar result. The lack of a significant relationship at Genelle was surprising, given the hydrophobic and lipophylic properties of these chemicals. The extreme variability in the Genelle data combined with small sample sizes might explain this result. As in the July 1992 study (Nener *et al* 1995), factors other than lipid content may affect muscle concentrations of PCDDs and PCDFs.

A statistically significant positive relationship between fish age and total dioxin and furan concentration was found in fish from the Genelle location only ($p=0.025$). The correlations were not significant at Beaver Creek, the Slocan River, or the two Columbia River sites combined. A regression analysis of TEQs and age provided similar results. At Beaver Creek, the regression equations were negative, meaning that younger fish (e.g., age 4) had higher PCDD/PCDF concentrations and TEQs than older fish (e.g., age 19). Small sample sizes limit conclusions from this analysis, however, it appears that dioxin concentrations in Beaver Creek fish may be related to microhabitat variables, such as food sources, habitat, and migration. The 1994 results were similar to the 1992 results.

Table 10: Results of regression analyses for organic contaminants in mountain whitefish collected from the Columbia and Slocan Rivers in July 1994

Dependent Variable	Independent Variable	Site	Regression R^2	Regression Std. Err.	ANOVA P value
Total Dioxin/Furan Concentration (pg/g)	Fish Age	Beaver	0.058	30.304	0.501
		Genelle	0.485	26.601	0.025*
		Slocan	0.103	0.702	0.366
		Beaver/Genelle	0.071	31.360	0.256
Total Dioxin/Furan Concentration (pg/g)	Lipid Content (%)	Beaver	0.668	17.997	0.004*
		Genelle	0.297	31.086	0.103
		Slocan	0.619	0.458	0.007*
		Beaver/Genelle	0.063	31.502	0.287
Cumulative Disease Severity (CDS)	Total Dioxin/Furan Concentration (pg/g)	Beaver	0.136	2.036	0.294
		Genelle	0.002	2.955	0.896
		Slocan	0.021	1.496	0.712
		Beaver/Genelle	0.024	2.445	0.518
Dioxin TEQ (pg TCDD/g)	Fish Age	Beaver	0.006	3.922	0.830
		Genelle	0.559	4.869	0.013*
		Slocan	0.030	0.075	0.631
		Beaver/Genelle	0.183	5.017	0.060
Dioxin TEQ (pg TCDD/g)	Lipid Content (%)	Beaver	0.569	2.583	0.012*
		Genelle	0.328	6.012	0.083
		Slocan	0.462	0.056	0.031*
		Beaver/Genelle	0.003	5.542	0.816
Cumulative Disease Severity (CDS)	Dioxin TEQ (pg TCDD/g)	Beaver	0.174	1.991	0.231
		Genelle	0.031	2.911	0.625
		Slocan	0.043	0.043	0.593
		Beaver/Genelle	0.059	2.400	0.300
Total PCB Concentration (ng/g)	Fish Age	Beaver	0.364	55.820	0.065
		Genelle	0.678	65.141	0.003*
		Slocan	0.227	2.246	0.164
		Beaver/Genelle	0.469	66.405	0.001*
Total PCB Concentration (ng/g)	Lipid Content (%)	Beaver	0.004	69.853	0.854
		Genelle	0.338	93.422	0.078
		Slocan	0.408	1.966	0.047*
		Beaver/Genelle	0.049	88.839	0.348
Cumulative Disease Severity (CDS)	Total PCB Concentration (ng/g)	Beaver	0.104	2.073	0.363
		Genelle	0.052	0.525	0.525
		Slocan	0.001	1.511	0.943
		Beaver/Genelle	0.075	2.380	0.244

Table 10: Continued.

Dependent Variable	Independent Variable	Site	Regression R^2	Regression Std. Err.	ANOVA P value
PCB TEQ (pg TCDD/g)	Fish Age	Beaver	0.311	1.436	0.094
		Genelle	0.700	1.904	0.003*
		Slocan	0.026	0.101	0.657
		Beaver/Genelle	0.445	1.962	0.001*
PCB TEQ (pg TCDD/g)	Lipid Content (%)	Beaver	0.029	1.706	0.641
		Genelle	0.329	2.847	0.083
		Slocan	0.621	0.063	0.007*
		Beaver/Genelle	0.038	2.584	0.410
Cumulative Disease Severity (CDS)	PCB TEQ (pg TCDD/g)	Beaver	0.123	2.051	0.320
		Genelle	0.028	2.917	0.645
		Slocan	0.041	1.480	0.599
		Beaver/Genelle	0.054	2.407	0.326
Total Organics TEQ (pg TCDD/g)	Fish Age	Beaver	0.017	4.947	0.716
		Genelle	0.619	6.584	0.007*
		Slocan	0.035	0.158	0.606
		Beaver/Genelle	0.275	6.706	0.018*
Total Organics TEQ (pg TCDD/g)	Lipid Content (%)	Beaver	0.427	3.779	0.041*
		Genelle	0.337	8.684	0.078
		Slocan	0.675	0.078	0.004*
		Beaver/Genelle	0.001	7.874	0.913
Cumulative Disease Severity (CDS)	Total Organics TEQ (pg TCDD/g)	Beaver	0.203	1.956	0.191
		Genelle	0.031	2.912	0.627
		Slocan	0.053	1.471	0.552
		Beaver/Genelle	0.062	2.396	0.289
Total PCB Concentration (ng/g)	Total Dioxin/Furan Concentration (pg/g)	Beaver	0.044	68.468	0.563
		Genelle	0.840	45.942	0.000*
		Slocan	0.518	1.774	0.019*
		Beaver/Genelle	0.401	70.492	0.003*
PCB TEQ (pg TCDD/g)	Dioxin TEQ (pg TCDD/g)	Beaver	0.223	1.525	0.168
		Genelle	0.884	1.185	0.000*
		Slocan	0.389	0.080	0.054
		Beaver/Genelle	0.690	1.466	0.000*

Male fish had higher mean concentrations of total dioxins and furans and 2,3,7,8-TCDD TEQs than female fish, however, these differences were not significant at any one of the sampling locations (Lawrence 1996).

Mean concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in muscle tissue of Columbia River mountain whitefish sampled in January 1991, July 1992, and July 1994 are shown in Fig. 10. The 1992 and 1994 studies were conducted at the same time of the year using the same field methods and the same analytical laboratory. The 1992 study had larger sample sizes (n=15) compared to the July 1994 (n=10) and

January 1991 (n=6) studies. However, all studies provide a relatively good comparison over time. They illustrate a sharp decline in concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF over this time period. The decline between 1991 and 1992 was likely attributable to 40 % chlorine dioxide substitution, the use of hydrogen peroxide in the delignification process, and an air-activated sludge secondary treatment system. These changes resulted in a 42% reduction in dioxin TEQs in the final effluent. Between July 1992 and July 1994 the concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF declined by approximately one-half the 1992 concentrations, but these changes were not statistically significant due to high variability and small sample sizes. This change was associated with a 31% reduction in dioxin TEQs in final effluent as a result of the new bleach plant that came on-line in mid-1993, and operation at 100 % chlorine dioxide substitution. The disappearance of the fibre mat from the substrate downstream of the mill might have contributed to declining PCDDs/PCDFs in fish muscle tissue, as the fibre mat was believed to be a sink for hydrophobic contaminants discharged from the pulp mill. Contaminated sediments may continue to provide a source of PCDDs/PCDFs to whitefish, through interaction with sediment particles or benthic food organisms.

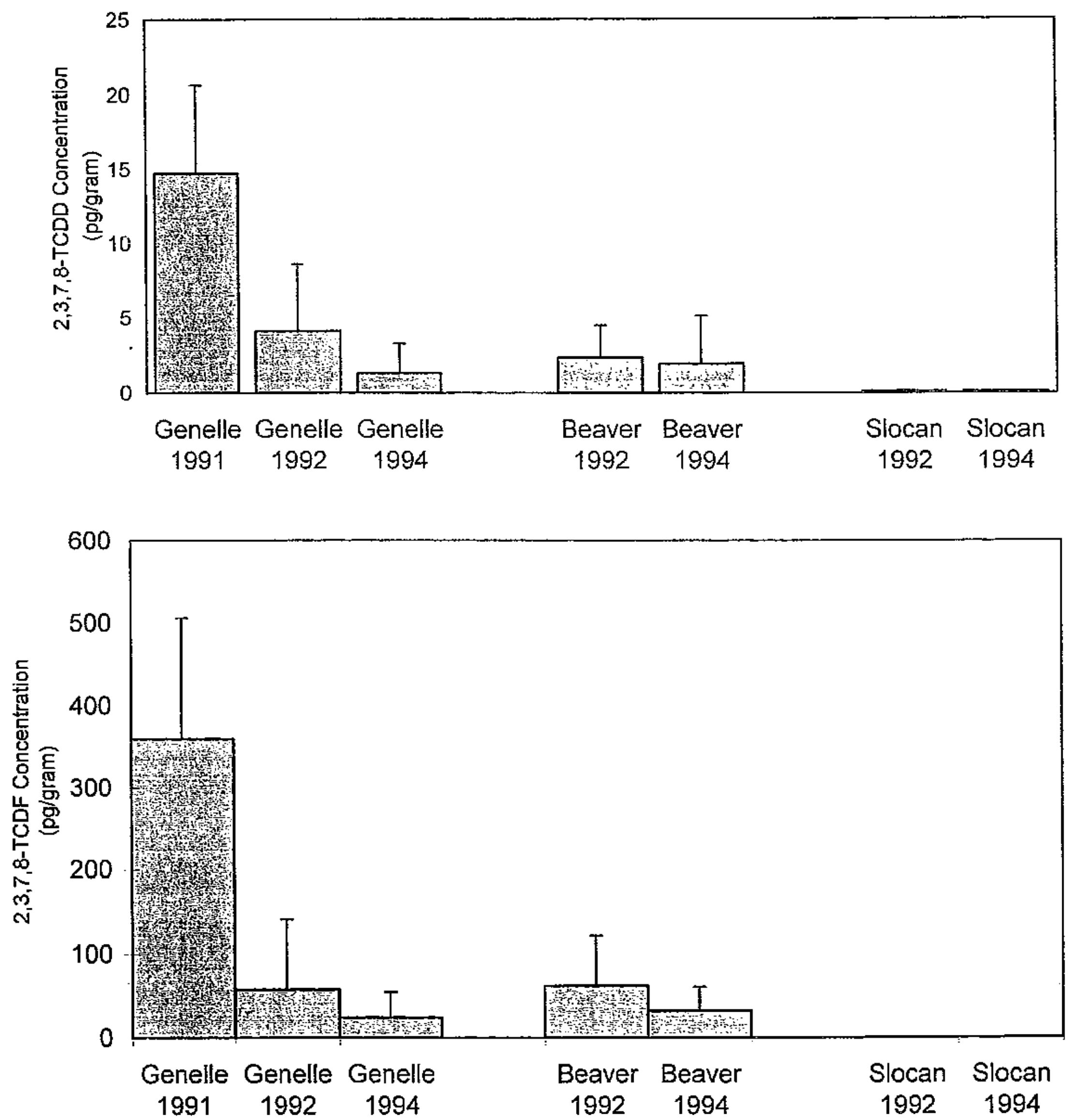


Figure 10. Time trend of 2,3,7,8-TCDD and 2,3,7,8-TCDF concentrations in mountain whitefish muscle tissue.

Polychlorinated Biphenyls (PCBs)

Fish muscle tissue was analyzed for PCB compounds, which included mono-ortho substituted PCBs and non-ortho substituted (coplanar) PCBs (Appendix 5A). The values reported for total PCBs (ng/g) are the sum of the congener family subtotals plus the coplanar PCBs (#77, 126,169), which are not included in the family subtotals. As only 103 of all 209 PCB compounds were measured, the total PCB values represent the total concentration of measured PCBs. In cases where all values for individual PCB compounds within a congener family were below detection limits, the largest individual compound detection limit was used as a conservative estimate of the sample concentration.

The PCB analyses were carried out in four batches, with each batch consisting of a maximum of nine samples plus one reference sample, one procedural blank, and one analysis duplicate. Quality assurance results were within the acceptable range of ± (20 % + Method Detection Limit) for duplicates, and ± 20 % of the certified range value for the four reference samples. Surrogate standard recoveries were within the acceptable range of 50 - 120 %. No sample contamination was detected in the procedural blanks. Blind duplicates analyzed by AXYS and IOS indicated that the concentrations of most compounds were similar, but IOS produced slightly higher concentrations of mono- and di-ortho substituted PCBs (Appendix 5B). The detection limits in 1994 were very similar to those reported in 1992, however, three coplanar PCB compounds had detection limits 10 to 100 times lower in 1994, as these compounds were analyzed by high resolution mass spectrometry.

PCBs were detected in mountain whitefish muscle tissue from all three sampling locations. Concentrations of all PCB congeners, total PCBs, and Aroclor 1254/1260 were higher at the two Columbia River sites, compared to the reference site. ANOVA was used to analyze among site differences for the following variables: PCB subtotals by congener family (e.g., diCB, triCB, tetraCB), three coplanar PCBs (#77, 126, 169), and total PCBs. With the exception of di- and deca- chlorinated biphenyls, mean concentrations were significantly lower at the Slocan River reach compared to the Genelle and Beaver Creek reaches, which did not differ significantly (Lawrence 1996). The mean concentration of di- chlorinated biphenyls did not differ significantly among sites, while the mean concentration of deca- chlorinated biphenyls was significantly greater at Beaver Creek compared to the Slocan River (Lawrence 1996). This pattern of among-site differences held when lipid-corrected data were used in the ANOVA, with the exception that both di- and deca- chlorinated biphenyls did not differ significantly among sampling locations (Lawrence 1996).

Although total PCB concentrations were significantly higher at the two Columbia River reaches compared with the reference site, the levels were generally low at all sampling locations (Appendix 5A). Health Canada's assessment of these data concluded that the concentrations of PCBs found in the fish from the Columbia and Slocan Rivers would not pose a health hazard to human consumers.

Table 11 provides PCB TEQs, expressed in units of picograms 2,3,7,8-TCDD equivalent per gram tissue, for both the WHO and Safe system of TEF values. All calculations in this table assume a concentration equal to the detection limit for all non-detected values, as a conservative approach. The PCB TEQs were significantly lower at the Slocan River reference site, compared to the two Columbia River sites, which did not differ significantly from each other, for both the WHO ($p<0.001$) and Safe ($p<0.001$) method of calculation (Lawrence 1996). The TEQs generated using the Safe (1994) system of TEF values were, on average, about 1.5 times higher than those of the WHO/IPCS system. However, for both systems of TEF values, the TEQs were low at all sampling locations. The PCB TEQs were lower than the TEQs reported for dioxin/furan congeners.

Table 11. Summary of toxicity equivalents for PCBs, PCDDs/PCDFs and Total TEQs (PCBs and PCDD/PCDF combined) for mountain whitefish muscle tissue collected in July 1994 from the Columbia and Slocan Rivers.

Site		PCB (WHO) (pg/g)	PCB TEQ (Safe) (pg/g)	PCDD/PCDF TEQ (ITEF) (pg/g)	TOTAL TEQ WHO+ITEF (pg/g)	TOTAL TEQ Safe+ITEF (pg/g)
Slocan	*Mean:*	0.26	0.34	0.36	0.61	0.70
	St. Dev.:	0.10	0.14	0.07	0.15	0.20
Beaver	*Mean:*	2.17	3.32	4.84	7.01	8.16
	St. Dev.:	1.63	2.39	3.71	4.71	5.26
Genell	*Mean:*	3.10	4.54	5.11	8.21	9.65
	St. Dev.:	3.28	4.38	6.92	10.06	11.13

Concentrations of coplanar PCBs were considerably lower than the other PCB congeners, yet they still contribute to the total toxicity of a sample because their TEF values can be up to several orders magnitude higher than those for mono- and di-ortho substituted PCBs. The contribution of the coplanar PCBs and the mono- and di-ortho substituted PCBs towards the total PCB TEQ was roughly equal (see Fig. 11).

Male fish had higher concentrations of total PCBs and PCB TEQs than female fish, however, these differences were not significant at any one of the sampling locations (Lawrence 1996).

The relationship between total PCB concentration and percent lipid content was significant only at the Slocan River site ($p=0.047$) (Table 10). A similar result was obtained for regression of PCB TEQ and lipid content (Lawrence 1996). This suggests that factors other than lipid content may be responsible for bioaccumulation of PCBs in fish muscle tissue.

The relationship between total PCBs and fish age was significant at Genelle ($p=0.003$) and for both Columbia River sites combined ($p=0.001$). Regression results for PCB TEQs and age were similar to those for total PCBs.

The relationship between total PCB concentration and total dioxin and furan concentration was significant at Genelle ($p=0.000$), Slocan ($p=0.019$), and both Columbia River sites combined ($p=0.003$). The relationship between dioxin TEQs and PCB TEQs was also significant at Genelle ($p=0.000$) and the two Columbia River sites combined ($p=0.000$). The lack of a significant relationship at the Beaver Creek site might be attributable to small sample sizes combined with high variability, or different exposure of Beaver Creek fish to organic contaminants.

Total PCBs and PCB TEQs did not differ significantly between 1992 and 1994 at each of the two Columbia River reaches (Lawrence 1996). PCB TEQs were found to be significantly lower in 1994 than 1992 at the Slocan River reference site, however, this difference was likely due to lower detection limits in the 1994 study. Time trends of Aroclor 1254/1260 concentrations in muscle tissue of fish collected from Genelle indicate that there has been little change in body burdens since the 1991 study. PCBs in the aquatic food chain are expected to decline over a longer time frame than that for dioxins because they have a much longer half-life.

PCDD/PCDF and PCB Toxic Equivalents

Total TEQs calculated using PCB TEFs from either WHO/IPCS (Ahlborg *et al.* 1994) or Safe (1994), were significantly lower at the reference site compared to the two Columbia River sites, which did not differ significantly ($p<0.001$) (Lawrence 1996). PCB congeners contribute slightly less than half of the total toxicity at a given sampling location, while the remaining proportion is attributable to dioxins and furans (Fig. 11). In July 1992 the PCB TEQs contributed approximately one third of the total TEQs in Columbia River fish (Nener *et al.* 1995). The contribution of PCBs toward the total toxicity was slightly higher in 1994 compared to 1992 because the dioxin TEQs were lower in 1994, while PCB TEQs were similar in both studies. Results from the January 1991 study cannot be compared as the toxic PCB compounds, for which TEF values have been associated, were not analyzed.

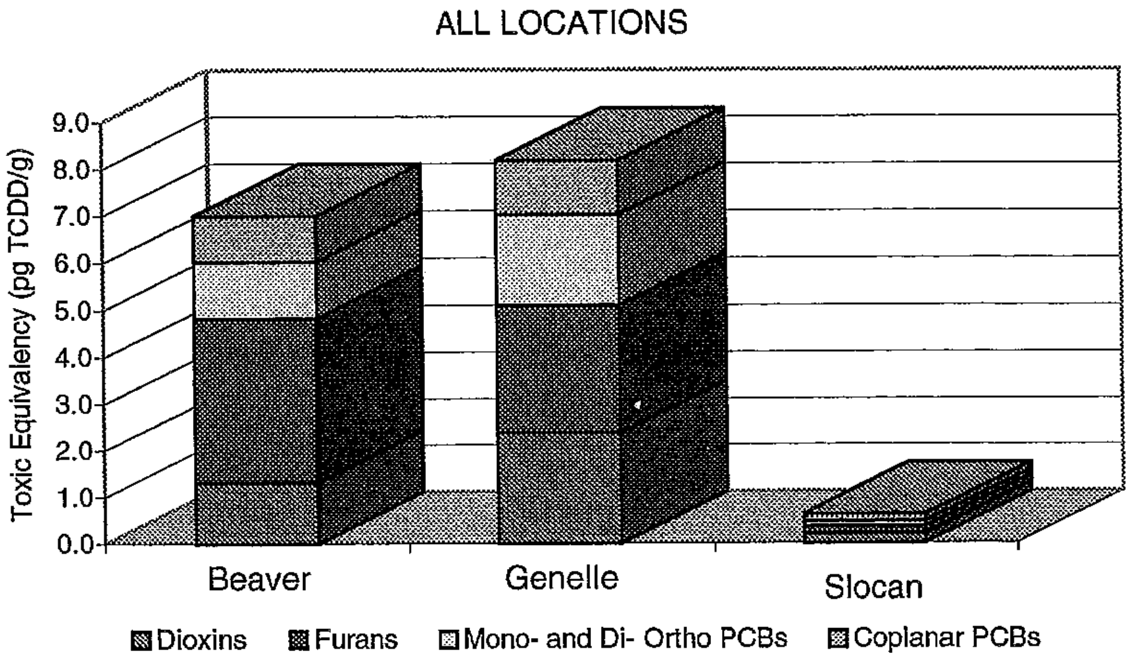


Figure 11. Contribution of PCDDs/PCDFs and PCBs to total toxic equivalents (pg TCDD/g). TEQs were derived using WHO interim TEFs for PCBs and TEFs From Nato (1988) for PCDDs/PCDFs

Organic Contaminants and Implications for Fish Health

Regression analyses (Table 10) showed that cumulative disease severity (CDS) was not correlated with body burdens of organic contaminants or toxicity. The relationship between the total concentration of all dioxin and furan congeners and CDS, and that between dioxin TEQs and CDS, was not significant at any sampling location, or when the two Columbia River sites were combined (Lawrence 1996). Similarly, there was no significant relationship between total PCBs and CDS, or between PCB TEQs and CDS, at any location (Lawrence 1996). CDS was also not related to the total TEQs calculated from both dioxins and PCBs at any sampling reach, or the Columbia River sites combined (Lawrence 1996). These findings were similar to those for mountain whitefish exposed to pulp mill effluent on the Wapiti River in Alberta, which found no correlation between elevated muscle dioxin or bile chlorophenolic concentrations and gross external pathology or histopathology results (Kloepper-Sams *et al.* 1994). Despite small sample sizes, these findings suggest that organic contaminants were not solely responsible for the increased cumulative disease severity in Columbia River mountain whitefish.

The relationship between organic contaminants and abnormalities in individual organs was examined separately for liver tissue and kidney tissue, as these may be target organs for various abnormalities related to contaminants. These organs were also selected because the prevalence and severity of liver and kidney abnormalities decreased significantly between 1992 and 1994, the time period during which PCDD and PCDF concentrations in muscle tissue and hepatic MFO activity decreased. Due to the small sample sizes used for organochlorine analyses, it was not possible to make definitive statements regarding the relationship between organic contaminant concentrations and abnormalities in liver or kidney.

MIXED FUNCTION OXIDASE ACTIVITY

Monooxygenase enzymes (also called mixed function oxidases or MFOs) have been shown to respond to exposure to some classes of compounds such as polycyclic aromatic hydrocarbons, PCDDs, PCDFs, and mixtures or effluents containing these compounds. The response (called 'induction') is produced when the inducing compound binds to the *Ah* receptor in the cell and causes an increase in the production of a particular form of the cytochrome P-450 enzymes known as P4501A. The resulting increase in catalytic activity can be measured and used as an index of exposure to these compounds or mixtures of effluents containing them (Hodson *et al.* 1991). For a more complete description of the cytochrome P-450 enzymes, the reactions that they catalyze, and their use as indicators of exposure to environmental contaminants, the reader is referred to several reviews (Jakoby 1980; Jimenez *et al.* 1990; Stegeman *et al.* 1992).

Two catalytic activities, ethoxyresorufin O-deethylase (EROD) and benzopyrene hydroxylase (AHH), and total cytochrome P-450 content have been measured in mountain whitefish taken the Columbia River at Genelle in January 1991, July 1992 and July 1994. Reference sites were the Brilliant Reservoir in 1991 and the Slocan River in 1992 and 1994. Samples were also taken at Beaver Creek, which is downstream of Trail, in 1992 and 1994. Results of the 1991 and 1992 studies are described in Boyle *et al.* (1992) and Nener *et al.* (1995). The 1994 data are provided in Appendix 6 and Fig. 12. For the subset of fish analyzed for MFOs in 1994, there was no significant difference in mean age, liver weight, or liversomatic index among sampling locations (Lawrence 1996).

EROD activity in 1994 was significantly higher at Genelle compared to Beaver Creek ($p=0.111$). Mean EROD activity in fish from Genelle was higher than that in Slocan River fish, however, the difference was not statistically significant due to high variability in samples from Genelle. Mean AHH activity was also significantly higher at Genelle compared to Beaver Creek ($p=0.022$), while cytochrome P-450 did not differ significantly among sampling location.

EROD, AHH, and cytochrome P-450 responses were significantly higher in males than females at all sampling locations (Lawrence 1996). After accounting for these sex differences, EROD activity at Genelle was still significantly higher greater than that at Beaver Creek ($p=0.009$), while EROD activity at Slocan did not differ significantly from that at the other two reaches.

The most striking observation to come from the 1994 data is the drop in EROD and AHH enzyme activity levels and ranges between 1991 and 1994 at Genelle (Fig. 12). EROD activity levels at Genelle in January, 1991 ranged from 0.083 to 1.004 nmoles/mg/min (mean 0.457). By July, 1994 the EROD activity levels had declined to a range of 0.004 to 0.102 (mean 0.027) which is not very different from the reference sites. Cytochrome P-450 did not change at the two Columbia River sites between 1992 and 1994 but there is an unexplained statistically significant difference in samples from the Slocan River site for the two years. The cytochrome P-450 test is generally less sensitive to change than the other two assays. Male and female fish also exhibited the same downward trend in MFO activity since 1991.

EROD induction in the January 1991 study was similar to that found for mountain whitefish exposed to secondary treated bleached kraft pulp mill effluent in the Wapiti River below the Grande Prairie mill in

Alberta in 1991. Columbia River fish, however, exhibited increased gross external abnormalities, kidney melanomacro-phages, parasitic infections, and histopathological abnormalities compared to the Wapiti fish (Kloepper-Sams and Benton 1994).

Fluctuation of enzyme activity has been shown to occur in other species of fish with changes in season generally having reduced activities at spawning time (Boychuk 1994; Luxon *et al.* 1987). Thus, direct comparison of the results between the 1991 and 1992 sampling must be treated with care (Nener *et al.* 1995). Samples taken in 1992 and 1994 were taken at the same time of year and are directly comparable in terms of location and time. In 1994 levels of the MFO enzyme activity were higher in male mountain whitefish than in females at all locations, which is consistent with observations from previous years and with other species (Boychuk 1994; Lockhart and Metner 1992; Spies *et al.* 1988).

Statistical analysis of the data showed significant correlations ($p<0.05$) between EROD and AHH from Beaver Creek and Genelle with some organochlorine contaminants or their combinations and associated TEQs (Lawrence 1996). The greatest number and strongest of the correlations occurred at the Genelle site and the weakest were at the Slocan reference site. In 1994 significant correlations with the overall organochlorine TEQ (PCDD/PCDF and PCB) were found at the Genelle site (EROD $r=0.932$; AHH $r=0.814$). These effects at Genelle were strong enough to cause a significant correlation when all of the Columbia River fish (Beaver and Genelle) were tested against the overall organochlorine TEQ (EROD $r=0.829$; AHH $r=0.725$). This correlation was not significant at either the Slocan River reference site or the Beaver Creek site when considered alone.

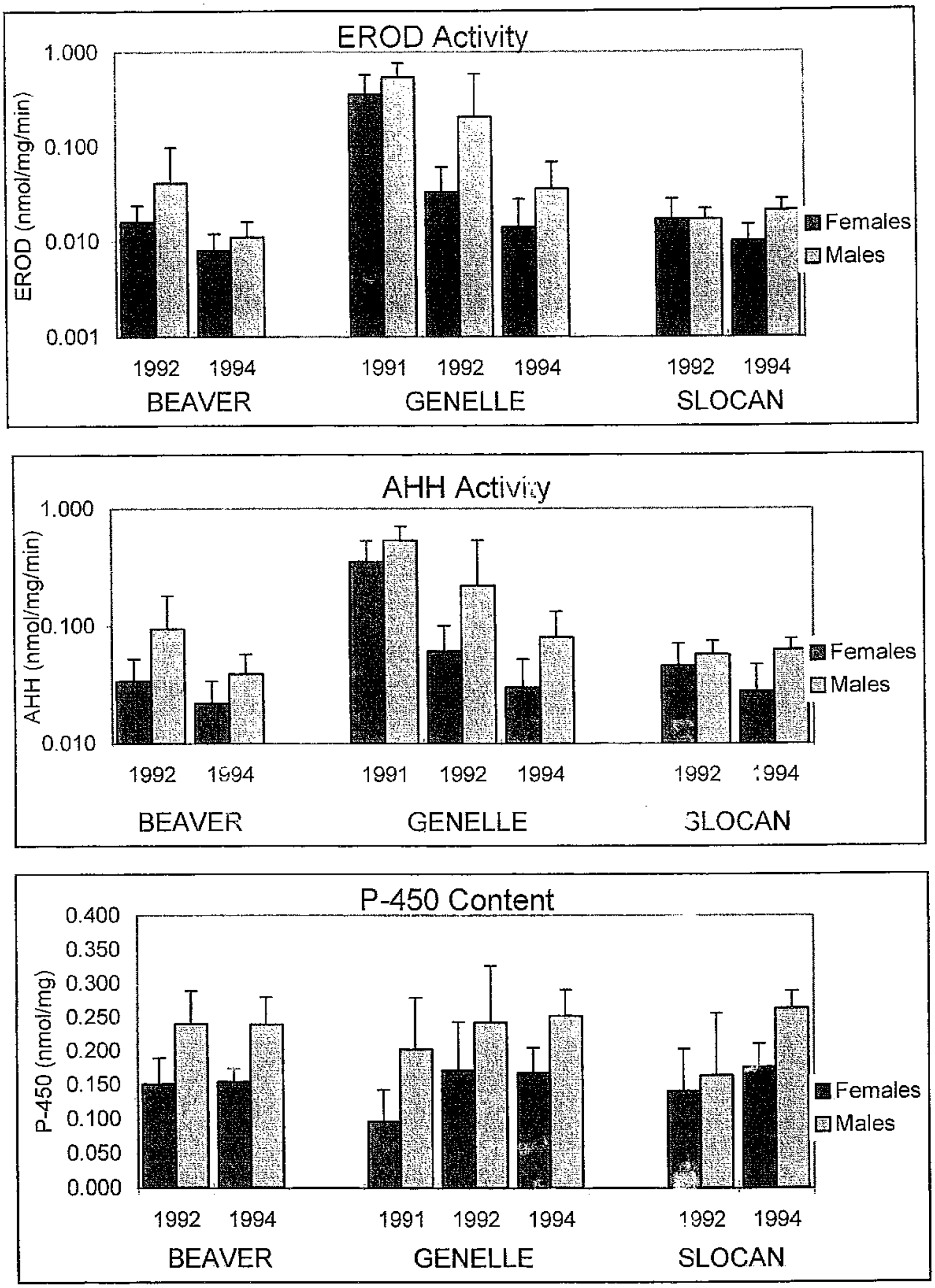


Figure 12. Enzyme activities measured in mountain whitefish from the Columbia and Slocan Rivers from 1991 to 1994.

The relationship between cumulative disease severity (CDS) and EROD was assessed using regression analysis. There was no significant relationship between CDS and log EROD at Genelle ($p=0.191$), Beaver Creek ($p=0.406$), the Slocan River site ($p=0.286$), or the two Columbia River sites combined ($p=0.055$).

Organochlorine inducers generally cause a very strong increase in the enzyme signal, which is very persistant. For example, Delorme (1995) did some work on the stability of induction by a pentachlorodibenzofuran, and observed that fish can remained induced for several years. The Columbia River data show a significant decline in MFO activity between the 1991 and 1992 studies, and the 1992 and 1994 studies, consistent with the general decline in organochlorine contaminants. Induction effects, however, have also been seen at non chlorinating mills in Ontario (Carey *et al.* 1993; Munkittrick *et al.* 1994) and at a sulphite mill in Manitoba (Friesen 1994). This argues that the induction of Columbia River mountain whitefish might not have been entirely due to chlorinated dioxins and furans (Servos *et al.* 1994), but also by more labile components of the effluent. The PCDD/PCDF components may be serving more as tracers for the effluent than as causes of the effects.

An observation of interest is the statistically significant lower EROD and AHH activities found at Beaver Creek when compared to Genelle. The fish at Beaver Creek may be exposed to lower levels of inducing materials in the river due to their distance downstream from Castlegar but this location is also downstream of the smelter at Trail. Several authors have reported inhibition effects by cadmium on hepatic microsomal enzyme activities in fish and other species (Fair 1986; Forlin *et al.* 1986; Soni *et al.* 1982). Forlin (1986) reported an inhibition in EROD activity in rainbow trout after intraperitoneal injection of cadmium but this inhibition did not occur when the fish were exposed to cadmium in the water. Fair (1986) reported a decline in benzopyrene hydroxlyase activity in black sea bass in the response to the intraperitoneal injection of benzo(a)pyrene following pretreatment of the fish by cadmium.

A linkage between monooxygenases and metals has not been sought previously in this study. Beaver Creek fish had the highest cellular liver cadmium concentrations and Genelle fish had the lowest muscle cadmium concentrations among the various sites in 1994. Direct comparison of cadmium and MFO activity was not possible since MFOs and metals were analzyed for in different fish. Any inhibition effects due to cadmium would be subtle and probably not observable in previous years due to the high variability of the enzyme activity data and the high levels of induction seen in some fish.

TRACE METALS AND METALLOTHIONEINS

Muscle Data

The trace metals data for whitefish muscle tissues are shown in Appendix 7A. Of the 34 elements determined by inductively coupled plasma spectrometry, only 22 provided data above limits of detection that could be used statistically. Although data for lead, arsenic, silver, mercury and nickel were insufficient to permit further analysis (i.e., no values exceeded detection limits), the detection limits were sufficiently low to indicate that these elements would not pose a threat to human health.

For the subset of samples analyzed for elements, mean age did not differ significantly among sampling location ($p=0.674$); whereas wet weight and fork length did differ significantly with Slocan fish being lighter and shorter, in comparison to fish at Genelle and Beaver Creek ($p<0.001$) (Lawrence 1996). Condition indices were significantly higher for fish from the Columbia River compared to fish from the Slocan River, however, the level of significance was marginal ($p=0.036$)(Lawrence 1996).

Preliminary analysis of the data indicated that metal concentrations did not vary by sex or age, and therefore ANOVA (not ANCOVA) was used in the statistical analysis. ANOVA results indicated that the elements calcium, chromium, and copper did not vary significantly across the three sampling locations (Lawrence 1996). In the cases of Ba, Cd, Fe, Mg, Se, Sr and Zn, concentrations in Slocan samples were significantly higher or did not differ from samples from the Beaver Creek site. Genelle samples were consistently lower than at the either of the other sites. Only the metalloid silicon was significantly higher at the site below the smelter at Trail, compared to the reference site and the Genelle reach of the Columbia River. These results (i.e., higher concentrations of most metals at the reference site) are consistent with the results from the 1992 sampling (Nener *et al.* 1995). It is also interesting to note that concentrations of the alkaline earth elements, Ba and Sr, are significantly elevated in Slocan samples. As with the previous studies, these observations can be attributed to higher levels of mineralization in the Slocan River and not to unknown inputs of industrial contamination.

Concentrations of Cu, Hg, Sr and Zn were compared between the 1992 and 1994 studies using the Student-t-test. Table 12 shows that concentrations of three of the metals (Cu, Sr, Zn) were significantly higher in 1994 compared to 1992 at Beaver Creek. Concentrations were significantly lower in 1994 compared to 1992 for Cu and Zn in Genelle and Slocan fish. Mercury was lower in 1994 only at Genelle; this may reflect continued reduction of environmental levels since controls on the use of mercurial slimicides were imposed two decades ago. The higher concentrations for Cu and Zn in 1994 at Beaver Creek may reflect continuing uptake of these metals from the smelter discharge. Increased Sr concentrations in Beaver Creek samples in 1994 are difficult to explain. This element is an alkaline earth and as such is rarely considered to be a contaminant. The observed changes at all sites, though statistically significant, might also be due to natural variations that reflect changes in water chemistry and fish nutrition.

Table 12. Comparison of selected muscle tissue trace metals results for mountain whitefish collected in July 1992 and July 1994.

Trace Metal		Genelle (n=16) 1992	Genelle (n=15) 1994	Slocan (n=15) 1992	Slocan (n=15) 1994	Beaver (n=20) 1992	Beaver (n=15) 1994
Copper (µg/dry kg)	Mean:	1.59	1.33	2.15	1.42	0.85	1.33
	St. Dev.:	(0.21)	(0.14)	(0.39)	(0.42)	(0.12)	(0.31)
Mercury (µg/dry kg)	Mean:	0.29	0.11	0.11	0.10	0.15	0.13
	St. Dev.:	(0.06)	(0.04)	(0.02)	(0.00)	(0.03)	(0.06)
Strontium (µg/dry kg)	Mean:	1.70	2.27	3.56	3.47	0.84	1.67
	St. Dev.:	(0.84)	(1.34)	(0.39)	(1.19)	(0.10)	(0.90)
Zinc (µg/dry kg)	Mean:	17.70	14.33	21.10	18.32	15.30	17.01
	St. Dev.:	(1.40)	(2.40)	(1.00)	(2.09)	(1.20)	(4.06)

Results from this study were compared with those from previous studies, including Norecol (1989), to provide a summary of data from 8 studies spanning over a 15 year period. For consistency with previous studies, mean concentrations (± one standard deviation) were expressed on a wet weight basis and all non-detected values were replaced by half the detection limit (Fig.s 13a to d). While the available data do not permit statistical analysis, they do provide interesting graphical comparisons.

Most lead concentrations in 1994 were below detection limits, having dropped sharply at the Genelle and Trail (or Beaver Creek) sites where they had remained stable between 1980 and 1992 (Fig. 13a). This might reflect changes in exposure to this element at the site below the lead smelter, following stricter controls on effluent and emissions. Given that Pb levels at Genelle are also significantly lower, this might just as likely represent reduced emissions due to the use of unleaded gas in the past decade. Additional data will be required for definitive conclusions.

Unlike lead, cadmium at Genelle and at Beaver Creek, in particular, showed an increase in 1994 (Fig. 13b). In the latter case, mean Cd values were as high as those found in the mid-1980s. Again these values, which were generally low, may reflect natural variation.

Copper values (Fig. 13c) have also exhibited some variability since 1980, although, as noted above, Beaver Creek fish had significantly higher levels in 1994. Mercury trends (Fig. 13d) are similar to those for Cu, although lower burdens might be due to real changes in environmental exposures in this instance.

Zinc and chromium burdens have changed very little over the 14 year period (Lawrence 1996).

With the exception of lead and mercury, there is little evidence to suggest any long-range, downward trend in muscle metal burdens. Observed variation in metal concentrations in muscle tissue could be ascribed to natural fluctuations.

Liver Metals and Metal-binding Proteins

Liver tissue is a repository for metals and organic contaminants, and it is the primary source of metal-binding proteins, which has been recognized as a biomarker of metal ingestion for about 30 years (Kägi and Nordberg 1979). These proteins are important in many roles; among them the homeostatic control of Cu and Zn and are part of a detoxification mechanism for these as well as Cd and Hg (see Kägi and Nordberg 1979). Three metals, cadmium, copper and zinc, have been long identified as those that bind naturally to MBP in liver tissue. It is therefore of some importance to obtain information on the distribution of MBP and how it relates to the metals in the whole tissue and in the supernatant cytosols.

In the 1992 study (Nener *et al.* 1995) it was found that only MBP in livers from Beaver Creek whitefish were significantly correlated to Cu and Cd in the cytosol fraction in spite of the fact that concentrations in fish form the other sites were comparable in value. This suggested that there was active uptake of metals, possibly linked to the ingestion of slag particles.

Many metal concentrations in the cytosolic and cellular components of liver tissues generally provide a better indication of the exposure of an organism to variations in the environmental concentrations. Most total metal values are invariably higher than in muscle, and thus are easier to obtain and permit more valid statistical comparisons. Changes in the distribution of copper, cadmium and zinc, in particular can provide valuable information on the factors at various sites.

Total protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers in July 1994 are shown in Appendix 7B. Summary data are presented in Table 13.

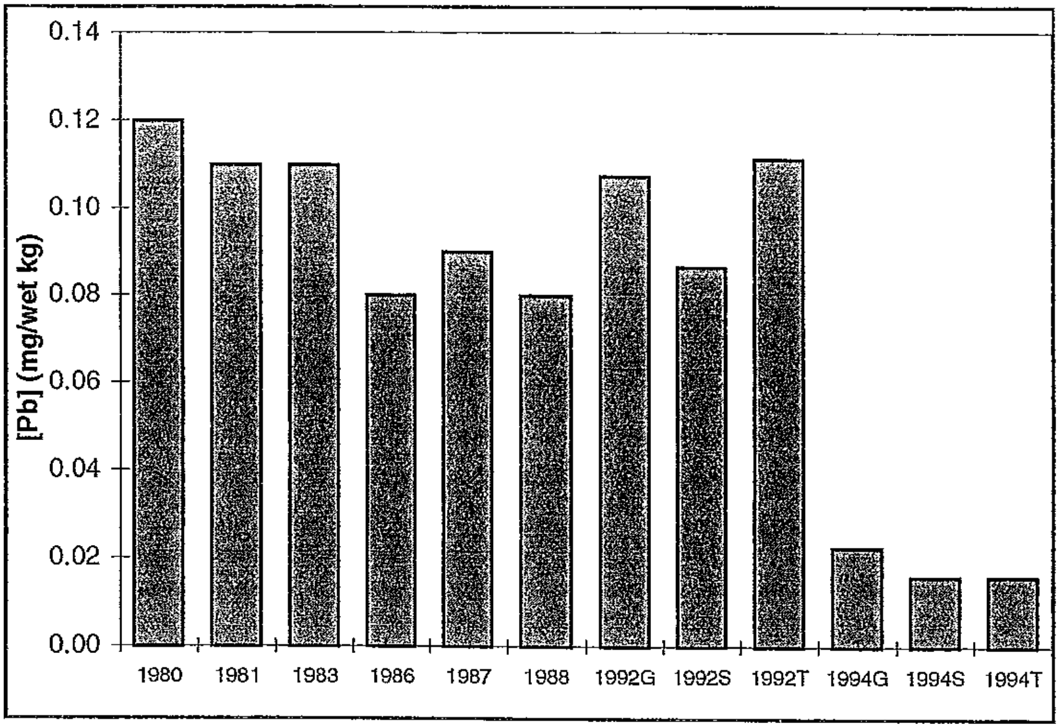


Figure 13a. Time series for lead (Pb) in mountain whitefish muscle tissue.
G= Genelle; T= Trail (also called Beaver Creek).
1980 - 1988 data from Norecol (1989).

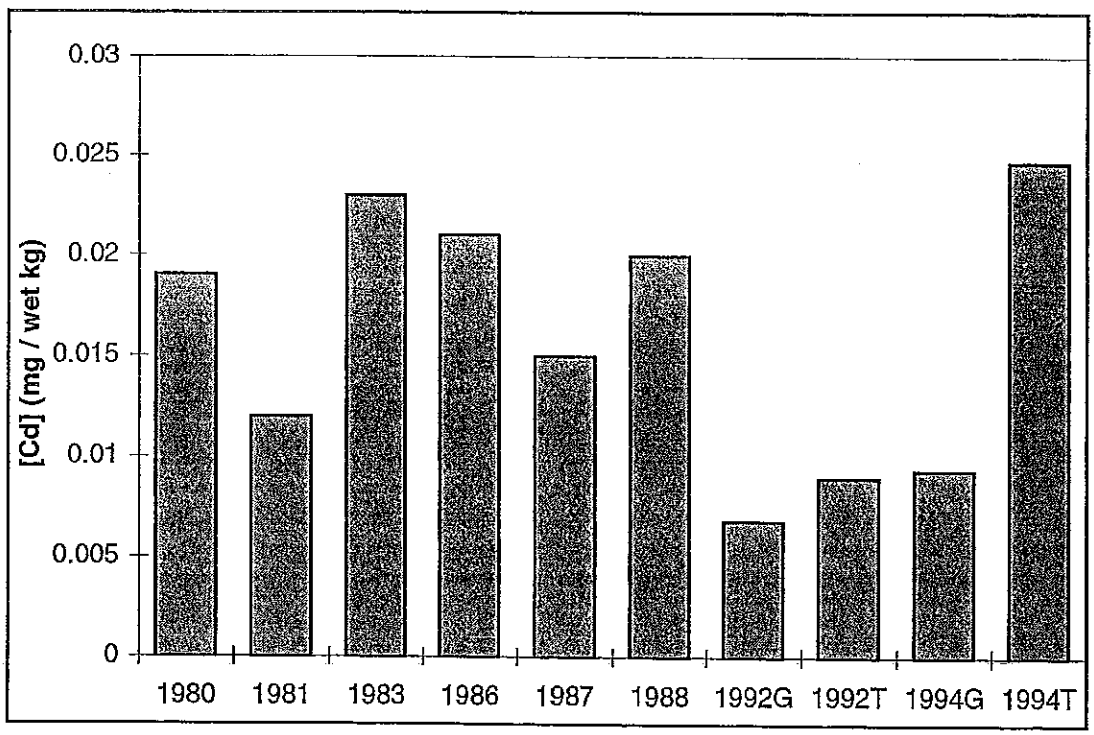


Figure 13b. Time series for cadmium (Cd) in mountain whitefish muscle tissue.
G= Genelle; T= Trail (also called Beaver Creek).
1980 - 1988 data from Norecol (1989).

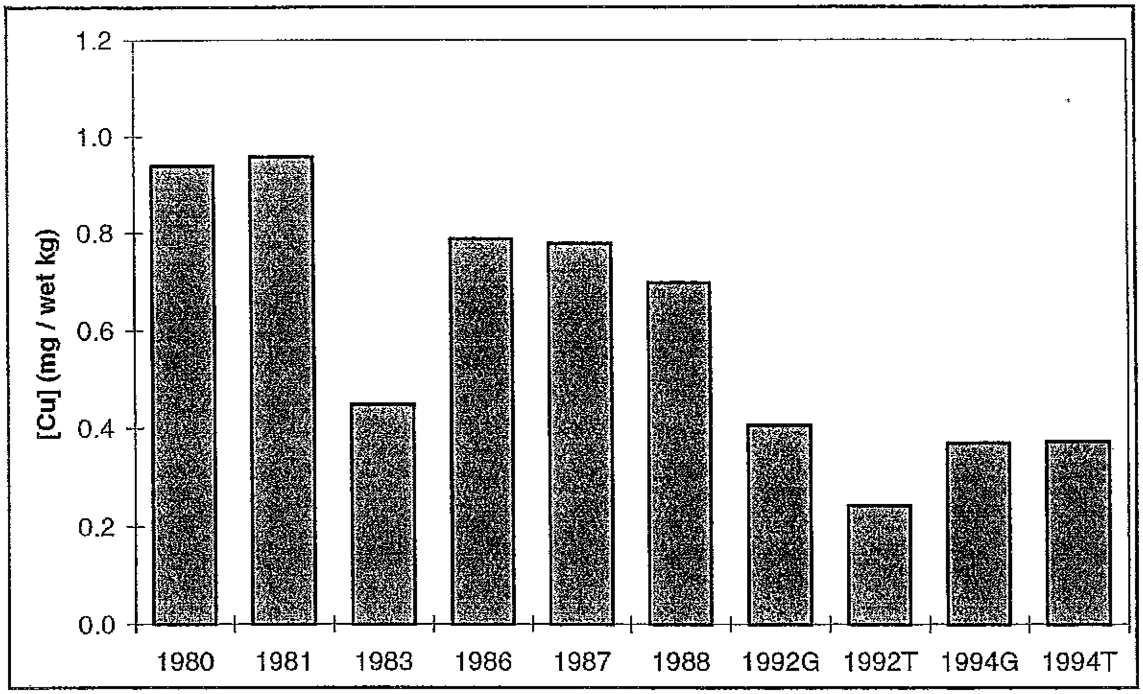


Figure 13c. Time series for copper (Cu) in mountain whitefish muscle tissue.
G= Genelle; T= Trail (also called Beaver Creek).
1980 - 1988 data from Norecol (1989).

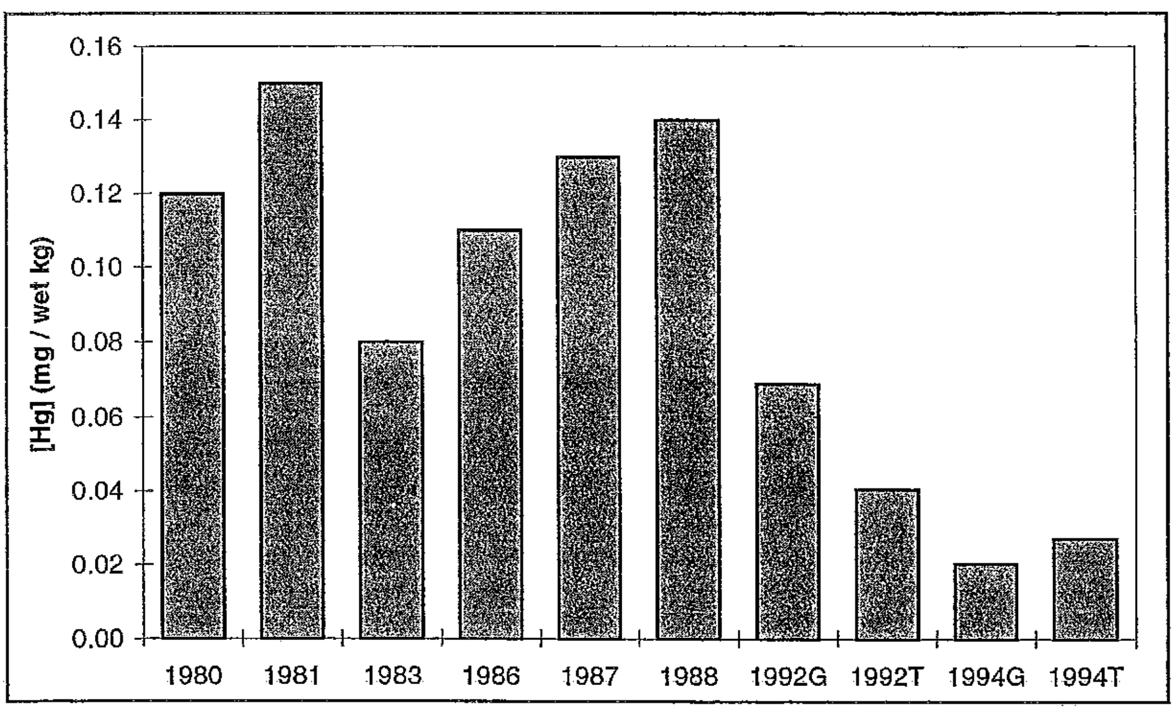


Figure 13d. Time series for mercury (Hg) in mountain whitefish muscle tissue.
G= Genelle; T= Trail (also called Beaver Creek).
1980 - 1988 data from Norecol (1989).

Table 13. Statistical summary for total protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers in July 1994.

Variable		GENELLE (n=15)	SLOCAN (n=15)	BEAVER (n=15)	P-Value	Outcome
Metallothionein (μ/dry kg)	Mean: St. Dev.:	80.22 25.60	95.96 20.55	112.90 46.57	p=0.029	G < B
Total Protein (grams/dry kg)	Mean: St. Dev.:	412.73 77.49	510.00 49.88	445.53 74.51	p=0.001	(G =B) < S
MBP normalized to Total Protein (μ/g)	Mean: St. Dev.:	0.20 0.08	0.19 0.04	0.26 0.12	- -	- -
Cytosolic Cd (μ/dry kg)	Mean: St. Dev.:	5.15 7.44	52.41 31.76	73.67 78.70	p<0.001	G < (S = B)
Cytosolic Cu (μ/dry kg)	Mean: St. Dev.:	75.54 44.20	164.53 66.84	306.91 204.16	p<0.001	G < S < B
Cytosolic Zn (μ/dry kg)	Mean: St. Dev.:	37.22 10.46	82.29 20.09	53.64 24.75	p<0.001	G < S < B
Cellular Cd (μ/dry kg)	Mean: St. Dev.:	13.39 14.67	63.70 32.84	123.75 107.33	p<0.001	G < (S = B)
Cellular Cu (μ/dry kg)	Mean: St. Dev.:	217.90 56.32	223.78 66.51	541.34 319.93	p<0.001	B > (G = S)
Cellular Zn (μ/dry kg)	Mean: St. Dev.:	1512.19 105.00	1662.08 173.59	1930.25 406.21	p=0.007	B > (G = S)
Cellular Hg (μ/dry kg)	Mean: St. Dev.:	1.70 1.95	1.60 1.00	1.06 0.84	p=0.397	n.a.
Cd Ratio (μ/cellular)	Mean: St. Dev.:	0.361 0.18	0.789 0.11	0.579 0.26	p<0.001	S > B > G
Cu Ratio (μ/cellular)	Mean: St. Dev.:	0.327 0.13	0.719 0.08	0.595 0.20	p<0.001	G < (S = B)
Zn Ratio (μ/cellular)	Mean: St. Dev.:	0.025 0.006	0.049 0.011	0.027 0.009	p<0.001	S > (G = B)

As was the case in 1992, metal concentrations in both compartments varied significantly among sampling locations. Mean cytosolic concentrations of Cd, Cu and Zn were significantly lower at Genelle compared to the other two sites, while Cu was significantly higher at Beaver than at either of the two other sites (Table 13). Zinc was significantly higher at the Slocan site, followed by Beaver Creek and then Genelle (Lawrence 1996).

Cellular concentrations (in liver tissue) also exhibited inter-site differences (Table 13). Cd was again significantly lower at Genelle than at the other two sites ($p<0.001$) while Cu and Zn were both highest at Beaver Creek. Mercury did not vary significantly among sampling locations.

The distribution of each metal between the two compartments also differed across the three sites. Molar ratios of cytosolic to cellular content (Table 13) were highest in Slocan fish and lowest in samples from Genelle.

Metal-binding proteins have been used extensively with varying degrees of success as biomarkers of metal uptake and retention, particularly Cd, Cu and Zn. In the 1994 study, MBP in Beaver Creek livers differed marginally from those at Genelle, with the mean for Slocan fish being intermediate between the other two. However, when normalized against total protein (Table 13, $\mu mol.g^{-1}$ basis), MBP in Beaver Creek samples was significantly higher than at the other two sites. This would suggest that fish at this site are being stressed by exposure to one or more of the three metals. Lawrence (1996) performed multiple regression analysis on the MBP and liver metal data to quantify possible relationships between them. MBP correlated significantly ($R^2 = 0.805$) with tissue-bound copper and cytosolic cadmium only in Beaver Creek samples. For the 1994 samples, mercury was also included in the analysis as a potential independent variable. It was also found that MBP was significantly correlated with age. Accordingly, a separate regression including age as an independent variable was calculated.

Results of regression analysis again showed significant relationships between MBP and liver-bound metals at Beaver Creek. The regression model obtained without age as a regressor was:

$$MBP = 27.063 + 0.122Cu_{cyt} + 0.587\ Zn_{cyt} + 0.135\ Cd_{tis} \qquad R^2 = 0.952,\ P < 0.001$$

where the subscripts *tis* and *cyt* refer respectively to the cellular and cytosolic components expressed in $\mu mol.kg^{-1}$.

Inclusion of age in the stepwise regression resulted in an even closer fit. The selected model was:

$$MBP = 35.532 + 0.111\ Cd_{cyt} + 0.167\ Cu_{cyt} + 2.207\ T \qquad R^2 = 0.973,\ P < 0.001$$

where T is the age in years.

Age was not included in the 1992 analysis. There is little information in the literature to suggest that MBP increases with age; although this cannot be ruled out. It is possible that the above correlation may be an artifact of this particular study. The previous (1992) regression for Beaver Creek fish did not include zinc and tissue-bound copper was replaced by the cytosolic component of this metal. In performing similar multiple regression analysis for fish from the two other sites, Lawrence (1996) reported a somewhat less significant correlation for Slocan fish which involved only cytosolic cadmium:

$$MBP = 68.257 + 0.435\ Cd_{cyt} \qquad R^2 = 0.483,\ P = 0.004$$

The 1992 and 1994 data sets made it possible to test for significant changes in liver metal and MBP concentrations with time using the two sample Student t test. Results of this comparison are shown in Table 14 and Fig.s 14 to 17. Both cytosolic Cd (Fig. 14) and tissue-bound Cd (Fig. 15) increased at only the Beaver site in the two-year period. Cytosolic Cu increased at Genelle and Beaver while there was a small but significant decrease in cellular Cu at Slocan (Table 14). Similarly, Zn in both compartments also increased in Beaver Creek fish, while there was a negative change in Slocan whitefish. This increase in Zn may be related to its addition as a term in the multiple regression equation above. It is of interest that liver MBP (Fig. 16) decreased significantly at all three sites, with the greatest drop occurring in Slocan fish. In the case of Beaver Creek fish, this would suggest that, although the copper burden had increased about 4-fold in the cytosolic fraction, this was not associated with induction of MBP.

Ratios of cytosolic to cellular Cd and Cu increased at all sites in 1994, compared to 1992 (Fig. 17). The changes in the distribution between these two compartments, and the decrease in MPB concentrations, suggest that the cytosolic component is the more mobile component, and represents the fraction of the metal that is being excreted from the cell. The significance of this change is not clear at this time. Zinc ratios did not change significantly at any of the sampling sites (Table 14).

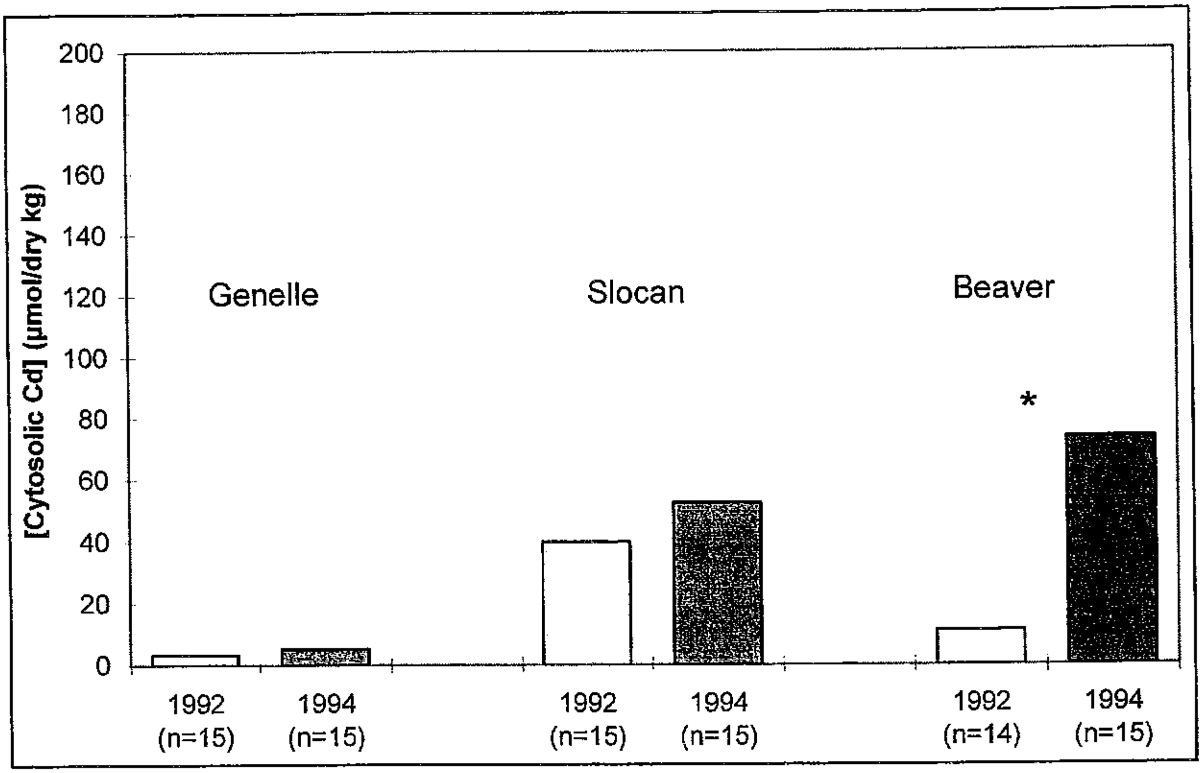


Figure 14. Inter-site comparison of 1992 and 1994 cytosolic Cd concentrations.
* denotes a statistically significant difference

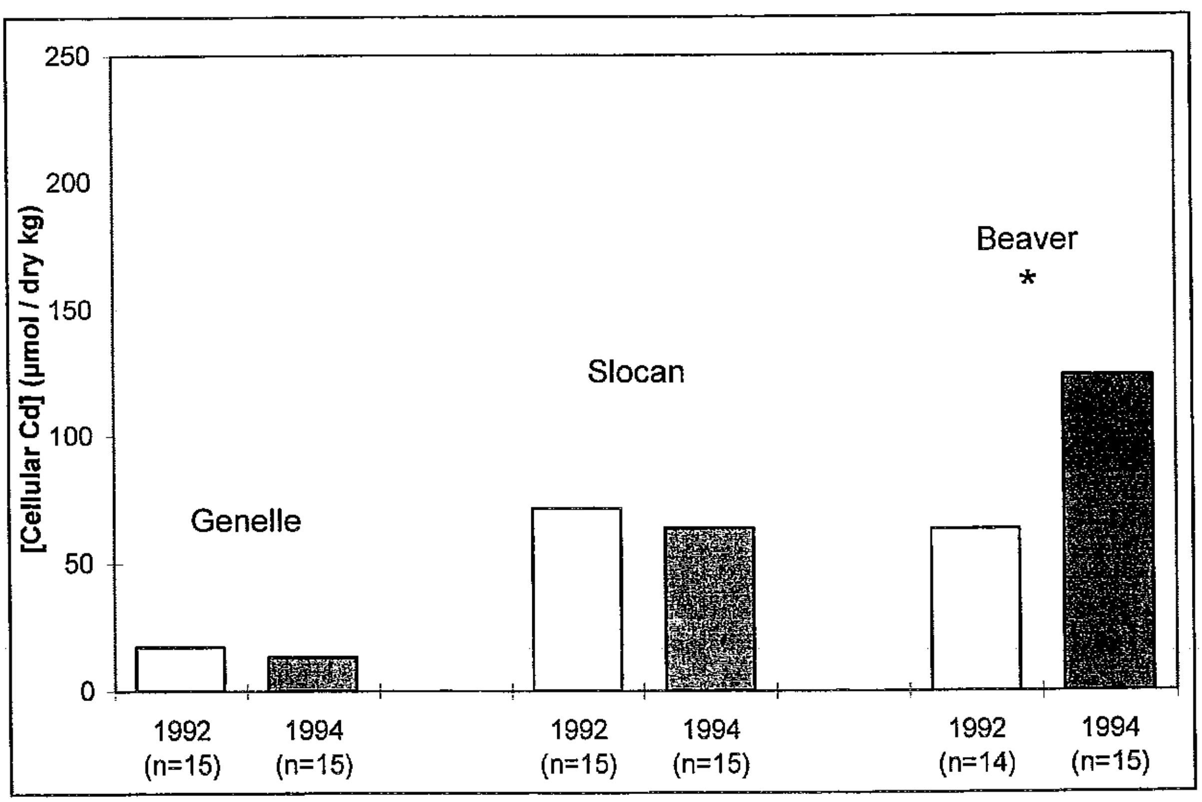


Figure 15. Inter-site comparison of 1992 and 1994 cellular Cd concentrations.
* denotes a statistically significant difference

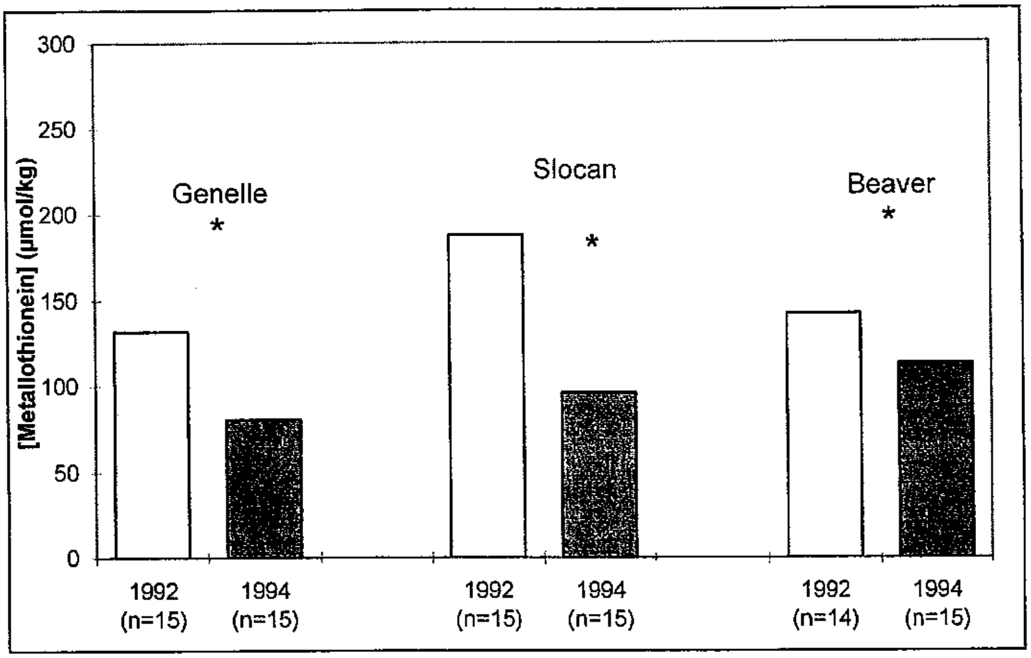


Figure 16. Inter-site comparison of 1992 and 1994 metallothionein concentrations.
* denotes a statistically significant difference

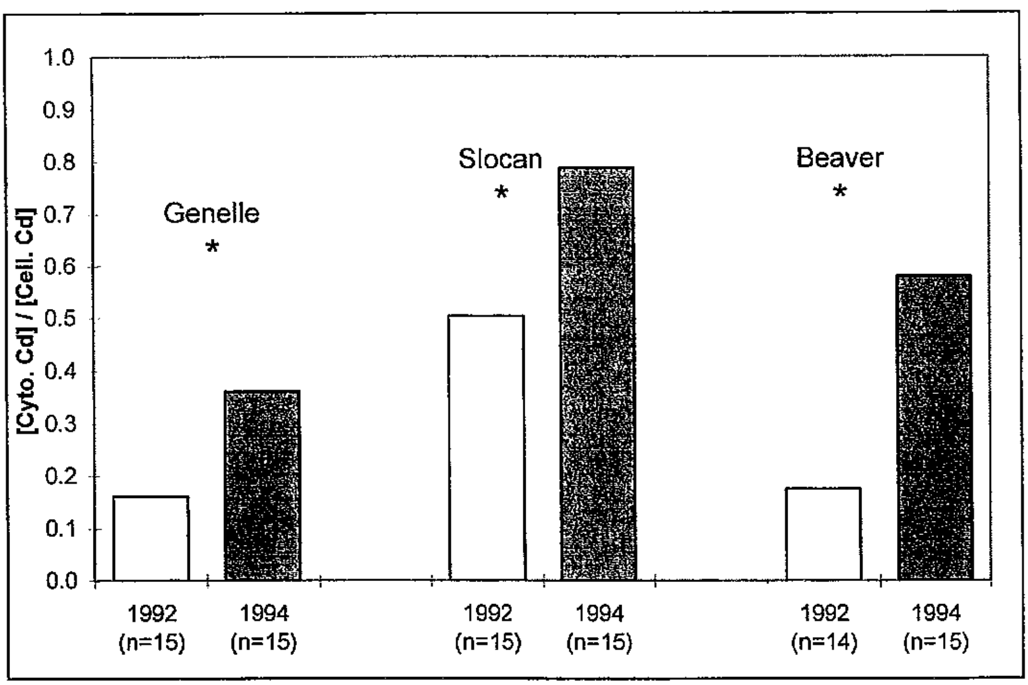


Figure 17. Inter-site comparison of 1992 and 1994 cytosolic/cellular Cd concentrations.
* denotes a statistically significant difference

Table 14. Summary data for total protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers in July 1992 and 1994.

Variable		Genelle (n=15) 1992	Genelle (n=15) 1994	Slocan (n=15) 1992	Slocan (n=15) 1994	Beaver (n=14) 1992	Beaver (n=15) 1994
Metallothionein (μ/dry kg)	Mean:	132	80	188	96	142	113
	St. Dev.:	(18)	(26)	(27)	(21)	(9)	(47)
Total Protein (grams/dry kg)	Mean:	338	413	361	510	303	446
	St. Dev.:	(17)	(77)	(21)	(50)	(12)	(75)
Cytosolic Cd (μ/dry kg)	Mean:	3.3	5.2	39.7	52.4	11.1	73.7
	St. Dev.:	(1.2)	(7.4)	(15.2)	(31.8)	(2.7)	(78.7)
Cytosolic Cu (μ/dry kg)	Mean:	47.3	75.5	138.0	164.5	130.0	306.9
	St. Dev.:	(8.6)	(44.2)	(32.8)	(66.8)	(27.0)	(204.2)
Cytosolic Zn (μ/dry kg)	Mean:	40.2	37.2	88.9	82.3	38.6	53.6
	St. Dev.:	(3.1)	(10.5)	(11.3)	(20.1)	(2.8)	(24.8)
Cellular Cd (μ/dry kg)	Mean:	17.4	13.4	71.6	63.7	63.4	123.7
	St. Dev.:	(3.7)	(14.7)	(20.3)	(32.8)	(13.0)	(107.3)
Cellular Cu (μ/dry kg)	Mean:	216	218	295	224	400	541
	St. Dev.:	(21)	(56)	(45)	(67)	(55)	(320)
Cellular Zn (μs/dry kg)	Mean:	1495	1512	1872	1662	1695	1930
	St. Dev.:	(79)	(105)	(103)	(174)	(64)	(406)
Cd Ratio (cytosolic/cellular)	Mean:	0.161	0.361	0.504	0.789	0.175	0.579
	St. Dev.:	(0.028)	(0.183)	(0.035)	(0.107)	(0.024)	(0.260)
Cu Ratio (cytosolic/cellular)	Mean:	0.213	0.327	0.429	0.719	0.314	0.595
	St. Dev.:	(0.031)	(0.132)	(0.045)	(0.079)	(0.028)	(0.200)
Zn Ratio (cytosolic/cellular)	Mean:	0.027	0.025	0.047	0.049	0.023	0.027
	St. Dev.:	(0.002)	(0.006)	(0.005)	(0.011)	(0.024)	(0.009)

In general, the concentrations of most metals in muscle and liver tissue do not reflect the environmental improvement projects implemented at the smelter. Projects implemented between July 1992 and 1994 included the smelter absorption heat exchanger in 1993 (which reduced mercury and cadmium in the effluent), a drainage project in the zinc plant area (this reduced zinc and cadmium loadings), blast furnace slag collection in December 1993 (reducing zinc, lead and cadmium loadings), and closure of the phosphate fertilizer plant in late July 1994 (which reduced mercury, gypsum, and phosphorus levels). At the site below the smelter, the concentration of Cd in muscle and liver tissue increased significantly between 1992 and 1994. Cu concentrations were also higher in 1994 compared to 1992 in both muscle and liver tissue, at the site below the smelter. Zn in muscle tissue did not differ significantly between 1992 and 1994, while cellular and cytosolic zn in liver tissue increased significantly between 1992 and 1994, at Beaver Creek. Pb concentrations in muscle tissue were much lower in 1994. Hg in muscle tissue did not differ significantly between 1992 and 1994 at Beaver Creek, however, significant reductions did occur between 1988 and 1992, following the installation of the mercury stripping plant at the smelter. These findings might reflect the tendency for mercury, lead, and copper tend to bioaccumulate in fish muscle tissue.

The decline in metallothionein levels in Columbia River whitefish livers between 1992 and 1994 may reflect the reductions in metals loadings to the Columbia River as a result of various abatement projects at the smelter. This decline has generally been taken as an indication of reduced metal (Cd, Cu, Zn) intake. However, that this decline was also observed in the reference samples tends to obfuscate the picture. It is conceivable that an unknown (natural or anthropogenic) source of one or more of these elements exists on the Slocan River and that recent decreases reflect downward inputs. The final sampling program (1996) will provide valuable information to further interpret these study results.

FLOW REGULATION

The Columbia River basin is a highly regulated system. There are several dams on the Columbia River (e.g., Mica, Revelstoke, and Hugh Keenleyside), Kootenay River (e.g., Brilliant, Libby, and Duncan), and the Pend d'Oreille River (e.g., Waneta, Seven Mile, and Boundary). The sampling site on the Slocan River is not influenced by flow regulation.

Regulation of the Columbia River system has influenced water flows, water levels, temperature, and total gas pressure (TGP). The adverse effects of TGP on aquatic life are well documented (Fidler 1988). Regulation has also dampened the magnitude of seasonal fluctuations in flow (i.e., reduced peak or flood flows), and operation of some facilities has resulted in greater short-term (daily to weekly) fluctuations in flow (Aquametrix Research Ltd. 1994). Two power generating facilities, the Brilliant and Waneta Dams, are operated as peaking facilities to meet higher energy demands during peak usage hours. This results in daily flow fluctuations below these facilities, which can affect primary and secondary productivity, and habitat availability.

Measurements of TGP, water temperature, discharge from Keenleyside, Keenleyside tailwater elevation and Columbia River flow at Birchbank were compiled for the time periods during which fish health studies were conducted on the Columbia River. These data were provided by B.C. Hydro in Castlegar and R.L and L. Environmental Services Ltd. in Edmonton, Alberta.

Keenleyside Discharge, Tailwater Elevation, and Columbia River Flow

Average daily measurements of Keenleyside tailwater elevation, Keenleyside discharge, and Columbia River flow at Birchbank are shown in Fig. 18a, b, and c, for the time periods during which the 1991, 1992, and 1994 fish health studies took place. These measurements were calculated from 24 hourly values. Flows at Birchbank were calculated as the sum of the Keenleyside discharge and the Kootenay River flow at the confluence of the Columbia River. Comparison of results for the July 1992 and July 1994 time periods indicate that Keenleyside tailwater elevation, Keenleyside discharge, and Columbia

River flow at Birchbank were higher during the July 1994 study, which occurred from July 4-15, compared to the July 1992 study, which occurred from July 6-15.

Keenleyside discharge and Columbia River flow at Birchbank were more constant around the time period of the July 1994 study than the July 1992 study. In general, fluctuations in discharge from Keenleyside appeared to have been reduced, based on a comparison of monthly mean discharge (for months during which fish health studies were conducted), standard deviation, and coefficient of variation (Table 15). This reduction is likely related to water availability, preferential use of north low-level ports over sluice ways, and flow orders that controlled discharge for downstream fish needs. Table 15 does not show clear trends in discharge variability from the Brilliant Dam on the Kootenay River. Reductions in flow fluctuations for the Columbia River at Birchbank and the international border are also evident. The Columbia River at the international border, however, is also influenced by the dams on the Pend d'Oreille River (e.g., Waneta, Seven Mile and Boundary dams). This analysis does not account for daily flow fluctuations, which should also be considered in future assessments, especially for all power generating facilities that operate as peaking plants.

Table 15. Variability in discharge from Keenleyside and Brilliant dams, Columbia River flow at Birchbank and the international border, and Keenleyside tailwater elevation, for those months during which Columbia River fish health studies took place.

Time Period		Keenleyside Tailwater (m)	Keenleyside Discharge (m^3/s)	Brilliant Discharge (m^3/s)	Columbia R. Flow at Birchbank (m^3/s)	Columbia R. Flow at int'l border (m^3/s)
July 1992	Mean[1]:	420.4	1275.4	783.4	2153.2	2560.7
	St.Dev.[2]	1.0	489.6	151.4	476.0	458.7
	C. V.[3]:	0.002	0.384	0.193	0.221	0.179
March 1993	Mean:	418.5	532.5	441.8	979.6	1381.9
	St. Dev.	0.3	109.2	81.5	101.7	156.2
	C. V.:	0.001	0.205	0.184	0.104	0.113
July 1994	Mean:	421.07	1866.4	861.1	2596.6	2929.4
	St. Dev.	0.3	188.8	318.5	243.9	367.6
	C. V.:	0.001	0.101	0.37	0.094	0.125
March 1995	Mean:	418.95	675.3	655.8	1321.9	2091.9
	St. Dev.	0.2	58.2	90.3	109.3	172.7
	C. V.:	0.000	0.086	0.138	0.083	0.083

1. Monthly mean
2. S.D. = one Standard Deviation
3. C.V. = coefficient of variation, C.V. = standard deviation/sample mean. The C.V. measures the amount of variability relative to the value of the mean.

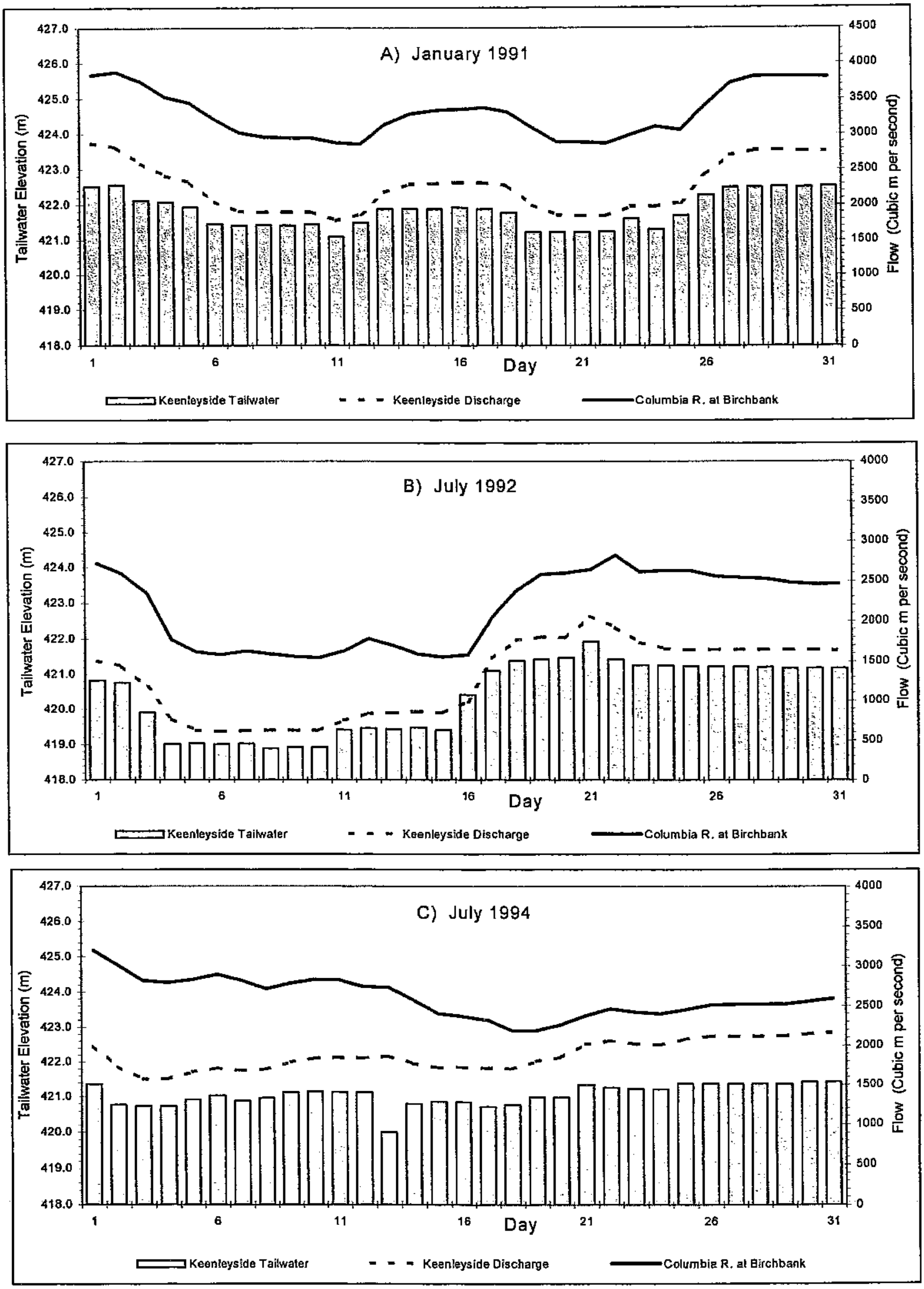


Figure 18: Keenleyside discharge, tailwater elevation, and Columbia River flow data for various time periods adjacent to fish health studies. A) January 1991 (Boyle *et al.* 1992); B) July 1992 (Nener *et al*. 1995); C) July 1994.

Total Gas Pressure

Fig.s 19a, b, and c show TGP data at four locations on the Columbia River for time periods during which the various fish health studies took place. The site closest to the Genelle reach of the Columbia River is Birchbank, which is 5 km downstream of Genelle. The Robson site is about 7 km downstream of Keenleyside Dam. During the July 1994 study, TGP levels averaged about 115 % (range: 112 % to 116 %) at Robson, and 113 % (range: 112 % to 115 %) at Birchbank. Although no TGP data are available for the exact time period of sampling in 1992, data presented in Aquametrix Research Ltd. (1994) suggest that TGP levels were in the range 125 % to 115 % during this time period. This range is slightly higher than that experienced during the July 1994 study. TGP levels were higher in July 1992 because water was being passed over the spillways at this time, rather than through the ports, as it was during the 1994 study. TGP levels during the 1991 study in January (116 %) were also similar to those recorded during the July 1994 study.

TGP levels in the Columbia River below Keenleyside have declined in recent years in response to operational changes. Early in the summer of 1994, B.C. Hydro began experimenting with use of the north and south low- level ports in order to reduce dissolved gas supersaturation. Changes in operating orders to allow for preferential use of the north low-level ports did not occur until 1995, hence any reductions in TGP would not be realized until after the July 1994 study.

Water Temperature

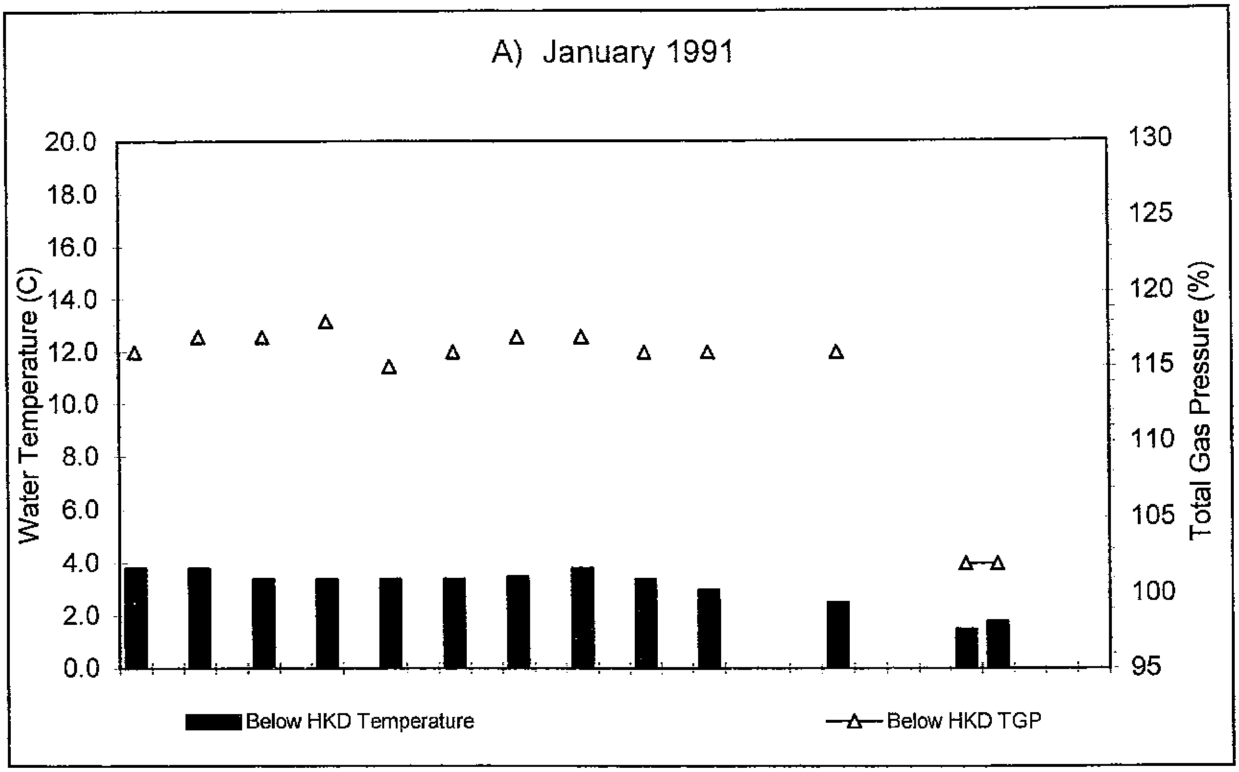
Water temperature data for the time periods of various fish health studies are shown in Fig.s 19a, b, and c. Average temperature during the July 1994 study was about 16 °C at Birchbank. During the 1992 study temperature was likely similar to that recorded during the July 1994 study, as temperature at Birchbank ranged from 14 to 16 °C from July 20 to 28, 1992.

Flow Regulation and Implications for Fish Health

Gas Bubble Disease

External signs of gas supersaturation can include bubbles or blistering: under the skin, between fin rays, on the head, or in the lining of the mouth. Exophthalmia and hemorrhaging at the base of the paired fins may occur with chronic gas bubble disease (Weitkamp 1976). No bubbles or blistering were seen in any fish sampled from the Columbia or the Slocan River upon gross external examination. These findings are consistent with the July 1992 study. Fish were not examined for more subtle signs of gas bubble trauma (GBT), such as bubbles in the gill lamella. Exophthalmia was noted in one fish each sampled from the Genelle and Beaver Creek reaches of the Columbia River in July 1994, and the prevalence of hemorrhaging at the base of the fins in 1994 was 23.5 % of fish from Genelle, 4.1 % of Beaver Creek fish, and 12.7 % of fish sampled from the Slocan River reference site. In both cases, however, bubbles or blistering were not observed in fish with either exophthalmia or hemorrhaging.

The incidence of GBT in mountain whitefish captured in the Columbia River between the Hugh Keenleyside Dam and the US border has been reported to be low (e.g., 0.07 % in 1990, 0.06 % in 1991, and 0.17 % in 1992) (R.L and L. Environmental Services Ltd. 1993). GBT incidence was found to be highest for suckers during this time period (2.5 % in 1990, 0.81 % in 1991, and 0.16 % in 1992), and slightly lower for rainbow trout (0.95 % in 1990, 0.87 % in 1991, and 1.5 % in 1992). These surveys examined only gross signs of GBT in adult fish, and some abnormalities might have been missed because sampling was conducted at night.



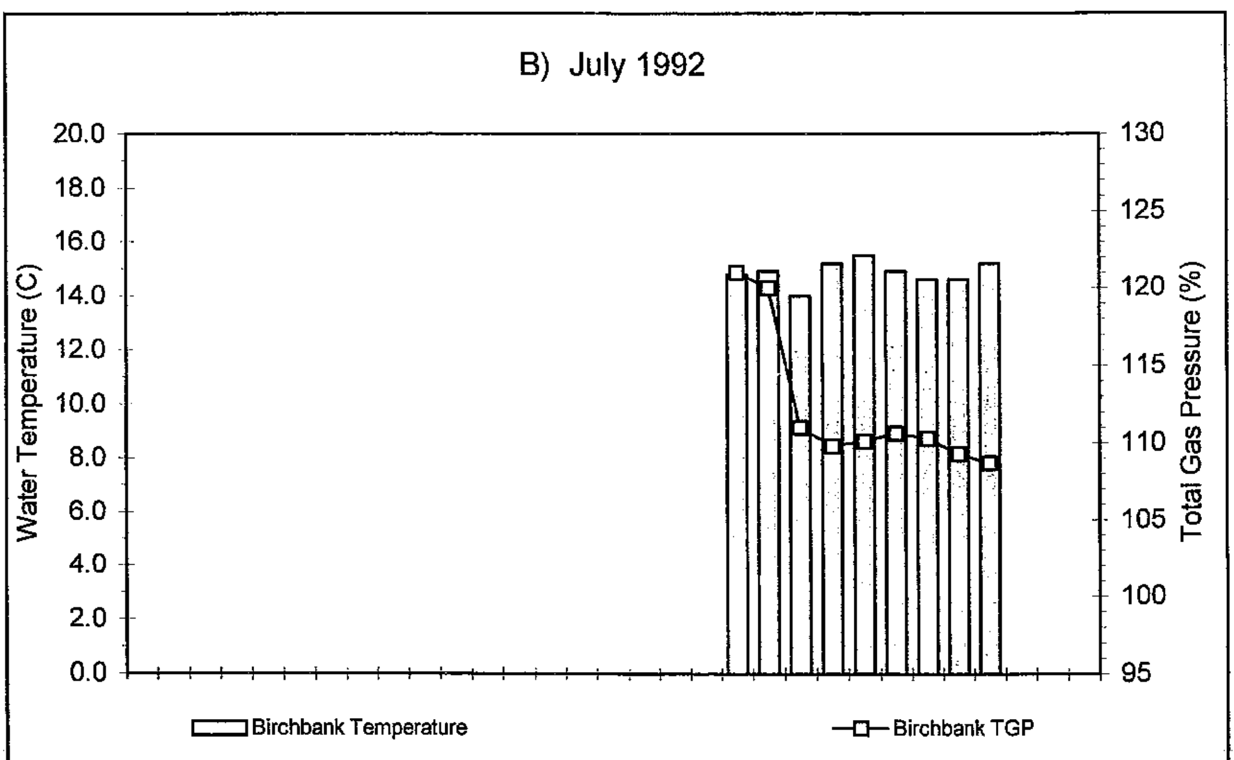


Figure 19: Water temperature and total gas pressure (TGP) data for various time periods adjacent to fish health studies. A) January 1991 (Boyle *et al*. 1992); B) July 1992 (Nener *et al.* 1995); C) July 1994.

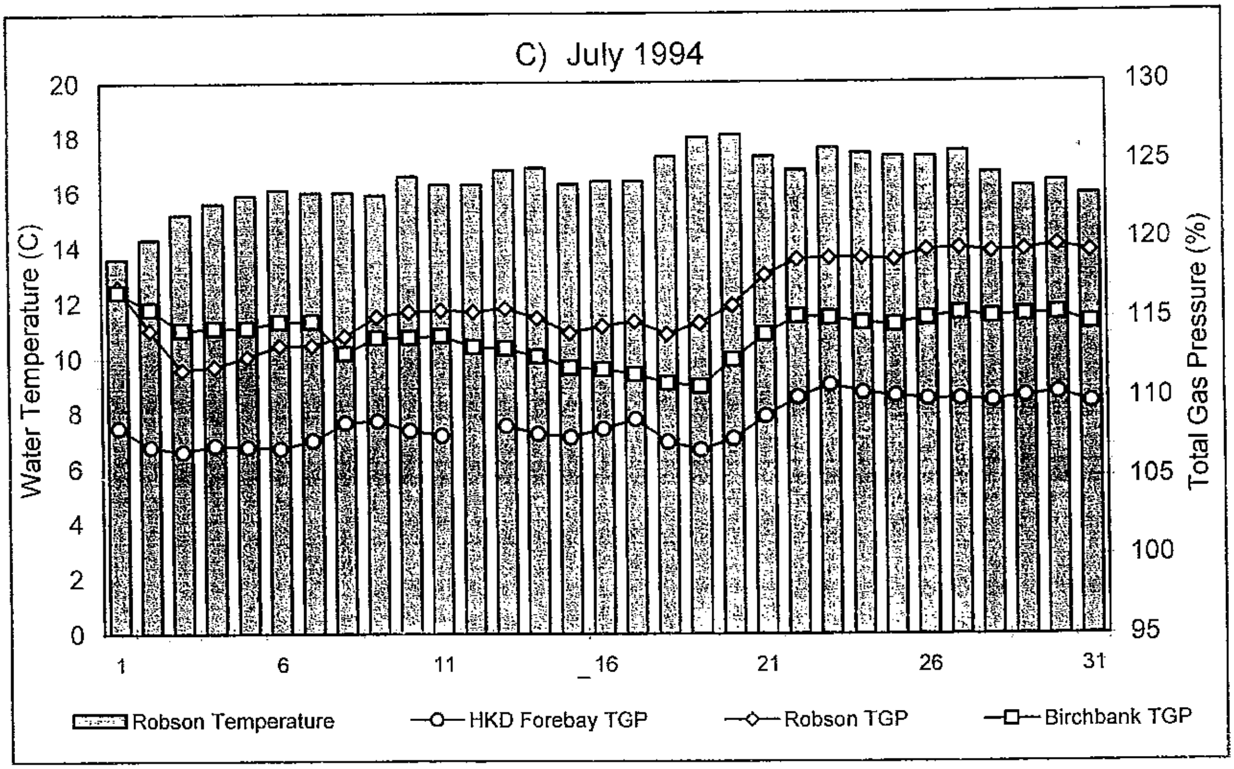


Figure 19: Continued.

General Discussion

A number of stress-related symptoms have been observed in fish captured below hydroelectric structures. These included thin and emaciated fish, mechanical damage, low liversomatic index (LSI), low gonadosomatic index (GSI), low condition factor, small stomach content volume (indicating lower feeding rates), low rate of circuli formation on the scales, and resorption of mature oocytes or non-spawning (Barnes *et al.* 1994). Barnes *et al.* (1984) also showed that variations in discharge from a hydroelectric control structure (with flow capacities ranging from 0 to 3400 m^3/sec) were correlated with liver somatic index, suggesting that stress increased with flow. They also showed that condition factor and GSI were not correlated with discharge. The sensitivity of LSI to environmental conditions was related to the use of the liver as the main lipid depot for Labrabor lake whitefish, rather than storage of fat in the body cavity.

The 1992 and 1994 studies showed no evidence of reduced LSI, GSI, condition factor or feeding in Columbia River mountain whitefish. In 1994, non-spawning and resorption of loose eggs was observed in a few fish sampled at the Genelle and Beaver Creek reach of the Columbia. In the 1991, 1992 and 1994 Columbia River studies it was not possible to correlate discharge with fish condition during any given study because discharge was relatively constant over the 8 to 10 days of field sampling. It might not be appropriate to correlate river conditions during a given sampling time with fish condition, as fish likely respond to water quality conditions encountered prior to as well as during a given sampling event. Low flows recorded during the July 1992 study are not representative because flows were lowered just prior to the study. The flow regulation data presented in this study are therefore for information purposes only.

CONCLUSIONS

Mountain whitefish sampled from the Genelle and Beaver Creek reaches of the Columbia River had significantly higher condition factors, growth (size-at-age), gonad weight, and gonadosomatic index (GSI) than similarly-aged fish of the same sex from the reference site, suggesting no adverse effects of effluent from the pulp mill or smelter on these variables. Liversomatic index (relative liver weight) was higher in female fish at Genelle; this effect has been associated with exposure to pulp mill effluent. The presence of loose eggs in the body cavity of several fish from Beaver Creek and Genelle might indicate non-spawning with resorption of eggs, possibly in response to stress. Increased feeding and condition factor observed in fish below the pulp mill from 1992 to 1994 might reflect increased availability of benthic prey items as a result of secondary treatment and 100% chlorine dioxide substitution for elemental chlorine in the bleaching process.

Mountain whitefish from the Genelle and Beaver Creek reaches of the Columbia River had consistently higher prevalence and severity of abnormalities when compared to the control site on the Slocan River. CDS, a rating which integrates the prevalence and severity of all abnormalities examined, was also significantly higher in fish from Genelle compared to the other two sites, and CDS in fish from Beaver Creek was significantly higher than that in fish from the reference site. This pattern of differences held even when the effect of natural aging on CDS was removed from the data. The disease survey results were similar to those from 1992, which found a higher incidence of stress-related abnormalities in fish from both Genelle and Beaver Creek, compared to fish from the same reference site on the Slocan River.

PCDD, PCDF and PCB concentrations were higher in fish from the two Columbia River sites than at the reference site, but all concentrations were below health hazard thresholds for human consumption. PCDD and PCDF concentrations declined substantially at the Columbia River sites compared with 1992 data, but these differences were not statistically significant due to high variability in dioxin concentrations. PCB concentrations have remained stable since the 1992 study. CDS could not be correlated with concentrations of organic contaminants or MFO activities.

Levels of two monooxygenase enzyme activities (EROD and AHH) in mountain whitefish sampled below the pulp mill on the Columbia River have declined since 1991, and were approaching levels similar to those found at the reference sites by 1994. This is indicative of a reduction of inducing materials present in the river over this time period. Although Genelle has statistically higher levels of enzyme activity than Beaver Creek, the levels at Genelle are similar to those at the Slocan River reference site, which is a major improvement over 1991.

Organochlorine concentrations were higher in fish from the two Columbia River sites than at the reference site, but all concentrations were below health hazard thresholds for human consumption. PCDD and PCDF concentrations declined substantially at the Columbia River sites compared with 1992 data, but these differences were not statistically significant due to high variability in dioxin concentrations. PCB concentrations have remained stable since the 1992 study. CDS could not be correlated with concentrations of organic contaminants or MFO activities.

Levels of two enzyme activities (EROD and AHH) in mountain whitefish sampled below the pulp mill on the Columbia River have declined since 1991, and were approaching levels similar to those found at the reference sites by 1994. This is indicative of a reduction of inducing materials present in the river over this time period. Although Genelle has statistically higher levels of enzyme activity than Beaver Creek, the levels at Genelle are similar to those at the Slocan River reference site which is a major improvement over 1991.

Although organochlorine residues and EROD and AHH activity for the most part correlated at the Genelle site, the size of the enzyme signal in all fish in 1994 was not as high as would be expected if the primary cause of induction was the widely known organochlorine inducers - PCDDs, PCDFs, and coplanar PCBs. The apparent induction seen in the 1994 samples at Genelle is consistent with more transient induction seen around non-bleaching mills, and organochlorines are probably a contributing factor rather than the exclusive cause.

Concentrations of metals in fish muscle tissue were generally highest at the reference site, followed by the Beaver Creek reach below the smelter and then the Genelle reach below the pulp mill. As in the 1992 study, all concentrations in muscle tissue remained low. Concentrations of metals in liver were typically highest at Beaver Creek (e.g., Cd, Cu, and Zn), followed by the Slocan River reference site and Genelle. Copper and cadmium increased in liver tissue in fish caught below the smelter between 1992 and 1994.

The very highly significant relationship between liver metals and metal-binding protein in Beaver Creek samples shown in the multiple regression analysis in the 1994 samples is similar to that found for the 1992 study, which would give support to the use of this statistical tool as a means of evaluating the impact of metals on a fish population. Unlike 1992, however, there was also a significant relationship shown for MBP and Cd in Slocan fish in 1994. This would support the possibility that there is some unidentified source of Cd near this site.

Metallothionein levels in Columbia River and Slocan whitefish livers declined significantly in 1994 over 1992. This has generally been taken as an indication of reduced metal (Cd, Cu, Zn) intake. However, that this decline was also observed in the reference samples tends to obfuscate the picture. It is conceivable that an unknown (natural or anthropogenic) source of one or more of these elements exists on the Slocan and that recent decreases reflect downward inputs.

The first two sampling phases of this study document a decline in PCDDs and PCDFs in muscle tissue and hepatic MFO activities in Columbia River mountain whitefish following secondary treatment and 100% chlorine dioxide substitution for elemental chlorine in the bleaching process. The consistently higher mean severity of abnormalities and CDS in Columbia River fish compared to fish from the reference site might indicate a decreased quality of environment. However, abnormalities commonly associated with exposure to pulp mill effluent or metal contamination (e.g., external lesions, severe liver and kidney abnormalities, fin erosion) were observed at low levels in fish sampled from the Genelle and Beaver Creek reaches of the Columbia River. Several abnormalities appeared to be stress-related. CDS was also not correlated with organic contaminant concentration or MFO activity, but incidence and severity of liver and kidney abnormalities decreased significantly between 1992 and 1994, as did levels of dioxins and MFO activity.

CDS did not differ significantly between 1992 and 1994 at any sampling location. However, the prevalence of liver and kidney abnormalities decreased between the 1992 and 1994 studies. Liver and kidney may be target organs for various abnormalities related to contaminants. The prevalence and severity of other abnormalities (e.g., hemorrhaging at the base of the fins, severity of external and gill abnormalities, prevalence of gill parasitism combined with significant levels of inflammatory activity), increased significantly at all reaches between 1992 and 1994. These types of abnormalities may be more indicative of overall stress or sampling conditions, rather than exposure to contaminants. Results suggest that the CDS rating likely reflects the cumulative effect of all stressors on the system, including effluent discharge from the pulp mill and smelter, and flow regulation.

These findings also indicate that although Columbia River fish appear to be stressed, the stressors have not resulted in reduced growth, condition factor, or relative gonad size. Further research is required to determine whether stress from flow regulation or other sources can effect non-spawning and resorption of mature oocytes. The final July 1996 sampling phase may further the interpretation of these data.

RECOMMENDATIONS

GENERAL RECOMMENDATIONS

1. The effect of flow regulation and other stressors on the health of Columbia River mountain whitefish, including non-spawning and resorption of mature oocytes, should be examined.

2. Other substances that may elicit EROD induction, such as resin acid metabolites or retene-like substances, should be examined.

RECOMMENDATIONS FOR FISH HEALTH ASSESSMENT

1. Age distributions among sampling locations should be similar to minimize confounding effects of age on fish health, since older fish tend to have a higher natural incidence of abnormalities and disease. In the Columbia River study, fork length was a poor predictor of age, and hence large sample sizes were required to obtain similar age distributions among sampling locations.

2. Changes in individual tissues or organs should be examined in addition to overall indicators such as Cumulative Disease Severity (CDS) or the Health Assessment Index (HAI), as single number indices can mask spatial and temporal changes in individual tissues or organs. In the Columbia River assessment, CDS did not change significantly between the 1992 and 1994 study, however, the prevalence and severity of liver and kidney abnormalities decreased significantly during this time period, as did concentrations of PCDD/PCDF in muscle tissue and MFO activity in liver tissue.

3. Normal or Baseline rates of disease and abnormalities, including natural variability, must be determined for interpretation of fish health assessment results.

4. Practitioners should develop and use consistent terminology when conducting fish health assessments to avoid bias.

5. A tiered fish health assessment should be considered, where applicable, by conducting gross external and internal examination in the field with preservation of tissue for future histopathological analyses.

6. The autopsy-based fish health assessment approach presented in this paper can provide a useful screening tool for evaluating the cumulative effect of all stressors on fish health. In the case of the Columbia River Study, the technique provided useful information in addition to that gained from conventional assessment of growth, reproduction (e.g., fecundity, age-at-maturity, relative gonad size), and energy storage (condition factor, liver size). In general, the application of the technique should be evaluated on a site-specific basis.

   Further research is required to evaluate whether fish health assessment can provide a diagnostic tool for monitoring environmental effects of major industrial developments, such as pulp and paper mill effluent, mining effluent, and hydro facilities. Fish health assessment methods must focus on key variables, and these variables may differ depending on the purpose of the monitoring program.

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Appendix 1. Biological characteristics of mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
1	Slocan	7	f	270	29.3	239.4	24	3.6	2	1.3	0.7	0
2	Slocan	11	m	384	32.3	332	23	2	3.4	0.5	0.9	2
3	Slocan	11	m	390	32.2	352	18	5	3.1	1.3	0.8	0
4	Slocan	6	f	234	27	203	19	5.5	3.4	2.4	1.5	4
5	Slocan	6	f	286	29.5	253	20	7.7	4.8	2.7	1.7	0
6	Slocan	12	f	530	35	455	33	26	4.5	4.9	0.8	2
7	Slocan	11	f	800	43.2	700	55	19	7.5	2.4	0.9	3
8	Slocan	18	f	1386	46.1	1097	190	40	14	2.9	1.0	-
9	Slocan	10	f	540	35.8	445	65	9	5	1.7	0.9	0
10	Slocan	10	m	450	34.2	363	44	4	5	0.9	1.1	1
11	Slocan	13	m	284	29.2	257	25	6	5	2.1	1.8	-
12	Slocan	6	f	390	32.9	337	37	5	5.2	1.3	1.3	2
13	Slocan	11	f	294	28.8	260	20	6	4	2.0	1.4	-
14	Slocan	8	m	283	29.5	256	18	3	3	1.1	1.1	-
15	Slocan	5	f	270	29	249	19	7	5	2.6	1.9	2
16	Slocan	7	m	235	27	209	24	4	5	1.7	2.1	3
17	Slocan	9	f	260	27.8	225	24	7	5	2.7	1.9	3
18	Slocan	9	f	473	34.8	408	45	8	6	1.7	1.3	2
19	Slocan	5	f	325	31.2	287	26	3	4	0.9	1.2	0
20	Slocan	8	m	596	38.8	522	54	3	8	0.5	1.3	4
21	Slocan	6	m	250	28.1	223	23	1	8	0.4	3.2	4
22	Slocan	7	f	248	27.5	222	13	5	2.1	2.0	0.8	3
23	Slocan	9	m	320	30.5	286	25	9	7	2.8	2.2	3
24	Slocan	9	f	374	30.9	309	40	4.5	3.5	1.2	0.9	2
25	Slocan	4	f	143	23	124	10	2.5	1.5	1.7	1.0	1
26	Slocan	14	m	444	33.2	372	61	2.5	4.5	0.6	1.0	3
27	Slocan	9	f	422	33	379	32	11.5	3.3	2.7	0.8	3
28	Slocan	5	f	150	25.1	130	10	2	1.2	1.3	0.8	1

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
29	Slocan	8	m	260	28.7	234	13.1	1.5	1	0.6	0.4	0
30	Slocan	7	m	308	30.1	270	18	3.5	2	1.1	0.6	0
31	Slocan	9	m	346	31.1	303	26	1.2	2.9	0.3	0.8	1
32	Slocan	6	f	239	28	219	16	3.5	1.5	0.5	0.6	0
33	Slocan	7	f	437	33.3	360	55	6.5	6.5	1.5	1.5	3
34	Slocan	7	f	302	30.2	276	12.2	6.5	1.7	2.2	0.6	0
35	Slocan	7	f	242	27.3	216	12	6.1	1.6	2.5	0.7	-
36	Slocan	4	f	230	26.8	201	12	5.5	2.1	2.4	0.9	3
37	Slocan	6	f	195	26.3	178	12	3.	1.8	1.5	0.9	1
38	Slocan	4	m	218	25.4	189	12.1	0.4	1.3	0.2	0.6	5
39	Slocan	7	m	348	31.5	303	27.8	0.8	2.6	0.2	0.7	1
40	Slocan	7	f	228	26.7	202	13.7	1.2	1.7	0.5	0.7	1
41	Slocan	9	m	383	30	266	18.2	1.83	2.5	0.5	0.7	-
42	Slocan	6	f	339	31	296.0	24.8	3.9	3.4	1.2	1.0	0
43	Slocan	4	m	188	25.1	168.0	10.3	3.1	1.1	1.6	0.6	0
44	Slocan	4	f	205	25.4	174	13.7	3.5	1.9	1.7	0.9	0
45	Slocan	5	m	239	27.5	209	15.8	0.5	1.3	0.2	0.5	1
46	Slocan	20	f	1291	48.2	1096	129.5	24.8	12.1	1.9	0.9	13
47	Slocan	5	f	197	26	177	12.7	2.2	1.4	1.1	0.7	3
48	Slocan	7	f	449	33.4	378	26.2	5.8	3.1	1.3	0.7	0
49	Slocan	8	m	428	34.3	417	35.5	3.3	3.1	0.8	0.7	2
50	Slocan	6	f	315	30.6	297	19.7	7.6	3.1	2.4	1.0	0
51	Slocan	6	m	287	29.2	259	17.7	0.8	2.2	0.3	0.8	-
52	Slocan	9	f	359	31.5	289	44	7.5	3.1	2.1	0.9	-
53	Slocan	5	f	270	28.8	246	17.1	3	1.7	1.1	0.6	5
54	Slocan	13	m	631	37.4	519	87	5.1	6	0.8	1.0	1
55	Slocan	6	f	203	27.3	188	8.5	2.9	1.2	1.4	0.6	2
56	Slocan	9	f	315	30	285	21.8	9.2	3.4	2.9	1.1	1

57	Slocan	8	m	336	30.3	301	23.7	4.6	2.7	1.4	0.8	2

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
58	Slocan	8	f	338	29.5	281	19.2	6.3	2.9	1.9	0.9	2
59	Slocan	9	f	299	30.5	257	22.3	4.9	2.1	1.6	0.7	5
60	Slocan	8	?	333	31.6	292	21.7	6.5	3.7	2.0	1.1	1
61	Slocan	11	f	421	33.5	369	33.3	8.1	4.1	1.9	1.0	3
62	Slocan	7	m	324	31.5	318	20	1.7	2.2	0.5	0.7	0
63	Slocan	8	f	298	29.5	257.0	19.5	7.9	2.9	2.7	1.0	3
64	Slocan	13	f	759	41.5	670	63.3	20.3	7.7	2.7	1.0	-
65	Slocan	10	m	385	32	354	27.4	1.1	2.5	0.3	0.6	0
66	Slocan	7	m	290	28.9	251	19.8	4.4	2.2	1.5	0.8	0
67	Slocan	8	m	255	29.7	238	11.9	0.5	1.6	0.2	0.6	2
68	Slocan	13	m	290	32	260	15.7	0.7	1.8	0.2	0.6	-
69	Slocan	9	m	520	34.5	469	24.5	1.8	3.7	0.3	0.7	3
70	Slocan	6	f	243	27.5	216	17.1	4.9	2.1	2.0	0.9	2
71	Slocan	6	f	210	24.9	186	12.8	3.6	1.8	1.7	0.9	1
72	Slocan	9	f	217	26.4	190	13.3	3.8	1.6	1.8	0.7	1
73	Slocan	11	m	518	34.6	499	37	0.7	3.2	0.1	0.6	0
74	Slocan	8	--	--	27.2	--	--	--	--	--	--	--
75	Slocan	8	--	--	33.1	--	--	--	--	--	--	--
76	Slocan	8	--	--	28.9	--	--	--	--	--	--	--
77	Slocan	8	--	--	31	--	--	--	--	--	--	--
78	Slocan	12	--	--	29.1	--	--	--	--	--	--	--
79	Slocan	7	--	--	27.4	--	--	--	--	--	--	--
80	Slocan	11	--	--	30.4	--	--	--	--	--	--	--
81	Slocan	7	--	--	26.6	--	--	--	--	--	--	--
82	Slocan	9	--	--	28.9	--	--	--	--	--	--	--
83	Slocan	6	--	--	25.4	--	--	--	--	--	--	--
100	Beaver Ck.	4	f	493	32.1	432	22.5	15.4	5	3.1	1.0	0
101	Beaver Ck.	5	m	608	34	515	25.1	40	4.3	6.6	0.7	3

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
102	Beaver Ck.	19	f	413	36.9	513	22.1	4.6	4.9	1.1	1.2	5
103	Beaver Ck.	7	f	876	35.7	545	25.6	19.7	5.7	2.2	0.7	5
104	Beaver Ck.	5	m	463	32.5	399	21.9	29.3	4.6	6.3	1.0	1
105	Beaver Ck.	5	m	363	30.8	321	19.1	0.5	2.4	0.1	0.7	0
106	Beaver Ck.	4	f	670	34.2	563	29.2	21.5	5.4	3.2	0.8	0
107	Beaver Ck.	2	f	263	27.4	238	10.6	4.7	2.2	1.8	0.8	1
108	Beaver Ck.	4	m	548	34.1	473	21.2	35.7	3.3	6.5	0.6	6
109	Beaver Ck.	7	f	597	33.5	585	21.4	23.4	6	3.9	1.0	3
110	Beaver Ck.	11	f	425	34.9	372	24.3	12.4	4	2.9	0.9	5
111	Beaver Ck.	16	m	889	41	810	39.4	9.7	6.1	1.1	0.7	3
112	Beaver Ck.	20	f	470	36.8	418	31	7.9	4.1	1.7	0.9	5
113	Beaver Ck.	5	m	408	32.1	376	15.2	3.2	2.7	0.8	0.7	4
114	Beaver Ck.	4	f	462	31	405	27	11.3	4.1	2.4	0.9	3
115	Beaver Ck.	12	f	396	34.4	359	23.6	6.3	3.8	1.6	1.0	3
116	Beaver Ck.	20	f	483	36.1	427	31.2	8.2	3.1	1.7	0.6	5
117	Beaver Ck.	11	f	687	37.6	596	38.9	19.6	8.6	2.9	1.3	0
118	Beaver Ck.	6	f	569	33.9	376	27.7	10.7	6.2	1.9	1.1	2
119	Beaver Ck.	16	m	489	35.8	400	24.2	1.1	3.6	0.2	0.7	6
120	Beaver Ck.	19	f	519	37.3	471	18.4	10.2	3.6	2.0	0.7	2
121	Beaver Ck.	3	m	400	30.6	348	17.9	12.9	3.6	3.2	0.9	3
122	Beaver Ck.	3	f	427	31.1	379	19	14.1	4.7	3.3	1.1	4
123	Beaver Ck.	5	m	428	32.4	378	16.4	20.8	3.2	4.9	0.7	3
124	Beaver Ck.	6	m	580	33.8	484	22.7	43.3	4.2	7.5	0.7	1
125	Beaver Ck.	3	f	444	31	385	22.6	9.4	4.4	2.1	1.0	1
126	Beaver Ck.	5	f	439	33	387	24.3	6.5	4.2	1.5	1.0	3
127	Beaver Ck.	9	f	564	36	513	27.2	10.6	5.1	1.9	0.9	3
128	Beaver Ck.	9	m	478	35.4	445	21.8	2.2	3.4	0.5	0.7	2
129	Beaver Ck.	5	f	460	34	413	22.2	8.5	5.1	1.8	1.1	2

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
130	Beaver Ck.	3	f	622	34.3	547	32.8	21.1	6.5	3.4	1.0	3
131	Beaver Ck.	15	f	546	36.8	489	29.9	13.6	4.8	2.5	0.9	2
132	Beaver Ck.	6	m	503	33.8	457	23	1.3	3.9	0.3	0.8	1
133	Beaver Ck.	5	f	664	34.7	594	28	19.1	6.4	2.9	1.0	2
134	Beaver Ck.	18	f	519	35.1	438	25.8	5.5	3.4	1.1	0.7	6
135	Beaver Ck.	8	f	567	35.1	476	27.1	12.6	5.1	2.2	0.9	0
136	Beaver Ck.	3	m	469	31.5	413	16.2	25.7	3.3	5.5	0.7	1
137	Beaver Ck.	14	f	468	35.1	425	25.8	8.7	4.4	1.9	0.9	4
138	Beaver Ck.	19	f	555	37.7	502	25.4	13.4	4.6	2.4	0.8	3
139	Beaver Ck.	2	f	308	27.6	265	21.4	2.3	2.3	0.7	0.7	3
140	Beaver Ck.	15	f	665	39.9	505	34.9	10	5.5	1.5	0.8	8
141	Beaver Ck.	10	f	575	36.6	505	38.1	17.4	6.1	3.0	1.1	1
142	Beaver Ck.	3	m	402	30.1	327	21.6	11.8	3.3	2.9	0.8	3
143	Beaver Ck.	3	m	300	29.4	273	17	3.9	2.1	1.3	0.7	4
144	Beaver Ck.	16	f	473	35.9	426	25.7	14.3	6.3	3.0	1.3	6
145	Beaver Ck.	5	f	713	33.5	557	22.6	13.2	6.2	1.9	0.9	4
146	Beaver Ck.	4	f	732	35.5	672	20	24.1	6.2	3.3	0.8	4
147	Beaver Ck.	19	f	948	42.9	884	37.5	21.8	8.1	2.3	0.9	4
148	Beaver Ck.	4	m	352	28.2	317	22	1.7	3.3	0.5	0.9	6
149	Beaver Ck.	5	f	437	32.6	386	23.5	11.8	4.3	2.7	1.0	3
150	Beaver Ck.	17	f	401	36.4	371	14.8	7.4	3	1.8	0.7	7
151	Beaver Ck.	8	f	492	34.7	544	28.4	10.3	4.4	2.1	0.9	1
152	Beaver Ck.	13	f	591	36.9	523	28.4	13.2	5.1	2.2	0.9	4
153	Beaver Ck.	5	m	584	34.9	498	25.7	42	6.2	7.2	1.1	3
154	Beaver Ck.	13	m	716	36.4	443	27	2.4	3.3	0.3	0.5	9
155	Beaver Ck.	14	m	405	36.8	375	18.9	2.6	3.3	0.6	0.8	5
156	Beaver Ck.	2	m	273	27.4	244	14.3	1.1	3.1	0.4	1.1	5
157	Beaver Ck.	9	m	518	33.7	451	32.6	6.5	4.8	1.3	0.9	3

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
158	Beaver Ck.	7	f	583	35.2	658	29.8	11.1	5.7	1.9	1.0	4
159	Beaver Ck.	12	m	448	34.6	404	29.1	0.7	4.3	0.2	1.0	2
160	Beaver Ck.	13	m	504	34.1	373	24.4	1.1	3.1	0.2	0.6	10
161	Beaver Ck.	10	f	780	38.2	747	32.5	26.1	6.7	3.3	0.9	4
162	Beaver Ck.	19	f	607	37.1	458	24.8	13.6	4.3	2.2	0.7	2
163	Beaver Ck.	15	m	399	35.1	359	26.5	2.3	3.8	0.6	1.0	4
164	Beaver Ck.	2	m	309	29.1	283	13.1	2.1	2.2	0.7	0.7	4
165	Beaver Ck.	7	f	476	34	428	24.1	10.9	4.7	2.3	1.0	2
166	Beaver Ck.	12	f	577	35.6	515	27.5	14.8	4.9	2.6	0.8	3
167	Beaver Ck.	9	f	693	35.4	603	31.4	34.3	8	4.9	1.2	3
168	Beaver Ck.	16	f	485	36.4	439	24.7	9.3	4.1	1.9	0.8	6
169	Beaver Ck.	14	f	584	37.5	525	29.2	16.8	5.1	2.9	0.9	2
170	Beaver Ck.	13	f	537	36.8	476	29.9	14.3	5.2	2.7	1.0	4
171	Beaver Ck.	16	f	420	36.3	377	25	5.6	3.6	1.3	0.9	6
172	Beaver Ck.	3	?	575	32.9	515	19.1	22.2	4.3	3.9	0.7	6
173	Beaver Ck.	8	?	716	36.9	--	--	--	--	--	--	--
174	Beaver Ck.	11	--	556	37	--	--	--	--	--	--	--
175	Beaver Ck.	15	--	633	36.7	--	--	--	--	--	--	--
176	Beaver Ck.	10	--	483	33.2	--	--	--	--	--	--	--
177	Beaver Ck.	4	--	691	33.8	--	--	--	--	--	--	--
178	Beaver Ck.	5	--	519	33.3	--	--	--	--	--	--	--
179	Beaver Ck.	10	--	452	34	--	--	--	--	--	--	--
180	Beaver Ck.	2	--	462	33.7	--	--	--	--	--	--	--
181	Beaver Ck.	10	--	568	36	--	--	--	--	--	--	--
182	Beaver Ck.	9	--	475	34.4	--	--	--	--	--	--	--
201	Genelle	7	m	702	36.1	613	17.4	58.3	4.3	8.3	0.6	1
202	Genelle	3	f	417	30.7	364	17.2	12.5	4.4	3.0	1.1	1
203	Genelle	3	m	308	29.9	274	16.4	4.5	2.2	1.5	0.7	3

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
204	Genelle	16	f	720	37.5	689	46.2	10.2	4.5	1.4	0.6	2
205	Genelle	3	m	339	28.7	298	21.3	3.7	3.5	1.1	1.0	7
206	Genelle	3	m	366	28.7	315	21.9	7.9	4.1	2.2	1.1	7
207	Genelle	5	m	511	33	446	19.3	26.7	3.1	5.2	0.6	9
208	Genelle	5	f	556	33.4	490	29.4	15.4	7.1	2.8	1.3	3
209	Genelle	5	m	621	32.9	534	18.6	47.8	4.1	7.7	0.7	2
210	Genelle	8	f	586	35	500	27.3	18.8	4.9	3.2	0.8	6
211	Genelle	4	f	537	33.1	475	26.8	10.4	5	1.9	0.9	7
212	Genelle	18	f	740	40.7	670	67.3	10.2	7	1.4	0.9	6
213	Genelle	3	f	301	28.6	265	18.8	2	2.1	0.7	0.7	3
214	Genelle	6	m	465	33.5	412	17.9	20.3	3	4.4	0.6	2
215	Genelle	18	m	441	35	390	18.3	6.3	2.4	1.4	0.5	7
216	Genelle	16	m	338	32.9	308	17.9	0.9	2.8	0.3	0.8	13
217	Genelle	20	m	411	34.5	377	19	2.8	4.9	0.7	1.2	9
218	Genelle	4	m	567	36.4	512	37	1.5	4.4	0.3	0.8	5
219	Genelle	17	m	431	34.9	390	26.6	1.3	2.5	0.3	0.6	4
220	Genelle	2	f	303	27.7	258	16	6.7	4	2.2	1.3	5
221	Genelle	4	f	421	31.7	368	17.1	10.4	4.4	2.5	1.0	4
222	Genelle	13	m	458	36.2	420	22.7	4.2	4.1	0.9	0.9	6
223	Genelle	4	f	440	32.1	390	15.1	14.5	4.7	3.3	1.1	4
224	Genelle	21	m	357	32.6	324	20.3	1.9	2.6	0.5	0.7	14
225	Genelle	4	f	359	29.4	320	15.3	4.7	2.1	1.3	0.6	5
226	Genelle	7	f	544	34.1	502	24.3	16.2	5.7	3.0	1.0	4
227	Genelle	4	m	362	30.2	320	19.7	5.5	4.3	1.5	1.2	4
228	Genelle	11	f	460	33.9	416	21.9	14.1	5.7	3.1	1.2	7
229	Genelle	12	f	502	35	450	27.8	12.8	5.3	2.5	1.1	1
230	Genelle	19	f	331	32.8	303	14.1	4.2	2.5	1.3	0.8	11
231	Genelle	4	f	562	34	507	21.3	12.7	5.8	2.3	1.0	0

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
232	Genelle	2	m	235	26	207	14	0.8	2.3	0.3	1.0	7
233	Genelle	2	m	236	26.4	215	10.5	1.4	2.1	0.6	0.9	1
234	Genelle	5	f	594	34.7	522	33.9	10.9	5.9	1.8	1.0	4
235	Genelle	4	m	505	32.7	439	18.9	20.6	3.8	4.1	0.8	5
236	Genelle	4	m	456	33.1	413	22.2	0.8	3.8	0.2	0.8	3
237	Genelle	5	f	522	33.2	469	20.5	18.4	4.8	3.5	0.9	6
238	Genelle	5	f	586	34.2	522	24.2	14.9	4.9	2.5	0.8	5
239	Genelle	7	f	557	33.3	494	25.6	18	5.3	3.2	1.0	5
240	Genelle	14	f	719	39.6	648	37.2	12.8	5.5	1.8	0.8	1
241	Genelle	14	m	598	36.6	545	26.3	2.5	5.8	0.4	1.0	7
242	Genelle	9	f	358	30.9	327	15.4	5.6	3.2	1.6	0.9	7
243	Genelle	4	m	367	28.7	308	12.7	33	2.7	9.0	0.7	4
244	Genelle	14	m	444	36.9	412	21.5	1.2	2.5	0.3	0.6	5
245	Genelle	3	f	375	29.7	321	26.6	6.9	3.1	1.8	0.8	3
246	Genelle	8	f	593	37	558	31.5	17.3	6.8	2.9	1.1	3
247	Genelle	12	f	743	41.8	662	38.6	23.7	7.9	3.2	1.1	7
248	Genelle	6	f	545	33.7	479	26.6	17.5	5	3.2	0.9	5
249	Genelle	15	m	500	37.2	471	16.4	2.3	3.4	0.5	.07	10
250	Genelle	5	f	477	33.5	429	21.5	12	5	2.5	1.0	5
251	Genelle	3	m	260	28.4	245	8	0.4	2.6	0.2	1.0	2
252	Genelle	2	f	258	27	227	20.7	0.1	3.8	0	1.5	4
253	Genelle	2	f	341	28.7	301	17.8	6	3.6	1.8	1.1	3
254	Genelle	3	m	418	31.7	381	16	8.5	2.1	2.0	0.5	1
255	Genelle	7	f	918	36.2	816	41.5	26.4	8.1	2.9	0.9	3
256	Genelle	12	m	390	35.1	363	17.4	3.1	3.8	0.8	1.0	-
257	Genelle	5	f	489	32.4	425	26.3	19	6.4	3.9	1.3	-
258	Genelle	8	f	612	35.1	531	31.5	29	6.7	4.7	1.1	1
259	Genelle	12	f	583	38.3	506	49.8	9.8	5	1.7	0.9	10

Appendix 1 continued.

Fish #	Location	Age (y)	Sex	Wet Weight (g)	Fork Length (cm)	Gutted Weight (g)	Stomach Weight (g)	Gonad Weight (g)	Liver Weight (g)	GSI	LSI	CDS
260	Genelle	5	m	543	34.4	481	29.1	17.6	6.3	3.2	1.2	2
261	Genelle	4	f	400	32	362	13	13.3	4.7	3.3	1.2	4
262	Genelle	10	f	550	38.6	481	34	10.8	8.1	2.0	1.5	3
263	Genelle	7	m	543	32.8	485	27.9	25.7	5.6	4.7	1.0	1
264	Genelle	3	f	244	26	216	14.6	2.5	3.9	1.0	1.6	4
265	Genelle	5	m	421	31	359	17.5	34.5	5.1	8.2	1.2	2
266	Genelle	2	f	252	27.2	222	15.9	2.5	4.3	1.1	1.7	5
267	Genelle	18	f	526	37.6	468	36	10	6.5	1.9	1.2	8
268	Genelle	13	f	619	35.9	535	46	23.3	9.6	3.8	1.6	5
269	Genelle	12	f	753	39.2	642	69.1	17	9.9	2.3	1.3	4
270	Genelle	20	--	637	41.4	--	--	--	--	--	--	--
271	Genelle	15	--	630	39.2	--	--	--	--	--	--	--
272	Genelle	15	--	1046	43.3	--	--	--	--	--	--	--
273	Genelle	20	--	660	42.3	--	--	--	--	--	--	--
274	Genelle	5	--	490	32.6	--	--	--	--	--	--	--
275	Genelle	6	--	538	34.6	--	--	--	--	--	--	--
276	Genelle	9	--	725	38.6	--	--	--	--	--	--	--
277	Genelle	15	--	798	41.1	--	--	--	--	--	--	--
278	Genelle	20	--	706	40.8	--	--	--	--	--	--	--
279	Genelle	13	--	772	43.1	--	--	--	--	--	--	--
280	Genelle	20	f	770	43.2	681.0	53.0	17.7	7.3	2.3	0.9	3

Notes. "--" or "- " inicates not determined

Appendix 2A. Number and types of prey organisms found in mountain whitefish stomachs sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Prey	BEAVER	GENELLE	SLOCAN
Eurycercus		5	
HYDRACARINA	1		2
ARANAEA			2
INSECTA (remains)			
DIPTERA			5
CHIRONOMIDAE	22	19	3
Chironominae		2	
Orthocladiinae	52	127	80
Eukiefferiella		2	
Tanypodinae			2
ATHERICIDAE			1
TIPULIDAE			9
SIMULIDAE	1	3	9
Simulium	3	15	
Prosimulium			1
HYMENOPTERA		1	1
Formicidae			6
Ichneumonidae			1
Chalcoidea		1	
Apidae			2
HEMIPTERA	4	1	5
Corixidae		2	1
COLEOPTERA		1	4
Staphylinidae			1
Curculionidae			1
Haliplus			4
Elmidae			1
Cerambycidae			1
EPHEMEROPTERA			2
Baetis sp.	5	22	1
Baetis tricaudatus	2	12	13
Heptageneiidae			1
Epeorus longimanus			2
Cinygmula	1		1
Ephemerella sp.	4	3	
Ephemerella inermis	320	112	95
Ephemerella grandis	323	164	299
Ephemerella hysterix	30	16	5
Ephemerella doddsi	1		7
PLECOPTERA	1	1	23
Skwala			11
Hesperoperla			1
Petronarcys			1
TRICHOPTERA	2	12	94
Limnephilidae	60	4	231
Apatania			4
Dicomoecus		2	53
Onocosmoecus			17
Neophylax			2
Hydropsychidae	620	846	576
Hydropsyche	2085	2279	540
Hydroptilidae		5	
Hydroptila		5	4
Glossosoma	4	5	117
Ceraclea	1	2	
Oecetis			18
Brachycentrus americana			364
Brachycentrus occidentalis	99	344	
Rhyacophila			12
Psychomyia	12	1	
PLANORBIDAE		3	1
Sphaeriidae	1		
TELEOSTEI	1		1
COTTIDAE	1		6
FISH SCALE			
PEBBLES			
CASE MATERIALS			
MUCUS			
TOTAL	3656	4017	2644

Appendix 2B. Numbers of prey items, sorted by origin and prey group, found in mountain whitefish stomachs sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Origin/Prey Group	BEAVER Total	BEAVER Average Per Fish	GENELLE Total	GENELLE Average Per Fish	SLOCAN Total	SLOCAN Average Per Fish
Benthic Origin						
TRICHOPTERA	2828	80.80	3453	98.66	1892	54.06
EPHEMEROPTERA	686	19.60	329	9.40	425	12.14
PLECOPTERA	1	0.03	1	0.03	35	1.00
COTTIDAE	1	0.03			6	0.17
TELEOSTEI	1	0.03			1	0.03
TIPULIDAE					9	0.26
COLEOPTERA					4	0.11
CHIRONOMIDAE	74	2.11	150	4.29	85	2.43
SIMULIDAE	4	0.11	18	0.51	10	0.29
MOLLUSCA	1	0.03	3	0.09	1	0.03
ARACHNIDA	1	0.03			2	0.06
HEMIPTERA	1	0.03				
TOTAL BENTHIC	3598	102.80	3954	112.97	2470	70.57
Drift Origin						
TRICOPTERA	55	1.57	52	1.49	140	4.00
HYMENOPTERA			2	0.06	10	0.29
PLECOPTERA					1	0.03
COLEOPTERA					6	0.17
HEMIPTERA	3	0.09			4	0.11
DIPTERA					5	0.14
ARACHNIDA					2	0.06
EPHEMEROPTERA					1	0.03
ATHERICIDAE					1	0.03
TOTAL DRIFT	58	1.66	54	1.54	170	4.86
Water Column Origin						
COLEOPTERA			1	0.03	2	0.06
HEMIPTERA			3	0.09	2	0.06
CLADOCERA			5	0.14		
TOTAL WATER COLUMN			9	0.26	4	0.11
ALL TYPES	3656	104.46	4017	114.77	2644	75.54

Appendix 3. Abnormality rating, number of abnormalities, and cumulative disease severity (CDS) for mountain whitefish sampled from two reaches within the Columbia River and a reference site within the Slocan River, July 1994.

Organ Examined	Abnormality	Abnormality Rating 0 = normal 1 = light 2 = moderate 3 = severe	Number of Abnormalities		
			Slocan (n=63)	Genelle (n=68)	Beaver (n=73)
External:	1. thin	2	0	11	19
	2. pale gills	2	8	14	9
	3. fungus on gills	2	3	0	0
	4. external fungus	1	2	0	0
	5. mechanical damage	1	6	11	4
	6. deformed	1	0	4	4
	7. fin erosion	1	0	0	2
	8. hemorrhagic spot at fins	2	8	16	3
	9. hemorrhagic spot on belly	2	0	2	0
	10. hemorrhagic spot on operculum	2	1	0	0
	11. external lesion	1	0	1	2
	12. external parasite	1	1	0	0
	13. other	1	0	1	2
		Total:	29	60	45
		CDS[a]:	49	103	76
Internal:	1. enlarged spleen	2	2	7	6
	2. enlarged kidney	2	1	1	1
	3. parasite lesion/cyst	1	3	9	5
	4. adhesions	1	0	0	4
	5. pale liver	1	1	2	1
	6. grey liver	1	0	2	0
	7. dark liver	1	0	10	6
	8. discoloured liver	1	0	2	9
	9. discoloured spleen	1	1	2	1
	10. pale spleen	1	0	3	1
	11. nodules in spleen	1	2	0	1
	12. nodules in kidney	2	0	1	0
	13. cyst in spleen	1	2	0	0
	14. cyst in liver	1	1	2	4
	15. other	1	0	0	2

Appendix 3. Continued.

Organ Examined	Abnormality	Abnormality Rating	Number of Abnormalities		
			Slocan (n=63)	Genelle (n=68)	Beaver (n=73)
		Total:	13	41	41
		CDS:	16	50	48
Gill:	1. aneurysm	1	11	6	7
	2. helminth	1	15	41	38
	3. inflammatory activity	2	1	38	30
	4. tumour	3	1	0	0
		Total:	28	85	75
		CDS:	31	123	105
Liver:	1. melanosis	2	0	1	0
	2. helminth	1	0	7	0
	3. hemorrhagic area	2	1	0	0
	4. granulomas	2	0	1	0
	5. fatty infiltration	1	0	1	0
	6. inflammatory activity	2	0	3	0
	7. lesion of unknown etiology - small	1	1	6	4
	8. lesion of unknown etiology - large	1	0	1	0
		Total:	2	20	4
		CDS:	3	25	4
Spleen:	1. melanosis	2	0	1	0
	2. sequestered organ parts	0	0	0	1
		Total:	0	1	1
		CDS:	0	2	0
Kidney:	1. granulomas	2	0	1	0
	2. lesion of unknown etiology - small	1	0	1	0
		Total:	0	2	0
		CDS:	0	3	0
P.C./Pancreas/ Gut:	1. helminth	1	0	2	5
		Total:	0	2	5
		CDS:	0	2	5
Other:	1. tumour	3	1	0	1
	2. attachment point	1	1	0	0
	3. abnormal gonad	1	0	1	3

Appendix 3. Continued.

Organ Examined	Abnormality	Abnormality Rating	Number of Abnormalities		
			Slocan (n=63)	Genelle (n=68)	Beaver (n=73)
		Total:	2	1	4
		CDS:	4	1	6
Myxobacteria[b]:	0. no bacteria	0	69	67	71
	1. long thin gram-negative rods	2	4	3	2
		Total:	4	3	2
		CDS:	8	6	4
Other bacteria[b]:	0. no growth	0	72	69	73
	1. BKD bacteria[c]	2	1	1	0
Other bacteria cont.		Total:	1	1	0
		CDS:	2	2	0
Mycobacteria[b]:	0. no bacteria	0	72	69	72
	1. acid-fast or growth	3	1	1	1
		Total:	1	1	1
		CDS:	3	3	3

Notes: a: CDS = cumulative disease severity
b: n = 73 (Slocan), n = 70 (Genelle), n = 73 (Beaver Creek)
c: *Renibacterium salmoninarum*

Appendix 4A. Dibenzodioxin and dibenzofuran concentrations in the muscle tissue of mountain whitefish collected from the Slocan River reference site, July 1994.

Sample	S01	S02	S03	S04	S06A	S06B	S09	S11	S12	S48	S49
Lipid (%)	3.8	7.0	5.0	4.6	4.6	4.6	5.1	3.3	4.7	5.4	5.0
2,3,7,8-TCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,7,8-PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,4,7,8-HxCDD	<0.2	<0.3	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,6,7,8-HxCDD	<0.2	<0.3	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,7,8,9-HxCDD	<0.2	<0.3	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,4,6,7,8-HpCDD	<0.2	<0.5	<0.2	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
OCDD	<0.3	<0.5	<0.4	<0.3	<0.6	<0.6	<0.7	<0.2	<0.2	<0.2	<0.2
2,3,7,8-TCDF	0.2	0.6	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.3
1,2,3,7,8-PCDF	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
2,3,4,7,8-PCDF	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1,2,3,4,7,8-HxCDF	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
1,2,3,6,7,8-HxCDF	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
2,3,4,6,7,8-HxCDF	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
1,2,3,7,8,9-HxCDF	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
1,2,3,4,6,7,8-HpCDF	<0.2	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
1,2,3,4,7,8,9-HpCDF	<0.2	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
OCDF	<0.2	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total TCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total HxCDD	<0.2	<0.3	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total HpCDD	<0.2	<0.5	<0.2	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total TCDF	0.2	0.9	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3
Total PCDF	<0.1	<0.2	<0.1	0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total HCDF	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1
Total HCDF	<0.2	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
TEQ (N.D. = D.L.)	0.372	0.546	0.352	0.342	0.373	0.342	0.312	0.301	0.351	0.301	0.311
TEQ (ENV. CAN.)	0.020	0.060	0.030	0.020	0.020	0.020	0.030	0.020	0.030	0.020	0.030
TEQ (B.C. MIN.)	0.196	0.303	0.191	0.181	0.196	0.181	0.171	0.161	0.191	0.161	0.171
AGE	7	11	11	6	12	12	10	13	6	7	8

N.D.=D.L. means nondetected values replaced by the detection limit

Appendix 4A. Dibenzodioxin and dibenzofuran concentrations in the muscle tissue of mountain whitefish collected from the Beaver Creek reach of the Columbia River, July1994.

Sample	T100	T102	T103A	T103B	T106	T108A	T108B	T109	T111	T112	T113	T115
Lipid (%)	5.2	1.7	7.2	7.2	6.2	8.2	8.2	10.4	4.7	6.0	5.8	1.7
2,3,7,8-TCDD	0.2	<0.1	0.8	0.8	0.5	1.7	1.9	1.7	1.4	3.8	0.8	1.0
1,2,3,7,8-PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
1,2,3,4,7,8-HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.1	<0.1
1,2,3,6,7,8-HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.1	<0.1
1,2,3,7,8,9-HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.1	<0.1
1,2,3,4,6,7,8-HpCDD	<0.2	<0.2	<0.2	<0.3	<0.2	<0.2	<0.4	<0.2	<0.2	<0.3	<0.2	<0.2
OCDD	<0.4	<0.2	<0.2	<0.4	<0.2	<0.3	<1.0	<0.3	<0.4	<0.4	<0.4	<0.2
2,3,7,8-TCDF	4.2	1.5	25.0	27.0	23.0	66.0	74.0	86.0	14.0	49.0	37.0	18.0
1,2,3,7,8-PCDF	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.3	0.4	<0.1	<0.2	0.2	<0.1
2,3,4,7,8-PCDF	<0.1	<0.1	0.2	0.2	<0.1	0.5	0.6	0.8	0.2	0.6	0.3	0.2
1,2,3,4,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.3	<0.4	<0.2	<0.1	<0.2	<0.2	<0.1
1,2,3,6,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.3	<0.4	<0.2	<0.1	<0.2	<0.2	<0.1
2,3,4,6,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.3	<0.4	<0.2	<0.1	<0.2	<0.2	<0.1
1,2,3,7,8,9-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.3	<0.4	<0.2	<0.1	<0.2	<0.2	<0.1
1,2,3,4,6,7,8-HpCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3	<0.5	<0.2	<0.2	<0.2	<0.4	<0.2
1,2,3,4,7,8,9-HpCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3	<0.5	<0.2	<0.2	<0.2	<0.4	<0.2
OCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3	<0.5	<0.2	<0.2	<0.2	<0.4	<0.2
Total TCDD	0.2	<0.1	0.8	0.8	0.6	1.7	1.9	1.8	1.4	3.8	0.8	1.0
Total PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1
Total HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.4	<0.2	<0.2	<0.2	<0.1	<0.1
Total HpCDD	<0.2	<0.2	<0.2	<0.3	<0.2	<0.2	<0.4	<0.2	<0.2	<0.3	<0.2	<0.2
Total TCDF	4.2	1.5	25.0	27.0	23.0	66.0	74.0	86.0	14.0	49.0	37.0	18.0
Total PCDF	<0.1	0.1	0.4	0.5	0.5	0.8	1.8	2.0	0.2	0.6	0.7	0.2
Total HCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.3	0.8	<0.2	<0.1	<0.2	<0.2	<0.1
Total HCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3	0.5	<0.2	<0.2	<0.2	<0.4	<0.2
TEQ (N.D. = D.L.)	0.802	0.431	3.531	3.803	3.051	8.804	9.961	10.917	3.062	9.258	4.831	3.031
TEQ (ENV. CAN.)	0.620	0.150	3.400	3.600	2.800	8.565	9.615	10.720	2.900	9.000	4.660	2.900
TEQ (B.C. MIN.)	0.711	0.291	3.466	3.701	2.926	8.684	9.788	10.818	2.981	9.129	4.745	2.966
AGE	4	19	7	7	4	4	4	7	16	20	5	12

N.D.=D.L. means nondetected values replaced by the detection limit

Appendix 4A. Dibenzodioxin and dibenzofuran concentrations in the muscle tissue of mountain whitefish collected from the Genelle reach of the Columbia River, July 1994.

Sample	G201	G202A	G202B	G203	G204	G207	G210	G212	G213	G214	G215
Lipid (%)	6.2	7.2	7.2	6.7	4.1	7.5	7.2	4.1	4.0	4.7	3.8
2,3,7,8-TCDD	0.5	0.1	0.1	<0.1	5.6	0.3	1.1	1.6	<0.1	1.2	12.0
1,2,3,7,8-PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4
1,2,3,4,7,8-HxCDD	<).2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	<0.2
1,2,3,6,7,8-HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	0.7
1,2,3,7,8,9-HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	<0.2
1,2,3,4,6,7,8-HpCDD	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3
OCDD	<0.3	<0.2	<0.2	<0.3	<0.2	<0.3	<0.2	<0.2	<0.2	<0.2	<0.4
2,3,7,8-TCDF	14.0	1.8	1.6	1.2	84.0	4.5	23.0	6.1	0.7	37.0	71.0
1,2,3,7,8-PCDF	<0.1	<0.1	<0.1	<0.1	0.3	0.1	0.1	<0.1	<0.1	0.2	0.6
2,3,4,7,8-PCDF	<0.1	<0.1	<0.1	<0.1	1.0	0.2	0.3	0.2	<0.1	0.3	2.0
1,2,3,4,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
1,2,3,6,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
2,3,4,6,7,8-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
1,2,3,7,8,9-HxCDF	<0.1	<0.1	<0.1	<0.2	<0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
1,2,3,4,6,7,8-HpCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3
1,2,3,4,7,8,9-HpCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3
OCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.4
Total TCDD	0.6	0.2	0.2	0.2	5.6	0.3	1.2	1.6	<0.1	1.2	12.0
Total PCDD	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.4
Total HxCDD	<0.2	<0.1	<0.1	<0.2	<0.2	<0.2	<0.1	<0.1	<0.1	<0.2	0.7
Total HpCDD	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3
Total TCDF	14.0	2.3	1.8	1.5	85.0	4.8	23.0	6.1	0.7	37.0	72.0
Total PCDF	0.4	0.3	0.4	0.5	1.7	0.9	0.6	0.2	0.1	0.8	2.7
Total HCDF	<0.1	<0.1	<0.1	<0.2	0.2	<0.2	<0.2	<0.1	<0.1	<0.2	<0.2
Total HCDF	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.3
TEQ (N.D. = D.L.)	2.112	0.461	0.441	0.472	14.711	1.052	3.721	2.441	0.351	5.256	20.530
TEQ (ENV. CAN.)	1.900	0.280	0.260	0.120	14.515	0.855	3.555	2.310	0.070	5.060	20.400
TEQ (B.C. MIN.)	2.006	0.371	0.351	0.296	14.613	0.953	3.638	2.376	0.211	5.158	20.465
AGE	7	3	3	3	16	5	8	18	3	6	18

N.D.=D.L. means nondetected values replaced by the detection limit

Appendix 4B. Comparison of Dioxin/Furan Concentrations (pg/g) Measured by AXYS and IOS Laboratories, July 1994.

DFO SAMPLE ID:	CR94T103			CR94T112		CR94G201		CR94G212		CR94G214	
LAB:	AXYS	AXYS	IOSD	AXYS	IOSD	AXYS	IOSD	AXYS	IOSD	AXYS	IOSD
2,3,7,8-TCDD	0.8	0.8	0.93	3.8	4.73	0.5	0.56	1.6	1.63	1.2	1.21
Total TCDD	0.8	0.8	1.03	3.8	4.82	0.6	0.64	1.6	1.71	1.2	1.21
1,2,3,7,8-PCDD	<0.1	<0.1	0.12	<0.2	0.14	<0.1	0.08	<0.1	<0.08	<0.1	0.11
Total PCDD	<0.1	<0.1	0.12	<0.2	0.14	<0.1	0.08	<0.1	<0.08	<0.1	0.11
1,2,3,4,7,8-HxCDD	<0.1	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.1	<0.10	<0.2	<0.10
1,2,3,6,7,8-HxCDD	<0.1	<0.2	0.22	<0.2	0.28	<0.2	0.22	<0.1	0.19	<0.2	0.22
1,2,3,7,8,9-HxCDD	<0.1	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.1	<0.10	<0.2	<0.10
Total HxCDD	<0.1	<0.2	0.22	<0.2	0.28	<0.2	0.22	<0.1	0.19	<0.2	0.22
1,2,3,4,6,7,8-HpCDD	<0.2	<0.3	<0.12	<0.3	<0.12	<0.2	0.14	<0.2	<0.12	<0.2	<0.12
Total HpCDD	<0.2	<0.3	<0.12	<0.3	<0.12	<0.2	0.14	<0.2	<0.12	<0.2	<0.12
Total OCDD	<0.2	<0.4	0.42	<0.4	<0.14	<0.3	0.43	<0.2	0.48	<0.2	0.50
2,3,7,8-TCDF	25.0	27.0	30.62	49.0	72.00	14.0	16.43	6.1	7.14	37.0	45.88
Total TCDF	25.0	27.0	30.69	49.0	72.37	14.0	16.90	6.1	7.23	37.0	46.02
1,2,3,7,8-PCDF	<0.1	<0.1	<0.06	<0.2	0.20	<0.1	0.09	<0.1	<0.06	0.2	<0.06
2,3,4,7,8-OCDF	0.2	0.2	<0.06	0.6	0.85	<0.1	<0.06	0.2	0.25	0.3	0.38
Total PCDF	0.4	0.5	<0.06	0.6	1.26	0.4	0.30	0.2	0.25	0.8	0.51
1,2,3,4,7,8-HxCDF	<0.1	<0.2	<0.08	<0.2	<0.08	<0.1	<0.08	<0.1	<0.08	<0.2	<0.08
1,2,3,6,7,8-HxCDF	<0.1	<0.2	<0.08	<0.2	<0.08	<0.1	<0.08	<0.1	<0.08	<0.2	<0.08
2,3,4,6,7,8-HxCDF	<0.1	<0.2	<0.08	<0.2	<0.08	<0.1	<0.08	<0.1	<0.08	<0.2	<0.08
1,2,3,7,8,9-HxCDF	<0.1	<0.2	<0.08	<0.2	<0.08	<0.1	<0.08	<0.1	<0.08	<0.2	<0.08
Total HxCDF	<0.1	<0.2	<0.08	<0.2	<0.08	<0.1	<0.08	<0.1	<0.08	<0.2	<0.08
1,2,3,4,6,7,8-HpCDF	<0.2	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10
1,2,3,4,7,8,9-HpCDF	<0.2	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10
Total HpCDF	<0.2	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10
Total OCDF	<0.2	<0.2	<0.12	<0.2	<0.12	<0.2	<0.12	<0.2	<0.12	<0.2	<0.12
TEQ (Env. Canada)	3.400	3.600	4.074	9.000	12.463	1.900	2.271	2.310	2.488	5.060	6.066
TEQ (B.C. Env.)	3.466	3.701	4.169	9.129	12.536	2.056	2.353	2.376	2.578	5.158	6.095
TEQ (N.D. = D.L.)	3.531	3.803	4.263	9.258	12.608	2.212	2.435	2.441	2.667	5.256	6.124

Appendix 5A. Polychlorinated biphenyls (PCBs) in the muscle tissue of mountain whitefish collected from the Columbia and Slocan Rivers in July 1994.

DFO ID	Site	Subtotals - By Congener Family (ng/g)									Coplanar PCBs (pg/g)			Total PCB (ng/g)	Aroclor (ng/g)
		diCB	triCB	tetraCB	pentaCB	hexaCB	heptaCB	octaCB	nonaCB	decaCB	PCB 77	PCB 126	PCB 169		
CR94S01	Slocan	0.03	0.03	0.04	0.16	0.28	0.11	0.07	0.05	0.04	1.70	0.58	0.70	0.81	1.1
CR94S02A	Slocan	0.02	0.06	0.58	2.11	3.21	1.58	0.26	0.03	0.03	4.40	2.60	1.80	7 89	10.0
CR94S02B	Slocan	0.03	0.05	0.59	2.25	3.40	1.69	0.40	0.06	0.05	4.60	3.00	2.20	8.53	11.0
CR94S03	Slocan	0.02	0.04	0.45	1.56	2.34	1.25	0.26	0.04	0.04	3.30	1.60	1.20	6.01	8.0
CR94S04	Slocan	0.03	0.03	0.04	0.30	0.68	0.29	0.08	0.05	0.05	2.50	1.20	0.70	1.55	2.6
CR94S06	Slocan	0.03	0.03	0.04	0.18	0.45	0.16	0.06	0.06	0.04	2.40	0.96	0.65	1.05	1.5
CR94S09	Slocan	0.02	0.03	0.05	0.42	0.77	0.30	0.18	0.04	0.03	2.60	1.40	1.10	1.85	3.0
CR94S11	Slocan	0.02	0.02	0.11	0.71	1.30	0.80	0.23	0.04	0.03	1.30	0.88	0.72	3.26	4.7
CR94S12	Slocan	0.03	0.03	0.04	0.14	0.73	0.30	0.08	0.05	0.05	1.90	0.88	0.72	1.45	2.5
CR94S48	Slocan	0.02	0.02	0.05	0.46	0.71	0.36	0.05	0.03	0.03	2.20	1.20	0.79	1.73	3.1
CR94S49A	Slocan	0.06	0.04	0.06	0.83	0.89	0.36	0.22	0.09	0.04	3.30	1.60	1.00	2.60	3.4
CR94S49B	Slocan	0.04	0.04	0.06	0.88	1.02	0.36	0.16	0.09	0.09	3.60	1.90	1.30	2.75	3.5
CR94T100	Beaver	0.04	0.05	0.79	3.49	5.74	3.66	1.31	0.10	0.06	24.00	4.80	1.10	15.27	19.0
CR94T102	Beaver	0.03	0.04	0.21	3.11	7.64	7.90	3.98	0.32	0.05	5.20	3.00	1.10	23.29	30.0
CR94T103	Beaver	0.03	0.07	0.95	5.08	9.78	6.31	2.83	0.25	0.05	26.00	9.40	3.40	25.39	31.0
CR94T106	Beaver	0.03	0.06	1.17	4.60	6.93	5.30	2.06	0.21	0.09	23.00	5.80	2.10	20.48	23.0
CR94T108	Beaver	0.04	0.06	5.16	20.30	26.56	17.11	5.51	0.44	0.06	42.00	13.00	3.70	75.30	84.0
CR94T109	Beaver	0.04	0.05	1.66	7.39	15.45	11.06	3.49	0.26	0.06	39.00	11.00	4.60	39.51	57.0
CR94T111	Beaver	0.04	0.05	3.85	35.21	64.22	48.67	18.39	1.70	0.09	10.00	14.00	4.10	172.25	230.0
CR94T112	Beaver	0.03	0.04	2.26	17.87	52.24	57.42	50.72	14.40	0.77	23.00	20.00	7.40	195.80	220.0
CR94T113A	Beaver	0.03	0.10	3.68	11.66	16.11	9.31	2.03	0.19	0.05	20.00	7.20	3.00	43.19	52.0
CR94T113B	Beaver	0.02	0.11	4.04	11.48	15.06	9.09	2.06	0.16	0.03	19.00	7.40	2.90	42.08	48.0
CR94T115	Beaver	0.03	0.04	0.56	4.13	10.25	6.82	2.80	0.27	0.05	8.90	5.40	1.90	24.97	36.0
CR94G201	Genelle	0.03	0.05	6.04	26.21	32.93	11.00	2.08	0.14	0.06	52.00	14.00	1.70	78.61	110.0
CR94G202	Genelle	0.03	0.04	0.38	3.89	6.15	3.89	0.60	0.04	0.04	16.00	3.00	1.60	15 08	21.0
CR94G203	Genelle	0.02	0.06	1.25	4.76	4.78	2.09	0.33	0.05	0.03	13.00	2.40	1.30	13.39	15.0
CR94G204	Genelle	0.02	0.04	6.31	36.18	96.05	84.48	25.71	1.29	0.04	33.00	26.00	8.00	250.19	380.0
CR94G207	Genelle	0.02	0.16	6.28	24.24	19.49	8.64	3.12	0.51	0.06	32.00	7.60	2.80	62.56	63.0
CR94G210	Genelle	0.06	0.05	1.00	4.98	12.20	8.88	2.50	0.11	0.03	19.00	7.20	4.20	29.84	41.0
CR94G212	Genelle	0.05	0.04	2.17	11.98	34.58	33.34	11.49	0.52	0.03	15.00	11.00	3.70	94.23	140.0
CR94G213A	Genelle	0.06	0.07	0.25	2.11	2.80	1.19	0.20	0.15	0.11	7.10	1.70	0.77	6.95	11.0
CR94G213B	Genelle	0.03	0.06	0.59	3.02	4.14	1.76	0.24	0.07	0.07	7.60	1.80	0.79	9.99	13.0
CR94G214	Genelle	0.03	0.33	4.02	15.04	24.15	14.11	1.77	0.07	0.05	26.00	9.60	5.00	59.61	78.0
CR94G215	Genelle	0.02	0.23	9.79	65.84	128.06	99.25	23.44	0.89	0.04	13.00	28.00	10.000	327.61	420.0

Values represent sums of individual PCB compounds. Where the sum is zero (non-detected), the largest individual compound detection limit is used as the sum.

Appendix 5B. Polychlorinated biphenyls (PCBs) in mountain whitefish muscle tissue; comparison of split samples analysed by AXYS and IOS Laboratories.

		Mono- and Di- Ortho Substituted PCBs (ng/g)										Coplanar PCBs (pg/g)		
LAB	DFO ID	PCB 105	PCB 114	PCB 118	PCB 123	PCB 156	PCB 157	PCB 167	PCB 189	PCB 170	PCB 180	PCB 77	PCB 126	PCB 169
AXYS	CR94T103	0.78	<0.04	2.00	n.a.	0.40	<0.08	n.a.	<0.08	1.10	3.10	26.00	9.40	3.40
IOSD	CR94T103	1.25	0.07	2.33	<0.00021	0.58	0.12	0.23	0.05	n.a.	n.a.	20.97	7.06	2.46
AXYS	CR94T112	2.60	0.14	7.20	n.a.	2.20	<0.07	n.a.	0.21	9.40	23.00	23.00	20.00	7.40
IOSD	CR94T112	4.63	0.28	14.65	<.00025	2.86	0.49	1.02	0.29	n.a.	n.a.	24.05	20.87	7.79
AXYS	CR94G201	1.30	0.06	3.90	n.a.	0.77	0.18	n.a.	<0.06	1.40	3.30	52.00	14.00	1.70
IOSD	CR94G201	2.10	0.12	5.16	<0.00010	0.93	0.21	0.41	0.05	n.a.	n.a.	47.96	14.07	1.59
AXYS	CR94G212	1.50	0.09	4.10	n.a.	1.50	<0.04	n.a.	0.15	5.70	14.00	15.00	11.00	3.70
IOSD	CR94G212	2.30	0.14	5.27	<0.00011	1.62	0.26	0.47	0.17	n.a.	n.a.	12.34	9.91	3.95
AXYS	CR94G214	0.98	<0.04	2.50	n.a.	0.45	0.10	n.a.	<0.07	1.60	4.30	26.00	9.60	5.00
IOSD	CR94G214	1.24	0.07	2.36	<0.00017	0.57	0.11	0.23	0.04	n.a.	n.a.	21.82	8.02	4.27

< = Value Not Detected. Number following is the detection limit.
n.a. = data not available (not measured)

Appendix 6. Mixed function oxidase activities in mountain whitefish collected from the Columbia and Slocan Rivers, July 1994.

BEAVER (n=20)				GENELLE (n=20)				SLOCAN (n=19)			
Sample	EROD*	AHH*	P-450*	Sample	EROD	AHH	P-450	Sample	EROD	AHH	P-450
CR94T100	0.004	0.011	0.141	CR94G201	0.004	0.021	0.194	CR94S01	0.005	0.016	0.158
CR94T101	0.012	0.034	0.218	CR94G202	0.005	0.013	0.166	CR94S02	0.023	0.049	0.267
CR94T102	0.005	0.025	0.187	CR94G203	0.024	0.081	0.256	CR94S03	0.015	0.069	0.294
CR94T103	0.006	0.011	0.123	CR94G204	0.048	0.081	0.163	CR94S04	0.012	0.037	0.205
CR94T104	0.008	0.032	0.256	CR94G205	0.028	0.045	0.269	CR94S05	0.007	0.019	0.179
CR94T105	0.021	0.033	0.260	CR94G206	0.014	0.042	0.259	CR94S06	0.005	0.012	0.137
CR94T106	0.008	0.023	0.143	CR94G207	0.007	0.026	0.237	CR94S09	0.008	0.019	0.123
CR94T108	0.007	0.029	0.197	CR94G208	0.010	0.026	0.151	CR94S10	0.022	0.055	0.281
CR94T109	0.005	0.010	0.136	CR94G209	0.025	0.086	0.293	CR94S11	0.016	0.052	0.250
CR94T110	0.009	0.023	0.143	CR94G210	0.014	0.034	0.166	CR94S12	0.005	0.013	0.171
CR94T111	0.013	0.042	0.203	CR94G211	0.006	0.018	0.128	CR94S13	0.013	0.026	0.168
CR94T112	0.020	0.053	0.155	CR94G212	0.014	0.027	0.147	CR94S14	0.012	0.044	0.223
CR94T113	0.010	0.031	0.198	CR94G213	0.007	0.024	0.252	CR94S15	0.014	0.060	0.205
CR94T114	0.006	0.015	0.176	CR94G214	0.023	0.055	0.273	CR94S16	0.032	0.079	0.289
CR94T115	0.009	0.025	0.144	CR94G215	0.060	0.135	0.228	CR94S39	0.020	0.059	0.277
CR94T132	0.009	0.082	0.311	CR94G216	0.024	0.041	0.169	CR94S41	0.020	0.075	0.230
CR94T144	0.004	0.013	0.172	CR94G217	0.102	0.165	0.282	CR94S42	0.021	0.062	0.242
CR94T146	0.007	0.016	0.144	CR94G218	0.026	0.089	0.273	CR94S48	0.006	0.016	0.168
CR94T147	0.011	0.034	0.182	CR94G221	0.005	0.018	0.173	CR94S49	0.033	0.086	0.266
CR94T148	0.006	0.029	0.265	CR94G222	0.093	0.175	0.294				
Mean:	0.0090	0.0286	0.1877	Mean:	0.0270	0.0601	0.2187	Mean:	0.0152	0.0446	0.2175
St. Dev.:	(0.0047)	(0.0168)	(0.0517)	St. Dev.:	(0.0282)	(0.0491)	(0.0562)	St. Dev.:	(0.0086)	(0.0244)	(0.0543)

EROD and AHH are expressed in (nmoles/mg/min)

Cytochrome P-450 is in (nmoles/mg)

Appendix 7A. Trace metals (µg/dry g) in muscle tissue of mountain whitefish collected from the Columbia and Slocan Rivers in July 1994.

Site	DFO ID:	Moisture (%)	(Al)	(As)	(Ba)	(Cd)	(Cr)	(Cu)	(Fe)	(Pb)	(Mg)	(Hg)	(Mo)	(Ni)	(Se)	(Si)	(Sr)	(Zn)
Slocan R.	CR94S43	75.39	8	<2	0.14	0.10	0.3	1.3	16.8	0.1	1560	<0.1	<0.5	<0.2	2	<5	4	19.8
Slocan R.	CR94S44	74.77	10	<2	0.26	0.05	0.3	2.6	15.3	<0.1	1360	<0.1	<0.5	<0.2	3	<5	3	18.0
Slocan R.	CR94S45	71.98	9	2	0.10	0.15	0.4	1.5	18.4	0.1	1130	<0.1	<0.5	<0.2	2	6	3	19.9
Slocan R.	CR94S47	73.77	10	2	0.17	0.08	0.3	1.2	15.7	<0.1	1230	<0.1	<0.5	<0.2	3	7	4	20.4
Slocan R.	CR94S50	73.29	8	<2	0.15	0.16	0.3	1.4	16.0	<0.1	1310	<0.1	<0.6	<0.2	4	<6	4	18.3
Slocan R.	CR94S51	73.30	8	<2	0.06	0.12	0.3	1.4	15.4	<0.1	1130	<0.1	<0.5	0.3	2	<5	3	17.7
Slocan R.	CR94S52	72.15	8	<2	0.13	0.09	0.3	1.5	25.6	<0.1	1210	<0.1	<0.5	0.3	3	7	2	17.6
Slocan R.	CR94S53	72.86	10	<2	0.25	0.09	0.3	1.0	26.1	<0.1	1220	<0.1	<0.5	<0.2	3	12	3	19.2
Slocan R.	CR94S54	69.19	6	<2	0.15	0.08	0.2	1.0	16.1	0.1	915	<0.1	<0.5	<0.2	<2	<5	2	13.3
Slocan R.	CR94S55	74.85	13	<2	0.09	<0.01	0.3	0.9	19.8	<0.1	1305	<0.1	<0.5	<0.2	<2	20	3	19.9
Slocan R.	CR94S56	72.03	9	<2	0.10	<0.01	0.3	1.1	17.0	<0.1	1170	<0.1	<0.5	<0.2	<2	9	2	17.4
Slocan R.	CR94S57	71.07	17	<2	0.56	0.05	0.2	1.7	21.1	<0.1	983	<0.1	<0.5	<0.2	<2	<5	6	17.2
Slocan R.	CR94S58	70.71	62	<2	0.57	0.05	0.3	1.8	60.8	<0.1	1150	<0.1	<0.5	0.2	<2	20	5	16.1
Slocan R.	CR94S59	74.49	16	<2	0.27	0.03	0.4	1.4	33.0	<0.1	1210	<0.1	<0.5	<0.2	3	9	3	22.2
Slocan R.	CR94S60	71.55	14	<2	0.33	0.08	0.4	1.5	29.0	<0.1	1040	<0.1	<0.5	<0.2	<2	<5	5	17.8
	Mean:	72.76	13.87	2.00	0.22	0.09	0.31	1.42	23.07	0.10	1194.9	<0.1	<0.5	0.27	2.72	11.25	3.43	18.32
	St.Dev.:	1.75	13.69	0.00	0.16	0.04	0.06	0.41	11.83	0.00	157.3			0.06	0.67	5.70	1.21	2.08
Beaver	CR94T107	72.83	9	<2	0.10	0.05	0.2	1.1	14.6	<0.1	1030	<0.1	<0.5	<0.2	<2	27	2	15.4
Beaver	CR94T116	74.36	10	<2	0.10	0.10	0.3	1.2	60.5	0.1	1150	0.3	<0.5	<0.2	<2	52	1	15.8
Beaver	CR94T117	69.45	4	<2	<0.05	0.15	0.2	2.0	19.9	<0.1	912	<0.1	<0.5	<0.2	2	26	<1	11.7
Beaver	CR94T118	78.38	35	<2	0.27	0.14	0.5	1.5	52.4	<0.1	1255	<0.1	<0.5	<0.2	<2	60	4	26.7
Beaver	CR94T119	76.78	8	<2	0.09	0.18	0.3	1.4	56.5	<0.1	1110	0.2	<0.5	<0.2	<2	41	2	25.2
Beaver	CR94T120	73.30	7	<2	<0.05	0.17	0.3	1.0	30.3	<0.1	1070	0.2	<0.5	<0.2	<2	34	1	14.8

Appendix 7A. Continued.

Site	DFO ID:	Moisture (%)	(Al)	(As)	(Ba)	(Cd)	(Cr)	(Cu)	(Fe)	(Pb)	(Mg)	(Hg)	(Mo)	(Ni)	(Se)	(Si)	(Sr)	(Zn)
Beaver	CR94T121	68.14	8	<2	0.07	0.05	0.2	1.0	16.4	<0.1	935	<0.1	<0.5	<0.2	<2	39	2	17.1
Beaver	CR94T122	71.08	7	<2	<0.06	0.05	0.3	1.9	14.8	<0.1	1190	<0.1	<0.6	<0.2	<2	43	<1	17.2
Beaver	CR94T123	72.90	20	<2	0.18	0.05	0.4	1.4	18.6	<0.1	1360	<0.1	<0.5	<0.2	2	60	3	16.3
Beaver	CR94T124	70.41	8	<2	<0.05	0.05	0.3	1.4	17.9	<0.1	1270	<0.1	<0.5	<0.2	<2	36	2	17.1
Beaver	CR94T125	66.46	6	<2	0.10	0.03	0.2	1.0	10.8	<0.1	955	<0.1	<0.5	<0.2	<2	33	<1	12.9
Beaver	CR94T126	74.04	7	<2	0.41	0.05	0.3	1.2	18.0	<0.1	1220	<0.1	<0.5	<0.2	<2	47	2	17.0
Beaver	CR94T127	71.43	6	<2	0.15	0.09	0.3	0.5	18.7	<0.1	1005	<0.1	<0.5	<0.2	3	58	<1	15.0
Beaver	CR94T128	72.00	10	<2	0.13	0.08	0.3	1.5	35.1	<0.1	1260	<0.1	<0.5	<0.2	2	58	1	18.8
Beaver	CR94T129	68.87	9	<2	0.13	0.05	0.5	1.1	18.2	<0.1	918	0.2	<0.6	<0.2	<2	30	<1	14.1
	Mean:	72.03	10.23		0.16	0.09	0.30	1.28	26.84	0.10	1109.3	0.23			2.13	42.90	2.00	17.00
	St.Dev.:	3.19	7.72		0.10	0.05	0.09	0.38	16.52		146.8				0.25	12.17	0.94	4.06
Genelle	CR94G219	74.80	9	<2	0.22	<0.01	0.3	1.6	27.7	<0.1	967	0.1	<0.5	0.2	2	14	4	14.4
Genelle	CR94G220	71.10	7	<2	<0.05	0.03	0.3	1.2	11.5	<0.1	977	<0.1	<0.5	<0.2	2	26	2	13.7
Genelle	CR94G223	67.94	5	<2	<0.05	0.05	0.3	1.2	12.6	<0.1	891	<0.1	<0.5	0.2	<2	33	<1.0	11.7
Genelle	CR94G224	74.01	10	2	0.41	0.07	0.3	1.4	44.5	<0.1	1030	0.2	<0.5	0.2	2	30	4	18.0
Genelle	CR94G225	70.00	5	<2	<0.05	<0.01	0.3	1.1	13.1	0.1	947	<0.1	<0.5	<0.2	<2	<5	<1	12.5
Genelle	CR94G226	70.29	15	<2	0.07	<0.01	0.3	1.4	15.7	<0.1	890	<0.1	<0.5	<0.2	<2	17	2	13.6
Genelle	CR94G227	73.40	8	<2	0.16	<0.01	0.4	1.4	14.7	<0.1	1160	<0.1	<0.5	<0.2	2	<5	4	16.1
Genelle	CR94G228	72.08	5	<2	<0.05	<0.01	0.3	1.2	17.1	<0.1	1010	<0.1	<0.5	<0.2	<2	<5	1	14.3
Genelle	CR94G229	66.22	5	<2	<0.05	0.07	0.2	1.3	17.6	<0.1	819	<0.1	<0.5	<0.2	<2	<5	2	11.4
Genelle	CR94G230	77.97	9	<2	0.14	<0.01	0.4	1.3	25.0	<0.1	1140	0.2	<0.5	<0.2	<2	<5	5	20.1
Genelle	CR94G231	69.12	6	<2	<0.05	<0.01	0.3	1.3	11.9	<0.1	944	<0.1	<0.5	0.4	<2	<5	2	12.0
Genelle	CR94G232	72.91	7	<2	<0.05	0.04	0.3	1.6	14.7	0.4	1030	<0.1	<0.5	<0.2	<2	<5	2	14.5
Genelle	CR94G233	72.82	6	<2	0.05	<0.01	0.3	1.3	10.6	0.1	1020	<0.1	<0.5	<0.2	<2	<5	2	15.5
Genelle	CR94G234	72.54	6	<2	<0.05	0.06	0.2	1.4	12.9	<0.1	948	<0.1	<0.5	<0.2	<2	<5	1	12.3
Genelle	CR94G235	72.70	6	<2	<0.05	0.05	0.2	1.3	11.3	<0.1	1060	<0.1	<0.5	<0.2	<2	<5	<1	14.8
	Mean:	71.86	7.23		0.18	0.05	0.29	1.33	17.39	0.20	988.9	0.17		0.25	2.00	23.90	2.58	14.32
	St.Dev.:	2.90	2.70		0.13	0.02	0.06	0.14	8.97	0.17	91.1	0.06		0.10	0.00	8.08	1.31	2.41

Appendix 7B. Protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers, July 1994.

Site:	DFO ID:	Dry/Wet Ratio	Total Protein (mg/g)	Metallothionein (mg/g)	Metallothionein (mg/gTP)	HD Cytosol Metals Cd (µg/dry g)	HD Cytosol Metals Cu (µg/dry g)	HD Cytosol Metals Zn (µg/dry g)	Whole Tissue Metals Cd (µg/dry g)	Whole Tissue Metals Cu (µg/dry g)	Whole Tissue Metals Zn (µg/dry g)	Hg (µg/dry g)
Slocan	CR94S43	0.256	539	0.62	1.14	2.25	7.32	5.65	3.14	11.9	100	<0.7
Slocan	CR94S44	0.254	555	0.36	0.66	2.94	6.83	5.78	3.96	10.1	109	<0.4
Slocan	CR94S45	0.252	443	0.70	1.57	7.91	9.41	5.87	9.62	13.1	109	<0.4
Slocan	CR94S47	0.246	592	0.62	1.05	4.45	10.42	7.57	5.98	13.4	125	<0.4
Slocan	CR94S50	0.256	534	0.76	1.43	7.33	22.76	6.33	8.32	25.8	105	<0.4
												<0.2
Slocan	CR94S51	0.253	553	0.68	1.22	7.66	13.04	5.99	8.13	15.4	105	<0.2
Slocan	CR94S52	0.241	538	0.66	1.23	9.00	14.19	6.83	10.42	18.7	112	<0.1
Slocan	CR94S53	0.241	523	0.77	1.47	15.14	11.78	7.05	17.24	15.9	134	<0.6
Slocan	CR94S54	0.259	398	0.54	1.35	9.33	11.15	3.12	9.82	15.5	116	<0.2
Slocan	CR94S55	0.251	507	0.61	1.20	4.88	11.31	4.65	6.42	15.1	122	<0.6
Slocan	CR94S56	0.253	482	0.42	0.87	2.41	6.58	4.05	3.44	9.4	98	<0.4
												<0.4
Slocan	CR94S57	0.255	485	0.54	1.12	3.97	9.89	4.89	5.14	14.8	99	<0.1
Slocan	CR94S58	0.262	479	0.39	0.81	2.34	9.15	3.46	3.54	14.2	104	0.1
Slocan	CR94S59	0.246	476	0.59	1.24	2.95	4.89	4.21	5.25	8.3	96	<0.2
Slocan	CR94S60	0.247	546	0.52	0.95	5.81	8.11	5.25	6.97	11.7	96	0.1

Appendix 7B. Protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers, July 1994.

Site:	DFO ID:	Dry/Wet Ratio	Total Protein (mg/g)	Metallothionein (mg/g)	Metallothionein (mg/gTP)	HD Cytosol Metals Cd (µg/dry g)	HD Cytosol Metals Cu (µg/dry g)	HD Cytosol Metals Zn (µg/dry g)	Whole Tissue Metals Cd (µg/dry g)	Whole Tissue Metals Cu (µg/dry g)	Whole Tissue Metals Zn (µg/dry g)	Hg (µg/dry g)
Beaver	CR94T107	0.261	490	0.41	0.84	0.91	10.40	2.69	1.60	15.2	94	<0.4
Beaver	CR94T116	0.238	450	0.88	1.95	14.65	22.19	3.65	18.52	27.6	128	0.2
Beaver	CR94T117	0.257	511	1.14	2.24	32.77	36.08	5.36	35.62	46.1	158	0.6
												0.1
Beaver	CR94T118	0.237	470	0.75	1.59	9.13	25.29	2.35	16.40	40.8	119	<0.1
Beaver	CR94T119	0.246	404	0.89	2.19	17.05	17.39	5.00	19.91	22.1	137	0.6
Beaver	CR94T120	0.251	228	0.72	3.17	4.61	13.21	2.65	41.78	69.4	136	0.3
Beaver	CR94T121	0.262	369	0.45	1.23	1.01	7.40	1.70	3.49	23.4	97	<0.1
Beaver	CR94T122	0.263	511	0.46	0.90	1.91	11.32	3.13	2.98	19.5	106	<0.1
Beaver	CR94T123	0.261	419	0.66	1.57	2.09	20.91	2.83	8.69	65.3	129	<0.1
Beaver	CR94T124	0.271	434	0.36	0.84	0.91	5.17	1.66	3.85	13.6	94	<0.2
												<0.2
Beaver	CR94T125	0.250	525	0.53	1.00	1.48	18.51	3.50	2.08	28.5	119	<0.1
Beaver	CR94T126	0.264	436	0.59	1.36	7.35	21.77	2.37	15.39	36.0	134	<0.1
Beaver	CR94T127	0.240	454	0.65	1.44	11.33	19.20	4.07	15.97	24.5	173	<0.02
Beaver	CR94T128	0.261	481	1.37	2.85	15.17	56.16	7.90	16.50	72.3	172	0.4
Beaver	CR94T129	0.233	501	0.47	0.93	3.84	7.54	3.74	5.86	11.7	97	0.1

Appendix 7B. Protein, metallothionein, and metals results for mountain whitefish liver tissue collected from the Columbia and Slocan Rivers, July 1994.

Site:	DFO ID:	Dry/Wet Ratio	Total Protein (mg/g)	Metallothionein (mg/g)	Metallothionein (mg/gTP)	HD Cytosol Metals Cd (µg/dry g)	HD Cytosol Metals Cu (µg/dry g)	HD Cytosol Metals Zn (µg/dry g)	Whole Tissue Metals Cd (µg/dry g)	Whole Tissue Metals Cu (µg/dry g)	Whole Tissue Metals Zn (µg/dry g)	Hg (µg/dry g)
Genelle	CR94G219	0.244	500	0.49	0.98	1.39	10.30	4.55	1.78	17.4	108	0.2
Genelle	CR94G220	0.250	503	0.31	0.62	0.07	2.03	2.73	0.18	9.9	101	<0.1
Genelle	CR94G223	0.252	399	0.44	1.11	1.16	9.72	2.01	2.60	20.4	101	0.2
Genelle	CR94G224	0.259	236	0.55	2.35	0.62	5.23	2.16	4.83	17.6	105	1.7
Genelle	CR94G225	0.250	435	0.36	0.83	0.08	2.31	2.42	0.27	9.1	89	<0.2
Genelle	CR94G226	0.253	431	0.30	0.71	0.27	3.09	2.38	0.80	11.2	105	<0.3
Genelle	CR94G227	0.265	426	0.36	0.85	0.13	4.81	2.28	0.39	17.0	97	<0.2
Genelle	CR94G228	0.252	346	0.34	0.97	0.24	6.03	1.73	1.35	17.9	99	0.2
Genelle	CR94G229	0.253	400	0.66	1.65	0.73	7.05	1.84	1.69	15.8	101	0.2
Genelle	CR94G230	0.243	444	0.72	1.62	3.21	7.57	2.67	5.54	13.5	98	<0.5
Genelle	CR94G231	0.247	395	0.50	1.26	0.25	2.81	2.08	1.03	11.9	103	0.1
Genelle	CR94G232	0.263	511	0.78	1.52	0.11	2.81	2.72	0.34	11.1	95	<0.4
Genelle	CR94G233	0.252	495	0.59	1.20	0.08	2.38	2.70	0.20	10.0	96	<0.3
Genelle	CR94G234	0.249	362	0.60	1.65	0.31	4.34	2.51	0.62	13.9	104	0.2
Genelle	CR94G235	0.286	308	0.34	1.10	0.04	1.52	1.72	0.95	11.0	81	<0.3