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FISH HEALTH ASSESSMENT

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The health of resident fish populations is an important indicator of ecosystem conditions, and a factor that can directly affect human health. Resident fish spend their entire life span in the river and reflect local conditions more than migrants such as salmon. Previous fish studies in the Fraser Basin concentrated on the biology, habitat and population sizes of commercially important migrants such as salmon and trout (Northcote and Burwash 1991). The Fraser River Action Plan (FRAP) provided a unique opportunity to conduct a basin-wide survey of resident fish tissue contaminant levels coincident with an assessment of fish health. FRAP assessed the condition of resident fish in the Fraser Basin, based on the contaminant levels and health of mountain whitefish (*Prosopium williamsoni*) and peamouth chub (*Mylocheilus caurinus*).

A relatively good historical record of fish tissue contaminants exists for the lower Fraser River. Pollution concerns in the early 1970s led to sampling the lower river for persistent organochlorine pesticides and PCBs in fish tissue (Hall *et al.* 1991; Albright *et al.* 1975). Fish tissue contaminant monitoring in the lower river continued as a result of the Fraser River Estuary Study (Singleton 1983; Swain 1986; Swain and Walton 1989) and because of concerns about lumber treatment facility run-off and sewage treatment plant effluent (Rogers and Hall 1987; Carey *et al.* 1988; Rogers *et al.* 1990; Rogers *et al.* 1992; Birch and Shaw 1995).

Information on contaminants in the upper basin has been collected more sporadically. Peterson *et al.* (1971) measured heavy metals in fish from lakes throughout British Columbia and Derksen (1986) measured metals in rainbow trout and mountain whitefish in the Thompson River. In the 1980s, fears about chlorophenolics, dioxins and furans from pulp mills resulted in research on effects of contaminants on juvenile salmonids and other ecosystem components in the upper Fraser and Thompson rivers and a province-wide dioxin survey which included sites on the Fraser and Thompson rivers (Rogers and Mahood 1982; Rogers and Mahood 1983; Rogers *et al.* 1988; Mah *et al.* 1989; Tuominen and Sekela 1992; Servizi *et al.* 1993). Dioxin and furan surveys were repeated by the pulp mills from 1990 to 1992 (Dwernychuk *et al.* 1993).

Mountain whitefish were selected for this study because previous research indicated that they accumulate dioxins and furans to higher levels than other species sampled (Mah *et al.* 1989; Dwernychuk *et al.* 1993; Pastershank and Muir 1995), and research was being conducted on their life history in the upper Fraser River (McPhail 1999). Peamouth chub were selected because they are widely distributed and abundant in the basin. They were a target of pulp mill effects research in the upper Fraser River (Gibbons *et al.* 1995) and were used in the Environmental Effects Monitoring Program (EEM) for pulp and paper mills on rivers in British Columbia.

Because the autopsy-based fish health assessment of Goede and Barton (Goede and Barton 1990) is being widely applied in environmental studies (Adams *et al.* 1993; Hatfield Consultants Ltd. 1996a; 1996b; Healey 1997), it has been incorporated in this study to test whether the health assessment abnormalities could be confirmed by histological analyses.

METHODS

Details of methods are presented in Raymond *et al.* (1999). Adult mountain whitefish and peamouth chub were collected between July and November in 1994, 1995 and 1996, from up to 11 reaches in the Fraser River Basin (Figure 1). The Hansard and North Thompson reaches are located above all major effluent discharges on the Fraser and Thompson rivers, respectively, and were chosen as reference reaches for this study. The Nechako reach is also above all major discharges in the basin, but most of its flow is diverted out of the basin for hydroelectric power generation.

In each reach, approximately 60 fish of each species were examined for external and internal abnormalities, according to Goede and Barton (1990). For the purpose of data analysis, the abnormalities were converted to a numerical health assessment index (HAI) based on Adams *et al.* (1993), with the following modifications: 1) fatty livers were considered normal in peamouth chub and 2) the thymus, pseudobranchs and blood parameters were not assessed. A higher HAI represents a higher incidence and severity of abnormalities. Fish ages were read

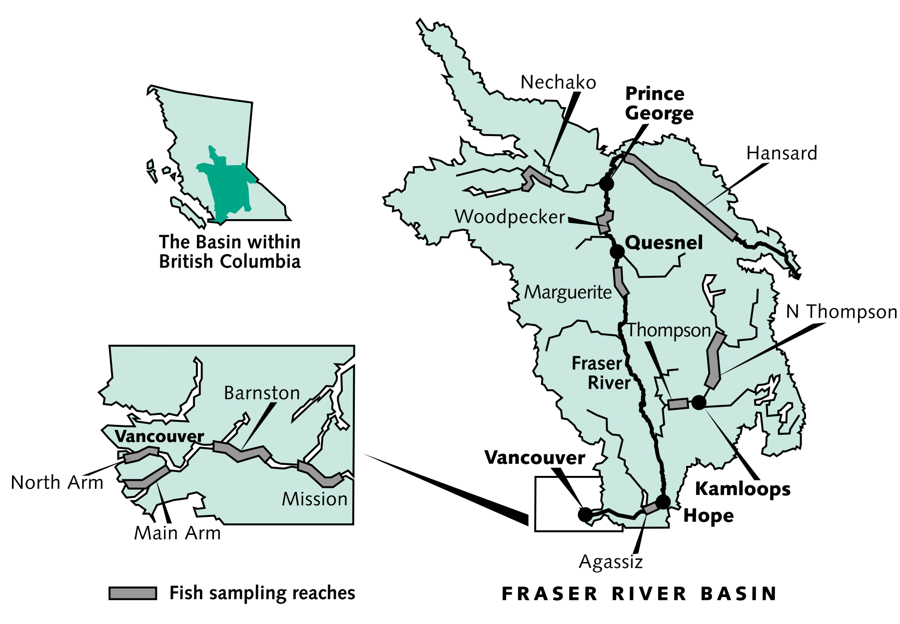


Figure 1*. Fish sampling reaches in the Fraser Basin.*

from surfaces and burnt cross-sections of the sagittal pair of otoliths. Tissue samples from the gill, liver, spleen, kidney, hindgut and pyloric caecae were analyzed following standard histological procedures (Humasen 1979). The histological evaluation noted only the presence of abnormalities without quantitative analysis of the extent of the abnormalities within each tissue section.

As an indicator of exposure to certain organic contaminants, activity of liver mixed-function oxygenase (MFO) enzymes was measured, as ethoxyresorufin-o-deethylase (EROD) activity, in up to 10 male and 10 female fish per reach. Organochlorine analyses were conducted on composite tissue samples by Axys Analytical (Sidney, B.C.) using standard extraction and cleanup protocols, with subsequent quantitation using gas chromatography (GC) and low-resolution mass spectrometry (MS) (chlorophenolics, PCB congeners, pesticides, resin acids) or high-resolution GC and high resolution MS (coplanar PCBs and dioxins/furans).

A suite of 12 metals was analyzed: arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium and zinc. Tissues from the estuary in 1994 were analyzed for most metals by inductively coupled plasma-atomic emission spectroscopy (ICP-AES), for mercury by cold-vapour AES and for arsenic, lead and selenium by graphite furnace AES (Quanta Trace Laboratories Inc., Burnaby, B.C.). All other samples were submitted to the National Laboratory for Environmental Testing, Burlington, Ontario, where arsenic and selenium were measured by ICP, mercury by cold-vapour atomic absorption spectrophotometry and all other metals by atomic absorption spectrophotometry. Laboratory and field QA/QC protocols were implemented to ensure data quality and validity for all samples.

CONTAMINANTS

Pesticides

Concern about the environmental effects of pesticides, particularly persistent organochlorine insecticides has led to their ban or highly restricted use throughout most of the world. Sources in the Fraser Basin are likely a combination of residual contamination from historical use, long-range atmospheric transport (Allan 1989; Kurtz 1990) and possible clandestine application of remaining stocks. Of the 24 pesticides determined in the analytical scan, all but two, lindane (gamma-hexachlorocyclohexane) and endosulphan, are banned in Canada. Many, including toxaphene and DDT, remain in use elsewhere in the world, particularly India, Central America and Russia (Voldner and Li 1993; Voldner and Li 1995).

The two registered pesticides were not the most frequently detected compounds in Fraser Basin fish in 1994 and 1995. Dieldrin, DDE (a metabolite of DDT), heptachlor epoxide, hexachlorobenzene and trans-nonachlor (a component of chlordane) were detected in more than 80 per cent of all muscle and liver analyses in both years. The highest tissue concentrations were of DDE and toxaphene, both of which are highly stable, bioaccumulative and readily transported atmospherically (Donald *et al.* 1993; Sanchez *et al.* 1993; Voldner and Li 1993).

Toxaphene and DDE concentrations on the main stem Fraser increased from the headwater sites with the highest levels in both peamouth chub and mountain whitefish being found in the Agassiz reach (Figure 2, Figure 3). Inter-species differences in body burden were apparent, probably related principally to differences in tissue lipid content, which is a strong determinant of organochlorine accumulation. The effect of lipid was particularly evident in peamouth chub liver, where lipid levels (12-30%) were typically two to six times those of mountain whitefish livers from the same sample reaches.

Industrial Chemical Contaminants

Organic chemical contaminants released by industry, particularly bleach-kraft pulp and paper mills, have long been a concern in the Fraser River Basin. The bleaching process releases a large volume of discharges

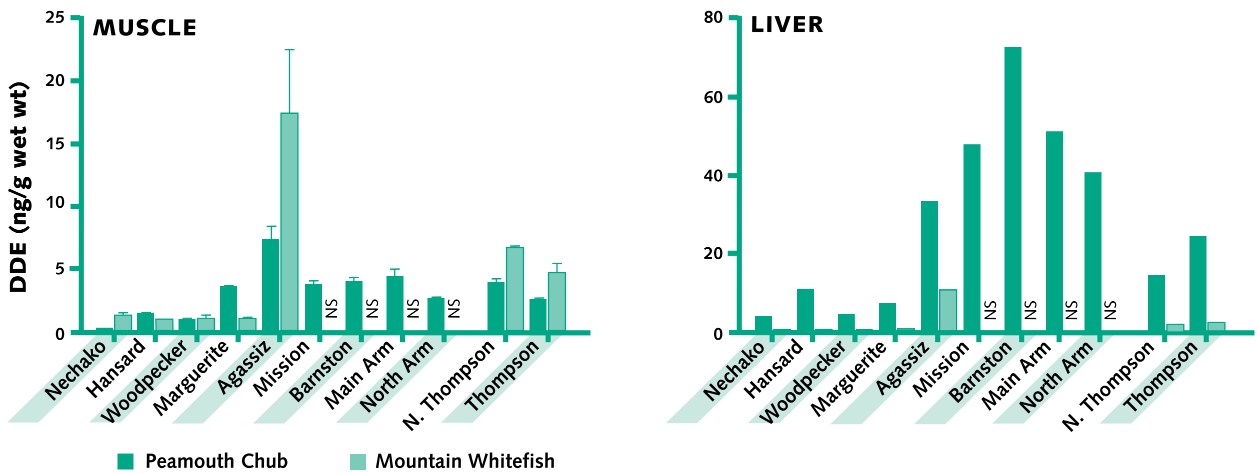


Figure 2. DDE in fish tissues from the Fraser River Basin, 1994. Values are mean (with standard error); four to five composites for muscle, and one or two composites for liver samples. NS denotes no samples.

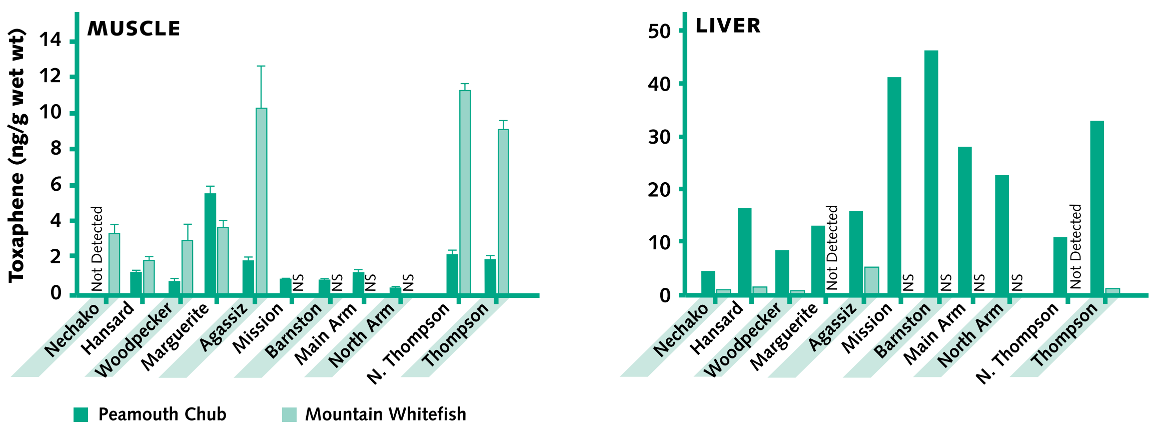


Figure 3. Total toxaphene in fish tissues from the Fraser River Basin, 1994. Values are mean (with standard error); four to five composites for muscle, and one or two composites for liver samples. NS denotes no samples.

with a huge number and spectrum of compounds (Dimmel *et al.* 1993; Owens 1991; Paasivirta *et al.* 1992). Particularly worrisome are the chlorinated dibenzodioxins, dibenzofurans and chlorophenolics, which are produced as byproducts of the chlorine bleaching process.

Throughout the Fraser Basin, dioxin and furan detections were dominated by the nearly ubiquitous 2,3,7,8 -tetrachlorodibenzofuran (TCDF) and, to a lesser extent, the more toxic 2,3,7,8-tetrachloro-dibenzo-*p*-dioxin (TCDD), both of which are characteristic components of pulp and paper effluent (Cleverly *et al.* 1997; Trudel 1991). TCDD concentrations were low (<1 pg/g wet weight) in mountain whitefish liver and rarely detected in either mountain whitefish muscle or peamouth chub tissues. The highest levels in 1994 were measured in the Thompson basin, both upstream and downstream of the pulp mill in Kamloops. Dioxin and furan congeners with dioxin-like activity may be expressed as toxic equivalent units (TEQs) relative to 2,3,7,8-TCDD (NATO 1988). Tissue levels of these TEQs throughout the Fraser Basin were well below the current tissue residue guidelines for consumption by humans, but did in some cases exceed a proposed guideline for protection of wildlife (Figure 4).

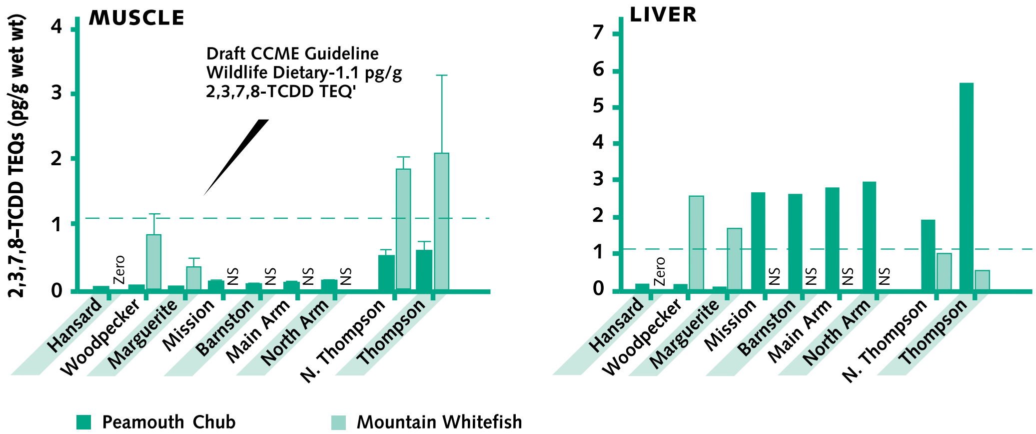


Figure 4. Total dioxin and furan 2,3,7,8-TCDD TEQs in tissues. Calculated using NATO I-TEFs (NATO 1988) with NDs=0. Values are mean (with standard error); four to five composites for muscle, and one or two composites for liver samples. NS denotes no samples.

[1]*CCME 1995 (draft)*

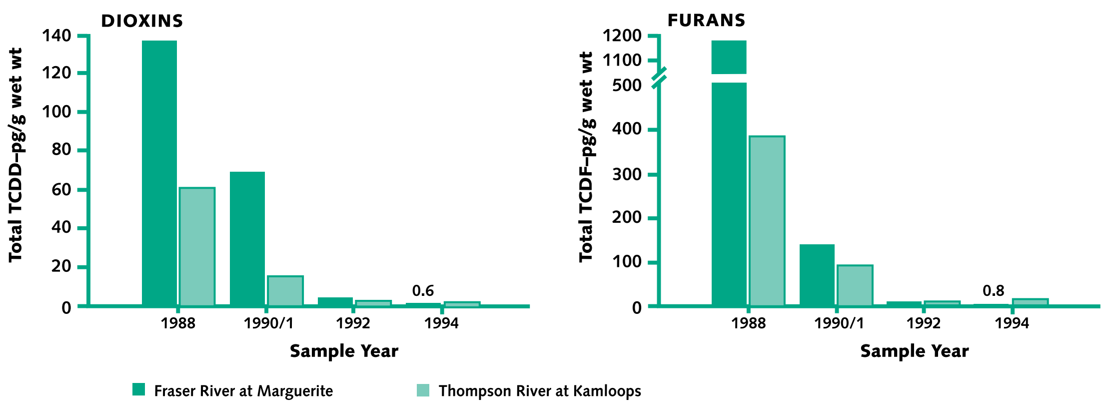


Figure 5. Dioxin and furan declines in mountain whitefish tissues following process changes at Fraser Basin pulp and paper mills.

Recent process changes undertaken by B.C. pulp mills (BC Ministry of Environment, Lands and Parks 1995; Krahn 1995), have resulted in dramatic declines in both effluent and environmental levels of organochlorine contaminants, including the most toxic dioxin congeners. From the extreme levels measured by Mah *et al.* (1989), levels in fish tissue have dropped to near-detection limits (Figure 5).

Chlorophenolics are another important class of contaminants released from pulp mills, wood treatment facilities and municipal wastewater treatment facilities in the Fraser Basin (Norecol 1993). Of the 47 chlorophenols and related compounds (guaiacols, catechols, etc.) targeted in the tissue analyses, nearly all were at low concentrations (<1 ng/g) or below detection in both muscle and liver. This result was not unexpected, since chlorophenolics are rapidly transformed to polar metabolites and excreted in bile (Brumley *et al.* 1996; Oikari 1986; Oikari and Holmbom 1986). They tend to have very short residence periods in tissues. Relatively high chlorophenol concentrations were detected in both peamouth chub and mountain whitefish bile downstream of pulp mill effluent sources (Figure 6). Two features are apparent in the patterns of chlorophenolics in bile. First, high concentrations are indicative of near-field, recent exposures, as was evident near mill effluent sources at Marguerite. The collection sites near Marguerite were as little as 20

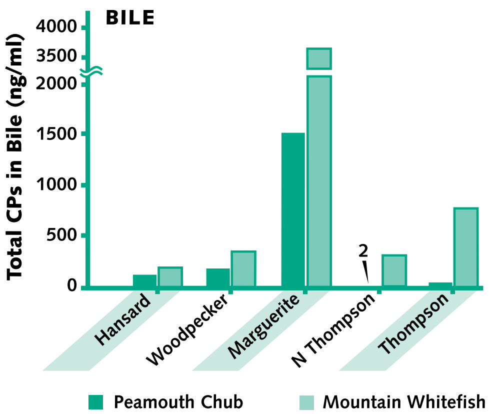


Figure 6. *Total chlorophenolics (CPs) in bile in fish from the Fraser River Basin, 1994.*

kilometres downstream of the mill effluent discharge at Quesnel, with consequently elevated chlorophenolics in bile of both fish species. Second, the similarity in bile total chlorophenolic concentration between the two reaches in the Thompson Basin indicates that mountain whitefish, in particular, may be moving considerable distances over relatively short periods of time.

Resin acids are also accumulated to high levels in bile (Oikari and Holmbom 1986) and their presence in bile is a sensitive indicator of recent exposure to water-borne resin acids. These are a group of naturally occurring wood extractives which are released from cut timber, as from sawmills, chipping mills, pulp and paper processing or similar industrial operations. Resin acid concentrations in peamouth chub and mountain whitefish bile from reaches near sawmill operations (Hansard and North Thompson reaches, Table 1) were greatly elevated, even compared to samples collected downstream of pulp and paper mills.

As with the organochlorine pesticides, use of polychlorinated biphenyls (PCBs) has been severely restricted since the 1980s. Residues persist in the environment due to the high stability and resistance of the compounds to degradation. Potential sources are many, from atmospheric transport to landfill leachate. Measurements of a total of 84 of the 209 possible PCB congeners in fish tissues in 1994 and 1995 indicated that 1) the contaminant sources (as represented by congener patterns) do not appear to be localized in particular reaches, 2) concentrations seem to be similar throughout the basin and 3) PCB concentrations and congener patterns are quite stable between years.

Table 1. Total resin acids in bile, 1994. Concentrations in μg/ml.

	HANSARD	WOODPECKER	N. THOMPSON	THOMPSON
Peamouth Chub	420.4	1.2	12.9	<0.7

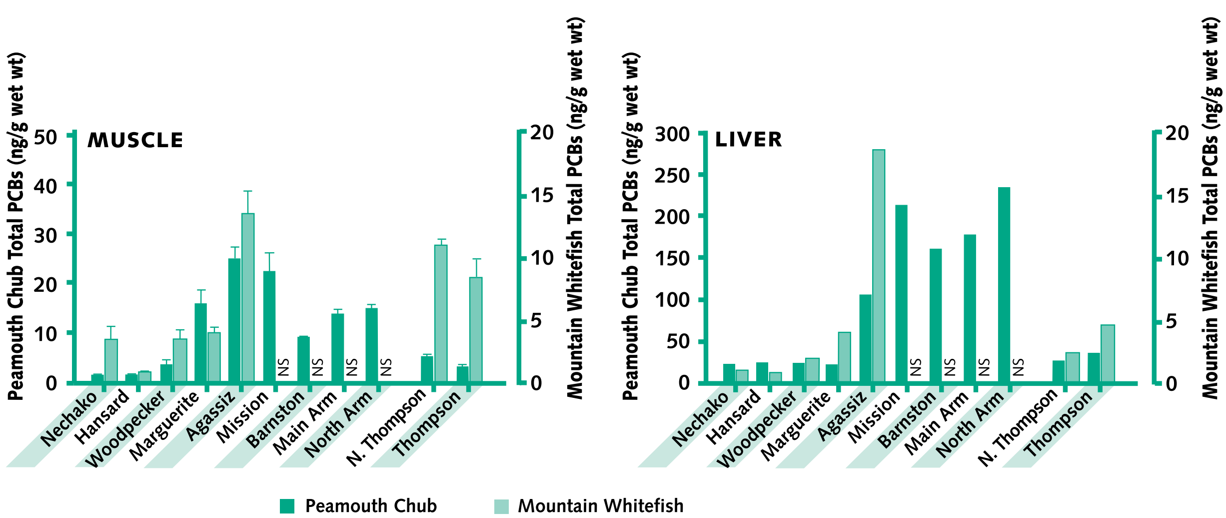


Figure 7. *Total PCBs in fish from the Fraser River, 1994. Values are mean (with standard error); four to five composites for muscle, and one or two composites for liver samples. NS denotes no samples.*

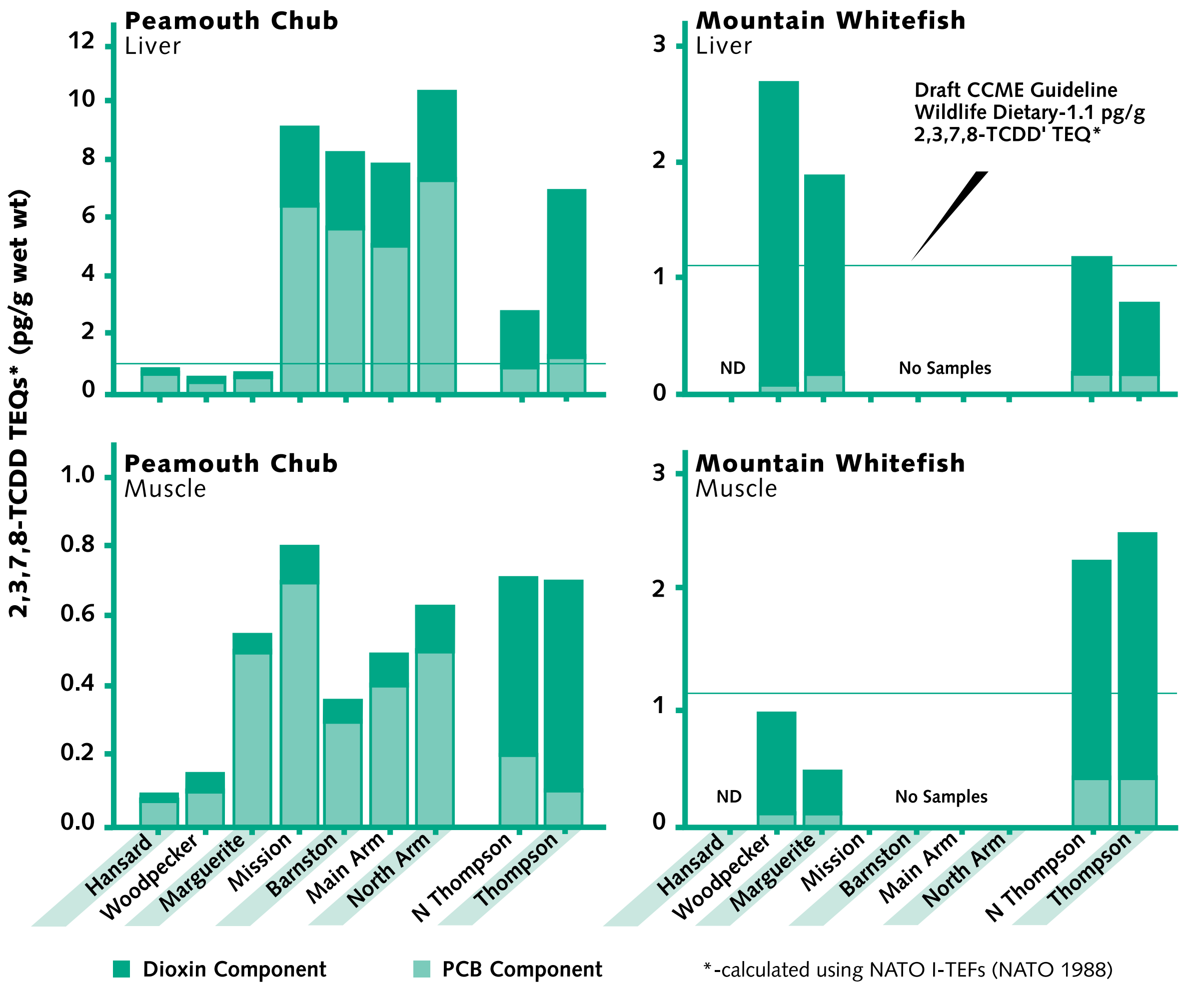


Figure 8. *Total TCDD TEQs as contributed by both dioxin/furan congeners and dioxin-like PCBs.*

[1] *CCME 1995 (draft)*

Total PCB concentrations measured in Fraser fish tissues were far below the current provincial criterion for human consumption (2000 ng/g wet wt.; BC MELP 1998) (Figure 7). However, when the toxicological significance of the level is considered, the potential exists for effects on wildlife consumers. A number of PCBs, particularly the coplanar congeners, have dioxin-like activity which may be represented as "toxic equivalence factors" (TEF) relative to 2,3,7,8-TCDD. Applying these factors in calculating a total toxic burden, it is clear that dioxin-like activity related solely to PCBs can exceed that related to dioxins and furans themselves (Figure 8). This is particularly evident in the lipid-rich livers of peamouth chub in the lower Fraser sampling reaches.

Tissue concentrations of polycyclic aromatic hydrocarbons (PAHs) were measured in peamouth chub tissues from the lower Fraser River reaches in 1994. This class of organic compounds is of particular concern to aquatic health because of the known carcinogenicity and probable teratogenicity of many members (Varanasi 1989). PAHs result from a wide array of sources and processes and are important indicators of urban and industrial contamination. Levels of both low and high molecular weight PAHs in peamouth chub tissue clearly show this association in the lower Fraser (Figure 9). Measured levels were highest in the Fraser River North Arm, a reach which receives a high number of stormwater and industrial discharges.

No metals were in excess of Canadian tissue residue guidelines for consumption by humans, and tissue levels were within expected ranges for fish from uncontaminated sites in British Columbia (Rieberger 1992).

Some levels of total selenium in mountain whitefish liver were slightly higher than the 3 µg/g B.C. tissue residue guideline for the protection of human health, but are unlikely to be of concern to consumers.

Overall, organic contaminant concentrations in fish tissues throughout the basin were low relative to existing environmental and human health guidelines, and have declined substantially from historical levels. Despite the success in removing or reducing release of persistent organochlorines in the environment, residues continue to be detected in fish tissues. The cumulative effect of these contaminants and their metabolic transformation products should remain a subject of some concern.

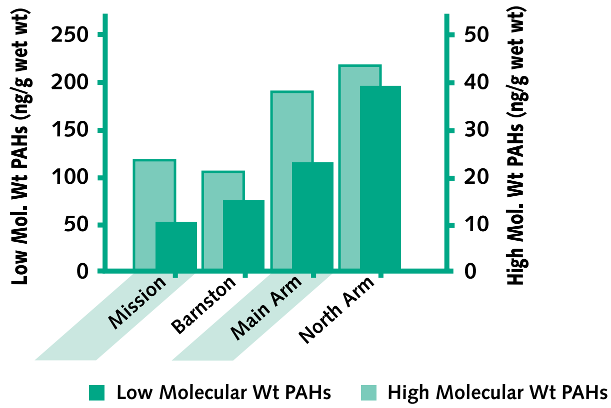


Figure 9. PAHs in peamouth chub liver from the lower Fraser to estuary.

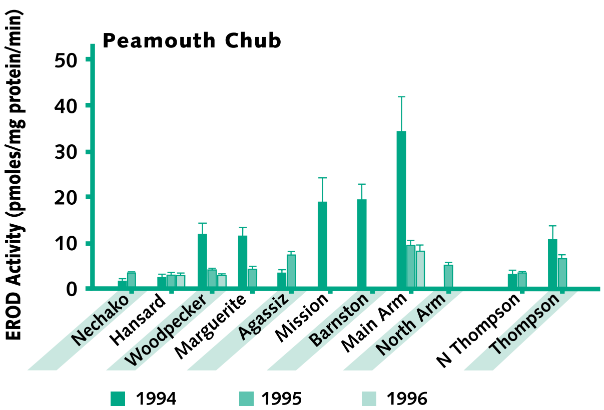


Figure 10. EROD activity levels in peamouth chub in the Fraser River Basin from 1994 to 1996.

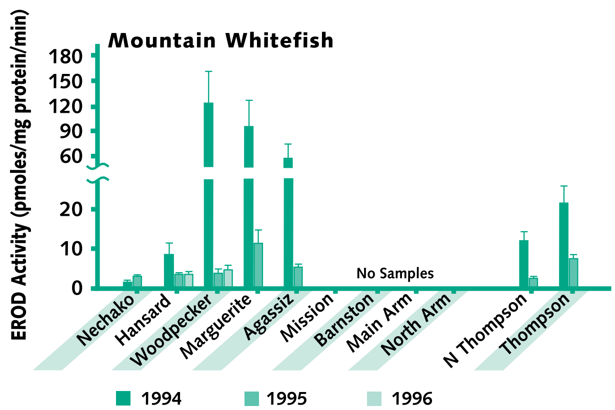


Figure 11. EROD activity levels in mountain whitefish in the Fraser River Basin from 1994 to 1996.

MFO ACTIVITY

MFO enzymes are consistent indicators of exposure to certain organic contaminants found in pulp mill effluent and urban runoff. EROD activity was induced downstream of urban centres and pulp mills in the Fraser Basin. (Fig. 10, Fig. 11). EROD induction in peamouth chub was highest in the Main Arm. Compared to reference reaches, up to 18- and 78-fold increases were seen in peamouth chub (Main Arm) and mountain whitefish (Woodpecker), respectively. These levels of induction were above levels seen in mountain whitefish collected downstream of pulp mills from the Wapiti River (30-fold), where there were no observed health effects (Swanson *et al.* 1993), and from the Columbia River (13-fold) where health effects were observed (Nener *et al.* 1995). There were no significant relationships between EROD induction and health effects in this study.

Higher EROD induction was measured in 1994 than in 1995 and 1996. The year to year variability could be attributed to either the low flow condition of the Fraser River in 1994 or a change in methodology between 1994 and 1995.

Data on contaminants in suspended and bed sediments were collected by FRAP studies concurrently from the same reaches as EROD activity (Sekela *et al.* 1995; Brewer *et al.* 1998; Sylvestre *et al.* 1998). The strongest relationship between EROD activity and body burdens of specific contaminants or classes of contaminants, or sediment contaminant levels, was with TEQs (dioxin, furan and PCB) in mountain whitefish liver in 1994 (r=0.89, p=0.05, n=5) (Figure 13). The correlation between EROD and TEQs in peamouth chub liver was weaker (r=0.70, p=0.05, n=8) (Figure 12); additionally, there were weak significant relationships between peamouth chub EROD and liver pesticide residues as well as bed sediment retene. The weak correlations between specific contaminants and EROD activity may be due to low contaminant body burdens, an unmeasured inducer, and/or synergistic/additive effects of complex mixtures.

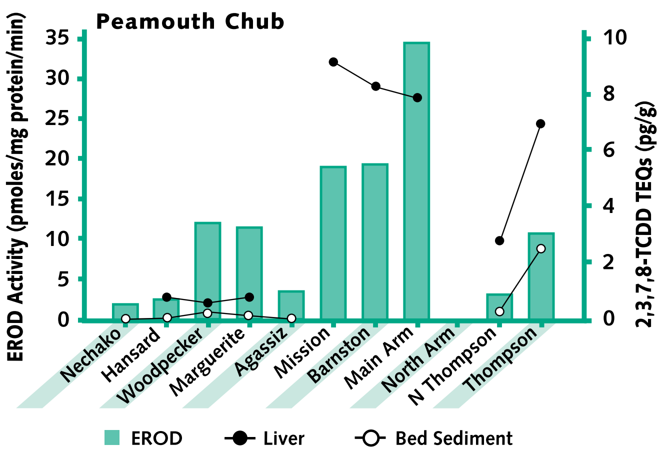


Figure 12. *EROD activity levels and dioxin, furan and PCB TEQs for peamouth chub liver and bed sediment in the Fraser River Basin in 1994.*

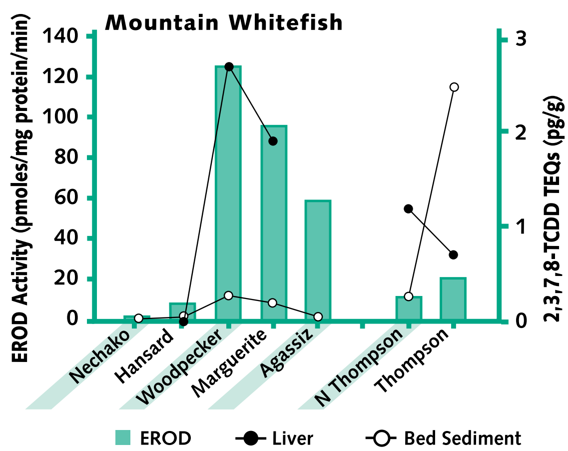


Figure 13. *EROD activity levels and dioxin, furan and PCB TEQs for mountain whitefish liver and bed sediment in the Fraser River Basin in 1994.*

FISH CONDITION, ENERGY RESERVES, GROWTH RATES, AND REPRODUCTIVE INDICATORS

Fish condition indices, based on the length-weight relationship, energy reserves, growth rates, and relative gonad size (gonadosomatic index) are generally used as indicators of the well-being of fish (Adams and Ryon 1994; Munkittrick 1992; Goede and Barton 1990). Low condition, energy reserves, and gonadosomatic index may be caused by stress such as contaminant exposure, but they also fluctuate seasonally with feeding activity, migrations and sexual maturation. In this study, energy reserves were assessed using lipid levels in major lipid storage depots—muscle for mountain whitefish and liver for peamouth chub—and a qualitative mesenteric fat index for both. Fish lengths, adjusted for the basin-wide mean ages (size-at-age), were used as indicators of growth rates. Condition indices and fat reserves are presented in Figures 14 and 15, size-at-age in Figures 16 and 17, and gonadosomatic indices in Figures 18 and 19. Mesenteric fat indices are not presented but they exhibited patterns similar to the lipid levels. Higher condition indices, lipid reserves, growth rates, and gonadosomatic indices infer better condition.

Peamouth chub condition indices, fat reserves and growth rates were all highest in the Nechako, Thompson and lower Fraser rivers. This was probably due to higher temperatures and lower sediment levels in the Thompson and Nechako rivers, and higher temperatures in the lower Fraser resulting in higher productivity. Peamouth chub condition and growth rates were lowest at Marguerite in the central basin downstream of Prince George and Quesnel. The low condition and growth rates may be due to contaminant inputs but were likely due to high suspended sediment levels causing stress on fish and reducing productivity in the river. Scrivener *et al.* (1994) suggested that sediment levels in the Fraser River downstream of Quesnel in

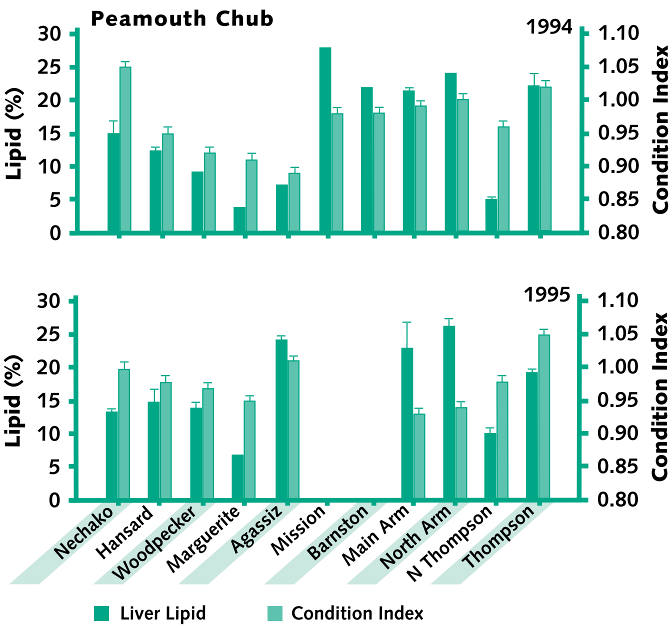


Figure 14. *Peamouth chub liver lipid levels and condition indices in the Fraser River Basin from 1994 and 1995.*

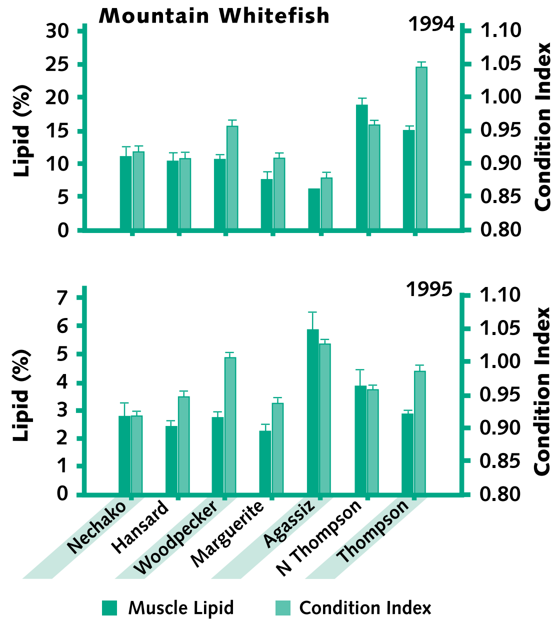


Figure 15. *Mountain whitefish muscle lipid levels and condition indices in the Fraser River Basin in 1994 and 1995.*

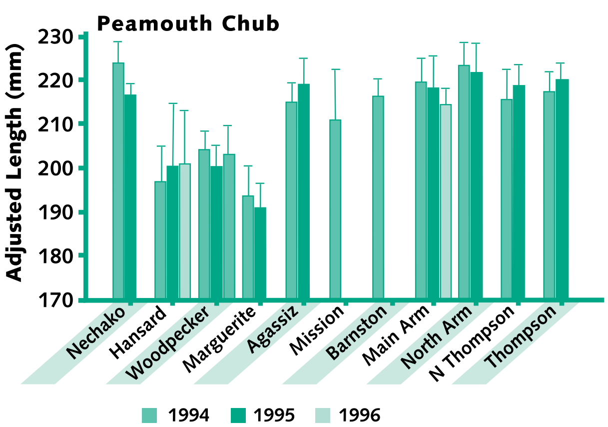


Figure 16. *Peamouth chub size-at-age—mean lengths adjusted for mean age 6.03 years.*

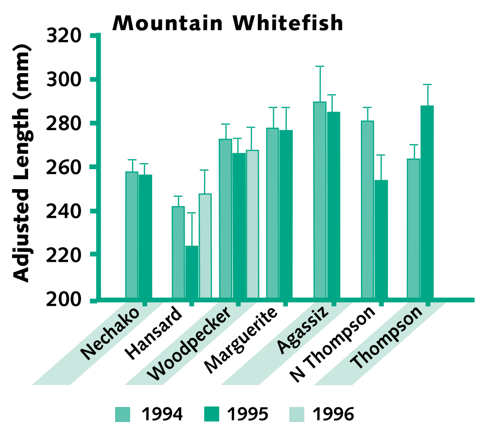


Figure 17. *Mountain whitefish size-at-age—mean lengths adjusted for mean age 4.10 years.*

spring and summer were high enough to harm juvenile salmonids by disrupting feeding, growth and social behaviour and increasing susceptibility to disease.

In contrast, mountain whitefish condition indices and lipid reserves were generally similar among reaches in the Nechako and Fraser rivers, and highest in the Thompson basin reaches. Condition was high at Woodpecker and Agassiz (in 1995) compared to other Fraser reaches. Growth rates increased from north to south (upstream to downstream), indicating that latitude and altitude were the primary controlling factors.

Mountain whitefish trends may be different from peamouth chub because mountain whitefish can migrate long distances (Swanson *et al*. 1993) and may not be good indicators of environmental factors at their capture sites. McPhail (1999) studied the movement of mountain whitefish in the Fraser River near Prince George. McPhail's research indicates that individual mountain whitefish return to the same summer forag-

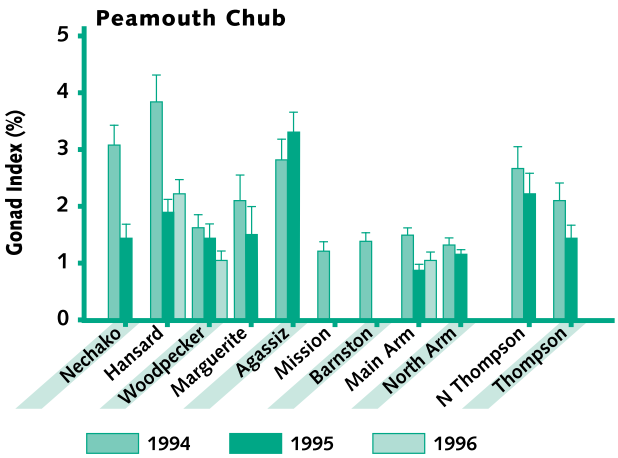


Figure 18. *Peamouth chub gonadosomatic index – gonad size as a percentage of body weight.*

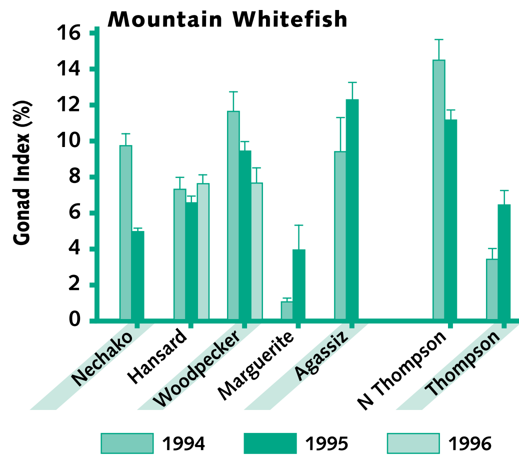


Figure 19. *Mountain whitefish gonadosomatic index – gonad size as a percentage of body weight.*

ing sites every year and that there is very little movement during the summer feeding period. However, fall aggregations in the main stem and large tributaries, which were sampled in this study, may contain mountain whitefish from various summer feeding locations, including smaller tributaries.

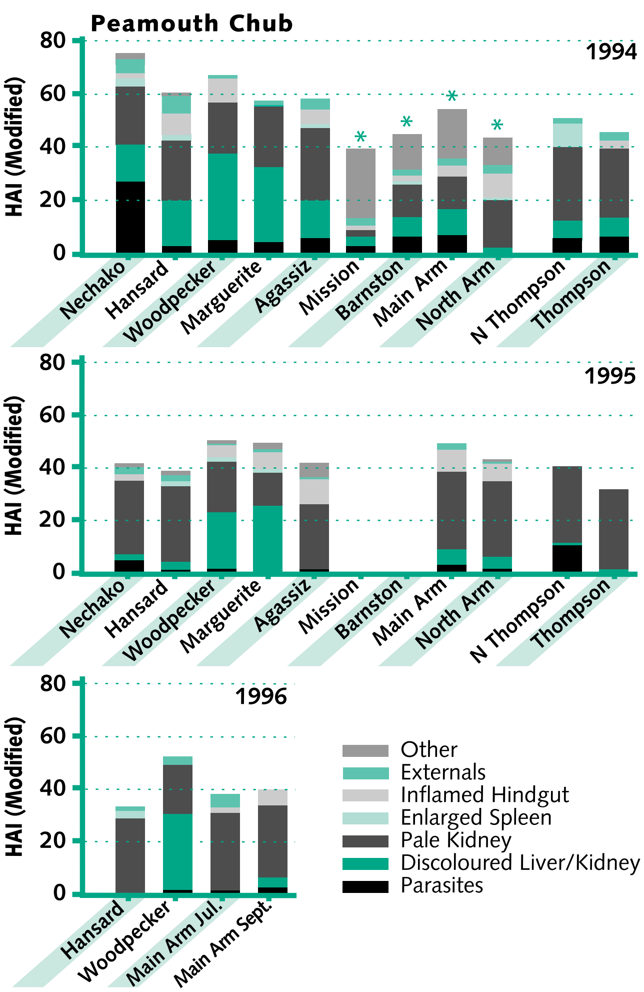
A standard weight equation has been calculated for mountain whitefish. This equation was developed by Rogers *et al.* (1996) to allow fisheries managers to compare condition of mountain whitefish among populations over a wide geographical range. Relative weights are calculated from the equation to produce values similar to the condition index, with the optimal relative weight being 100 per cent. Mean relative weights for the Fraser Basin ranged from 78.6 per cent to 91.7 per cent, except at Agassiz in 1995 (101.1%). These data indicate that mountain whitefish from the Fraser Basin were thinner than optimal for the species and that problems may exist in food and feeding relationships (Anderson and Gutreuter 1983). However, genetic dimorphism in Fraser Basin mountain whitefish populations, with some adults having a long, slender snout and thinner bodies ("pinnochios"), may result in low condition indices which may bias estimates of fish health (McPhail 1999).

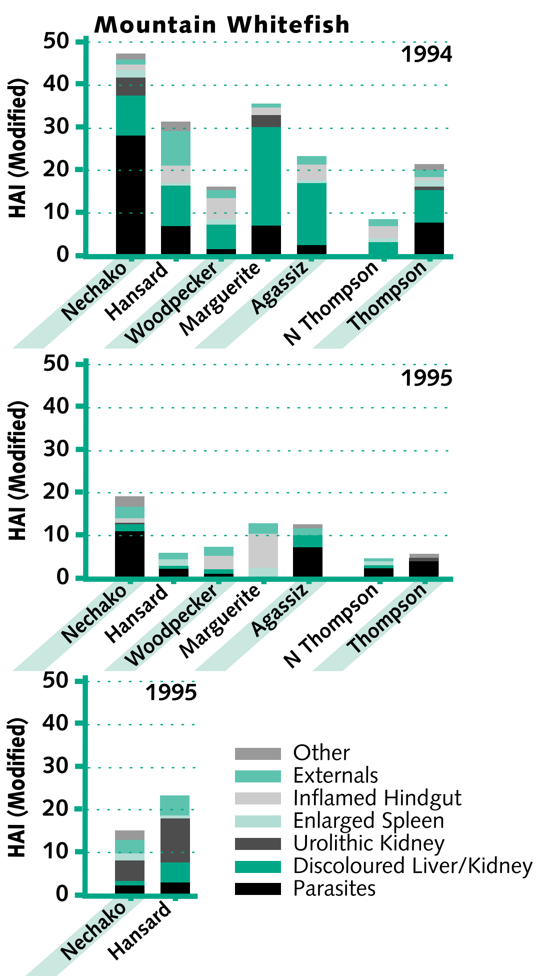
Although sampling dates were partially standardized to eliminate seasonal effects, reaches were sampled a month earlier in 1995 than in 1994. It may be noted from the figures that condition and lipid reserves at Agassiz, the latest-sampled reach, were lowest in both species in 1994 but highest in 1995. These year-to-year differences in condition may reflect seasonal effects due to the change in sampling dates. In addition, fish were sampled in a north (Hansard) to south (Agassiz) progression, from mid-September to early November in 1994. The upstream to downstream decrease in peamouth chub condition indices and fat reserves in 1994 may also be partially explained by seasonal effects. However, the same pattern was still evident in 1995 when the sampling was conducted earlier.

Gonadosomatic indices (GSI) were measured as an indicator of reproductive maturity and capacity. Generally, larger GSI indicates greater maturity and capacity. Age- or size-at-maturity are also important indicators because the age and size at which fish achieve reproductive maturity affects reproductive capacity of the population (Weatherley and Gill 1987). For both fish species, GSI were low and age/size-at-maturity were high in the central basin at Marguerite and in the Thompson River compared to upstream reaches, indicating impaired reproductive capacity. This was particularly the case for mountain whitefish females from Marguerite, which had small, and sometimes swollen and discoloured gonads, despite large body size. Perhaps mature mountain whitefish move out of these reaches to spawn, *i.e.*, into tributaries from the central main stem Fraser or up the North Thompson from the Thompson River; therefore we could be sampling only from populations that were not spawning. However, the fact that both reaches are immediately downstream of pulp mill inputs and urban centres suggests that more study is warranted to assess whether or not contaminants are causing the impairment.

FISH HEALTH

An elevated HAI has been linked to contaminant exposure and associated decreased growth and condition in other studies (Adams *et al.* 1993; Adams *et al.* 1996). In the Fraser Basin, HAIs did not increase downstream of urban centres and pulp mills and, therefore, did not appear to be associated with contaminant exposure or EROD activity (Figure 20, Figure 21). In fact, HAIs at reference reaches, where contaminant levels were low, were generally higher than or comparable to other reaches in the basin. The highest HAIs occurred in the Nechako River, due primarily to heavy parasite infestations. In addition, the pattern of variability in the HAI was different from those of condition, lipid levels and growth. Therefore, in this study, observed "abnormalities" used to compute the HAI cannot be linked to decreased growth and condition.





*** Note that "Other" category is mostly undescribed abnormal kidneys**

Figure 20. Peamouth chub HAIs at reaches in the Fraser River Basin from 1994 to 1996.

Figure 21. Mountain whitefish HAIs at reaches in the Fraser River Basin from 1994 to 1996.

One possible response to contaminant exposure was a high incidence of discoloured (highly pigmented) organs of both species downstream of Prince George and Quesnel at Woodpecker and Marguerite, respectively. Discoloured or dark kidneys and livers were also seen in mountain whitefish sampled downstream of a pulp mill and metals smelter at Trail on the Columbia River (Nener *et al.* 1995) and in peamouth chub sampled for the pulp mill EEM program at Prince George, Woodpecker and Quesnel (Hatfield Consultants Ltd. 1996a).

HAIs and their component abnormalities varied between species, among reaches and even between years within the same reaches, confounding the interpretation of the data. Examples of this variability are:

1. Peamouth chub HAIs were higher than mountain whitefish primarily because all peamouth chub kidneys were swollen and most were pale. Pale, swollen kidneys may be normal for this species or be caused by a myxosporidean parasite that infested all peamouth chub collected in this study.

2. HAIs and parasite ratings were highest in 1994, possibly a result of the extreme low flows and high water temperatures in the Fraser Basin in 1994.

3. Mountain whitefish from Marguerite had the second highest HAIs (after Nechako) in both 1994 and 1995, the result of discoloured livers in 1994 and inflamed hindguts in 1995.

In spite of observing the above health assessment abnormalities, microscopic (histological) examination of tissues indicated that tissues were generally in good condition. As with the HAI, histological abnormalities did not appear to be related to contaminant exposure, since incidences were as high at reference reaches as at downstream reaches. Most histological abnormalities were attributed to parasite infestations, which were most common in the Nechako River.

CONCLUSIONS AND RECOMMENDATIONS

- Peamouth chub and mountain whitefish were successfully used as indicators of contaminant exposure in fish in the Fraser Basin – they were captured throughout the basin and showed differences in contaminant levels and MFO induction between sites upstream and downstream of contaminant sources.

- Levels of organochlorine contaminants and metals in tissue were virtually unchanged between 1994 and 1995, were low relative to existing environmental and human health guidelines, and have declined significantly from historical levels. These compounds could be measured at long-term intervals to monitor trends unless some local change dictates a closer interval.

- Despite the success in removing or reducing release of persistent organochlorines in the environment, residues continue to be detected in fish tissues. The cumulative effect of these contaminants and their metabolic transformation products should remain a subject of some concern.

- The value of peamouth chub and mountain whitefish as indicator species for the Fraser Basin will be enhanced with a better understanding of their life histories to support interpretation of health and contaminant data. Data need to be acquired on patterns of movement and geographic and temporal variability in parasitism, condition, biochemistry, physiology, reproduction and growth. Results from this study support this recommendation. Two years was too short a time period to establish baselines of fish condition—variability between the years in the health assessment, somatic indices and growth was significant, particularly at Agassiz and in the Thompson basin.

- The increase in PAHs in fish tissue in the estuary is of concern because of continuing population growth in the Lower Fraser Valley. Levels and effects of these compounds should continue to be monitored to assess the effectiveness of urban pollution abatement activities. Suitable methods for monitoring PAH biomarkers or metabolites need to be developed and applied.

- Environmental levels of non-bioaccumulating compounds, such as current-use pesticides and surfactants, and their effects on fish, need to be assessed.
- One goal of this study was to assess effects of contaminants on fish health in the Fraser Basin. However, elevated contaminant levels in environmental samples could not be linked to elevated HAI or decreased growth and condition because the specific factors affecting these variables could not be isolated. Many natural factors, such as flow, sediment loads and temperature, which affect fish health, growth and condition, were too variable over the large geographic area sampled to allow for a separation of effects due to contaminants alone. Local, sub-basin comparisons over a gradient of contaminant levels or long term experimental exposures may be more successful in assessing the effects of contaminants on fish health.
- Contaminant levels and fish health were assessed in the main stem Fraser and its largest tributaries because of concerns about high-volume point sources of contaminants in these reaches. As contaminants from non-point sources in small tributaries flowing through urban and agricultural areas are not as diluted as those entering the main stem or larger tributaries, it is likely that fish condition and HAI responses would be more definite in such streams. It is recommended that selected streams exposed to non-point sources should be assessed with techniques utilized in this study.

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