# 3.7

# FISH COMMUNITY STRUCTURE AND INDICATOR SPECIES


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**This chapter summarizes the characteristics and distribution of fish assemblages within the Fraser Basin. The detailed information has been assembled in a database which will provide a baseline for the assessment of future changes in both the distribution of individual species and the characteristics of fish assemblages in different portions of the basin. The chapter includes an in-depth assessment of the life history, habitat use and seasonal movements of mountain whitefish (*Prosopium williamsoni*) in the Prince George region of the Fraser Basin. This information is then examined to assess the suitability of the species as an indicator species for contaminant tracking in this reach of the Fraser and, to some degree, in other reaches of the Fraser and its major tributaries (*e.g.* the Thompson River).**


## FISH DISTRIBUTION AND COMMUNITY STRUCTURE

The core of this project is a database consisting of information on the distribution of fishes throughout the entire Fraser Basin (*i.e.* from the estuary to Yellowhead Lake) (McPhail *et al*. 1998). The bulk of the information in the database comes from the fish collection in the Department of Zoology at the University of British Columbia, but also includes information from the Royal British Columbia Museum; BC Ministry of Environment, Lands and Parks; Department of Fisheries and Oceans; and grey literature (unpublished theses, consultants' reports and government files). Although the database does not include the detailed physical and geomorphological data available in larger government databases, it is designed to interact with them through Geographic Information System programs like ArcView.

A unique property of this database is that it includes distributional information on all 59 species (native and introduced) that occur within the Fraser Basin above the estuary. In contrast, the larger government fisheries databases (both provincial and federal) rarely contain data on species other than salmonids and, when they do contain information on other species, the identifications are unreliable. Thus, the main strength of this database is the breadth and reliability of its coverage of species distributions.

Analysis of the distribution of the 40 native freshwater species in the drainage system and the eight marine species that regularly enter the river (Table 1; see the end of the chapter) suggests three natural species assemblages. An estuarine assemblage (Table 2; see the end of the chapter) occupies the estuary (out to Sturgeon Bank) and the river to the upper limits of tidal influence at Mission. An example of the distribution of a typical estuarine species (starry flounder, *Platichthys stellatus*) is given in Figure 1. A lower river assemblage occupies the river from Mission upstream to the Fraser Canyon (Table 3; see the end of the chapter). This assemblage is characterized by eight native species not found upstream of this reach in the Fraser system. An example of the distribution of a typical lower river species (threespine stickleback, *Gasterosteus aculeatus*) is presented in Figure 2. A distinctive upper river assemblage occupies the river upstream of the Fraser Canyon (Table 4; see the end of the chapter). This assemblage is characterized by six species and one subspecies that are not found below the canyon. Two other species (lake trout [*Salvelinus namaycush*] and lake whitefish [*Coregonus clupeaformis*]) originally absent below the canyon have been transplanted from the upper basin to the lakes in the lower basin. An example distribution of a typical upper river species (lake chub, *Couesius plumbeus*) is also presented in Figure 2.

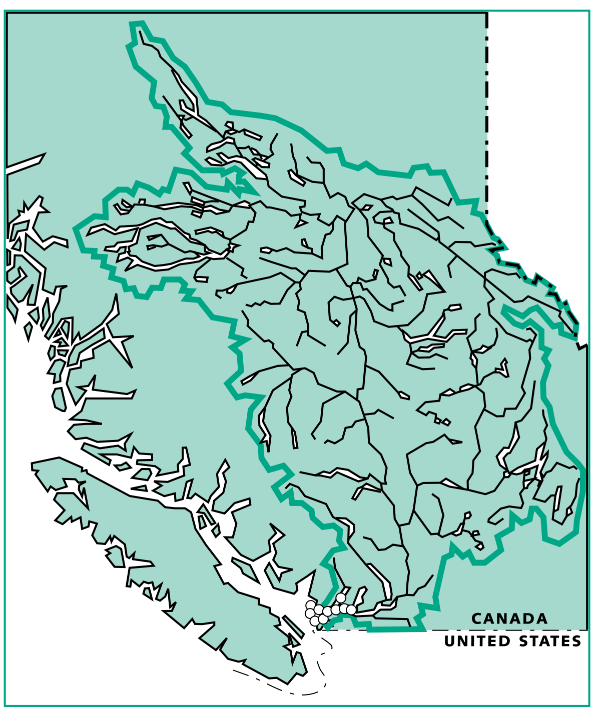


***Figure 1.*** *The Fraser Basin distribution of the starry flounder,* Platichthys stellatus, *a typical member of the Fraser estuarine assemblage.*

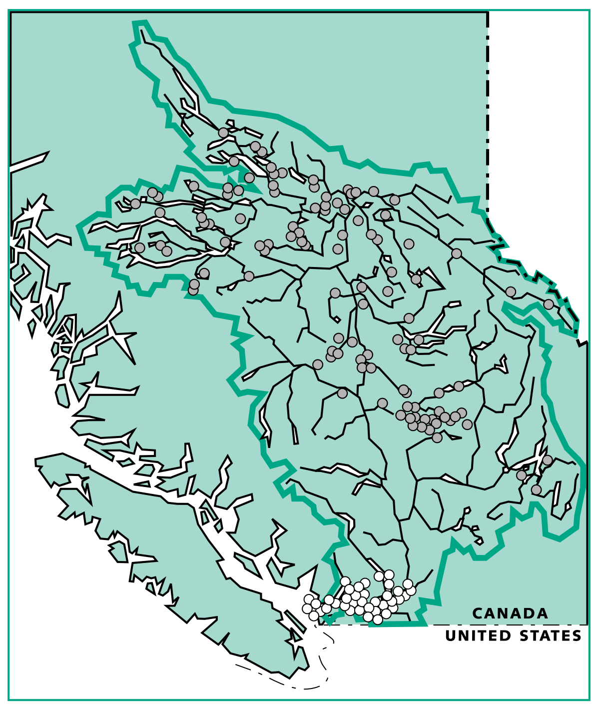


***Figure 2.*** *The Fraser Basin distributions of the threespine stickleback,* Gasterosteus aculeatus, *and the lake chub,* Couesius plumbeus, *typical members, respectively, of the lower and upper Fraser assemblages.*

The upper river assemblage is further divisible into a species assemblage that occupies the river from the Fraser Canyon upstream to about the confluence of the Bowron and Fraser rivers, and an assemblage that occupies the river above this junction. This uppermost assemblage is characterized by the loss of species—eight species common in the Prince George area (*e.g.* the Nechako River drainage) drop out somewhere between Prince George and the confluence of the Fraser and Bowron rivers (Table 5). The distribution of the white sucker (*Catostomus commersoni*) is typical of species that drop out of the fauna upstream of Prince George (Figure 3). Above this junction, the main stem fish assemblage is dominated by species adapted to life in swift glacial rivers. Interestingly, similar reductions in diversity occur in the upper parts of most Fraser River tributaries, often involving the same species (McPhail and Carveth 1992). Tables 2, 3 and 4 also indicate relative abundance of each species as estimated by the author.


***Figure 3.*** *The Fraser Basin distribution of the white sucker,* Catostomus commersoni, *a species that drops out of the upper river assemblage between Prince George and the confluence of the Fraser and Bowron rivers.*

Another set of species is found throughout the entire Fraser Basin. These species (Table 6) are ecological generalists tolerant of a wide range of environments. One goal of the Fraser River Action Plan (FRAP) was to identify and assess the suitability of fish species such as these as indicators of aquatic ecosystem health, particularly for bioaccumulative toxic chemicals. One desirable characteristic of an indicator species is a basin-wide distribution in the drainage system. This set of widespread species constitutes the pool of potential indicator species. Most of these fish are resident in the river throughout their life cycle and occupy a variety of habitats, both among species and at various life history stages. The two salmon species only reside in the basin during their first year and in their short spawning period. Figures 4 and 5 show the Fraser distribution of two promising potential indicator species: the mountain whitefish and the peamouth chub (*Mylocheilus caurinus*).

An alternative to using one or a few indicator species is to use fish assemblages to monitor, detect and assess anthropogenic impacts on aquatic ecosystems (Scott and Hall 1997). Fish assemblages and individual species distributions are known to change when habitats are modified (Li *et al.* 1987; Rutherford *et al.* 1987) and various authors have attempted to quantify such changes (for a review see Fore *et al.* 1994). In the Fraser system, in the vicinity of Prince George, it is clear that the fish assemblages in some tributary streams have changed in the last three decades. An example is Wright Creek, a tributary of the Salmon River near Prince George. Table 7 presents a list of the species present in Wright Creek in the early 1960s and in the mid-1990s. In this case, the number of species in the creek has been reduced to almost half the number present three decades ago. Interestingly, the species that have disappeared all require cool, clean water.

Similar shifts in species composition have occurred in Lower Fraser Valley tributaries and, perhaps, in the Thompson system. So far, there is no evidence of species loss in the main stem Fraser; however, it is clear that some species (*e.g.* eulachon, *Thaleichthys pacificus*) have declined dramatically in the last two decades (Hay *et al.* 1997). Some of this decline is due to over-fishing but at least part of the decline probably results from exposure to contaminants in the lower river (Rogers *et al.* 1990). Similarly, white sturgeon (*Acipenser*

*Table 5. A comparison of the fish faunas of the Nechako and upper Fraser River (above the confluence with the Bowron River).*

| SCIENTIFIC NAME | COMMON NAME | NECHAKO | UPPER FRASER |
|---|---|---|---|
| *Lampetra tridentata* | Pacific lamprey | + | - |
| *Acipenser transmontanus* | white sturgeon | + | + |
| *Couesius plumbeus* | lake chub | + | + |
| *Hybognathus hankinsoni* | brassy minnow | + | - |
| *Mylocheilus caurinus* | peamouth chub | + | + |
| *Ptychocheilus oregonensis* | northern squawfish | + | + |
| *Rhinichthys cataractae* | longnose dace | + | + |
| *Rhinichthys falcatus* | leopard dace | + | - |
| *Richardsonius balteatus* | redside shiner | + | + |
| *Catostomus catostomus* | longnose sucker | + | + |
| *Catostomus columbianus* | bridgelip sucker | + | - |
| *Catostomus commersoni* | white sucker | + | - |
| *Catostomus macrocheilus* | largescale sucker | + | - |
| *Oncorhynchus mykiss* | rainbow trout | + | + |
| *Oncorhynchus nerka* | sockeye salmon | + | + |
| *Oncorhynchus tshawytscha* | chinook salmon | + | + |
| *Salvelinus confluentus* | bull trout | + | + |
| *Salvelinus malma* | Dolly Varden | + | - |
| *Salvelinus namaycush* | lake trout | + | + |
| *Coregonus clupeaformis* | lake whitefish | + | + |
| *Prosopium coulteri* | pygmy whitefish | + | + |
| *Prosopium williamsoni* | mountain whitefish | + | + |
| *Lota lota* | burbot | + | + |
| *Cottus asper* | prickly sculpin | + | - |
| *Cottus cognatus* | slimy sculpin | + | + |

*+ indicates presence*
*- indicates absence*

*Table 6. A list of species found throughout the Fraser Basin (potential indicator species).*

| SCIENTIFIC NAME | COMMON NAME |
|---|---|
| *Acipenser transmontanus* | white sturgeon |
| *Mylocheilus caurinus* | peamouth chub |
| *Ptychocheilus oregonensis* | northern squawfish |
| *Rhinichthys cataractae* | longnose dace |
| *Richardsonius balteatus* | redside shiner |
| *Oncorhynchus mykiss* | rainbow trout |
| *Oncorhynchus nerka* | sockeye salmon |
| *Oncorhynchus tshawytscha* | chinook salmon |
| *Salvelinus confluentus* | bull trout |
| *Prosopium williamsoni* | mountain whitefish |

*Table 7. Changes in the fish assemblage in Wright Creek (1954–1996).*

| SPECIES PRESENT IN THE 1950s Scientific and Common Name | | PRESENT IN 1996 |
|---|---|---|
| *Oncorhynchus mykiss* | rainbow trout | |
| *Oncorhynchus tshawytscha* | chinook salmon | ✓ |
| *Prosopium williamsoni* | mountain whitefish | |
| *Catostomus catostomus* | longnose sucker | |
| *Catostomus columbianus* | bridgelip sucker | ✓ |
| *Ptychocheilus oregonensis* | northern squawfish | ✓ |
| *Rhinichthys cataractae* | longnose dace | ✓ |
| *Richardsonius balteatus* | redside shiner | ✓ |
| *Lota lota* | burbot | |
| *Cottus cognatus* | slimy sculpin | |

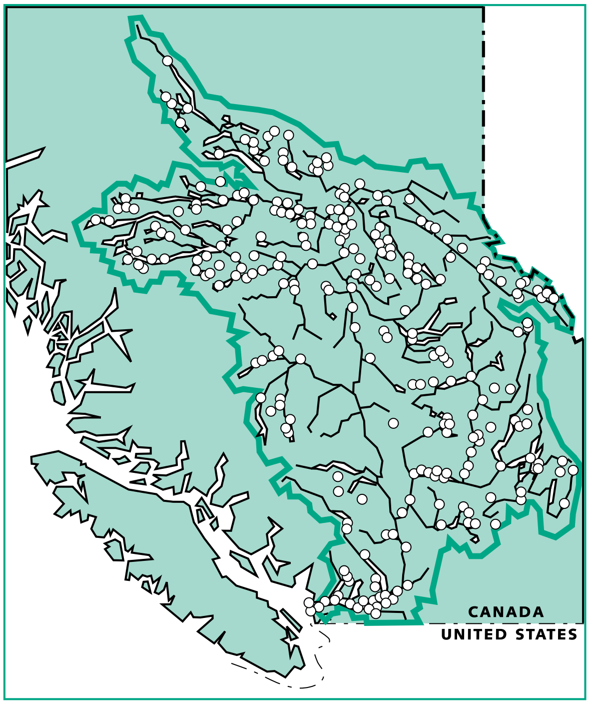


***Figure 4.*** *The Fraser Basin distribution of the mountain whitefish,* Prosopium williamsoni, *a potential indicator species in the Fraser Basin.*

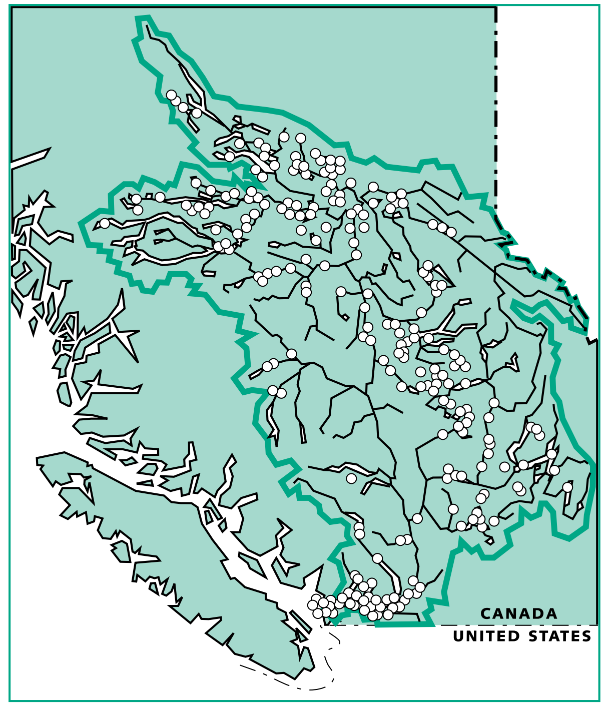


***Figure 5.*** *The Fraser Basin distribution of the peamouth chub,* Mylocheilus caurinus, *a potential indicator species in the Fraser Basin.*

*transmontanus*) in the Fraser system have declined to the point that they are listed by the Committee on Endangered Wildlife in Canada (COSEWIC) as "vulnerable" (Lane 1991). Consequently, there is no longer a commercial fishery for this species and the recreational fishery is catch and release only. The Fraser distribution of another fish, the Salish sucker (a genetically distinct form of longnose sucker, *Catostomus catostomus*), has contracted dramatically in the last few decades and COSEWIC now lists it as an "endangered" species (McPhail 1987).

Fish assemblages have been used to assess and monitor anthropogenic impacts in other northwestern drainage systems (Friesen and Ward 1996; Hughes and Gammon 1987) and there is no reason to suppose they would not be useful in the Fraser system. Monitoring with fish assemblages would be relatively simple—a series of permanent stations could be identified on the lower, middle and upper Fraser. Initially, to establish a normal range of seasonal and annual variation in species number and abundance, these stations would have to be sampled for several years. Once this baseline was established, the stations likely would only need to be sampled once a decade to detect changes in the state of fish assemblages in the river. An advantage of using fish for this purpose is that no elaborate equipment is needed for sampling and fish are easy (relative to invertebrates) to identify. With their intimate knowledge of the river and concern for traditional fisheries, First Nations groups along the river might provide the monitoring crews.

Potentially, both individual fish species and fish assemblages can be used to monitor the health of aquatic ecosystems. Individual species are probably best used for contaminant monitoring, but they are also useful in detecting local changes in distribution. Typically, the local distribution of species changes before differences in the composition of entire fish assemblages can be detected. For example, the fish assemblage in the Salmon River near Fort Langley contains the same species in 1997 (pers. observ.) as it did in 1954 (Hartman 1968); however, over this same time period, the distribution of the Salish sucker within this river contracted steadily and the species is now confined to only a small section of the upper river (Inglis *et al.* 1992). In contrast to individual species, assemblages are best at detecting subtle environmental changes. This is because interactions among species can be sensitive to minor changes to the environment. For example, the competitive interaction between rainbow trout (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*) appears to change with temperature—in cold water bull trout are dominant (in terms of numbers), but in only slightly warmer water rainbow trout predominate (Parkinson and Haas 1996). Potentially, changes in the relative abundance of these two species could be used to detect subtle changes in the annual temperature regime of a river. Similarly, the observation that exotic species are associated with altered habitats (Karr 1981) suggests that the ratio of introduced to native species in an assemblage could be used to assess anthropogenic impacts on aquatic ecosystems.

## BIOLOGY OF MOUNTAIN WHITEFISH

The rest of this chapter focuses on the considerations that must be taken into account when using mountain whitefish as an indicator species. (FRAP also evaluated peamouth chub as an indicator [Culp and Lowell 1999] and both species were used to assess the health of fish populations throughout the basin [Raymond *et al.* 1999]). While the mountain whitefish has been used as an indicator species for tracking contamination in northwestern rivers like the Columbia (Nener *et al.* 1995), the Fraser (Mah *et al.* 1989; Dwernychuk *et al.* 1993) and the Athabasca/Peace system (Muir and Pastershank 1996), remarkably little is known about its biology. Northcote and Ennis (1994) reviewed the biology of the mountain whitefish throughout its geographic distribution. Their review reveals two aspects of its biology that are of potential concern regarding the species' usefulness as an indicator of fish health and contaminant loads: (1) the complex migrations that appear to be characteristic of this species and (2) the species' propensity to form local populations (stocks). If mountain whitefish regularly move between the main stem Fraser and its tributaries, their exposure to contaminants in the main river may be sporadic or occur only at certain life-history stages. Also, if there are distinct stocks in the region that differ in the pattern of their migrations, these stocks may differ in the length of time they are exposed to main stem contaminants.

From the perspective of using mountain whitefish as an indicator species in the basin, there are two important questions to be answered about their biology: (1) are there different stocks in the upper Fraser system and, specifically, is there a stock resident in the main stem Fraser and (2) do samples collected from fall aggregations of mountain whitefish reflect the contaminant loads of main stem residents, or are these aggregations mixtures of stocks with potentially different histories of exposure to contaminants?

To address these questions, this project examines the movements, stock structure, and general biology of mountain whitefish in the Fraser River and its tributaries near Prince George (McPhail and Troffe 1998). This region was chosen because there were other studies planned under FRAP in this same area to examine the effects of pulp mill effluent on benthic communities and on peamouth chub (Culp and Lowell 1999; Raymond *et al.* 1999).

In British Columbia, most mountain whitefish populations spawn from mid-October through November at temperatures ranging from about 3–5ºC (Northcote and Ennis 1994); however, some populations spawn as late as February (McPhail and Lindsey 1970; Anonymous 1997). Spawning was not directly observed in the Prince George area but running-ripe mountain whitefish were collected in October 1995, both in the Nechako River about one km above its confluence with the Fraser and in the main stem Fraser. At about the same time, males with fully developed spawning tubercles were observed in the lower Willow and Bowron rivers. Thus, spawning times in the study area appear to be consistent with other B.C. sites. The eggs incubate over winter and newly emerged fry appear in late April. These fry are distributed throughout the main stem Fraser and its tributaries, suggesting that spawning occurs in both the main river and throughout the length of some major tributaries (*e.g.* the Willow River). Thus, the fry at different sites are exposed to different temperature regimes, and temperature clearly influences the growth rate of the fry. In the warmer western tributaries (*e.g.* Nechako and Chilako rivers), fry grow more rapidly and reach a larger size by the end of the growing season than fry in the cooler eastern tributaries (*e.g.* McGregor and Bowron rivers). These differences in first year growth produce different scale circuli counts in different tributaries and provide a scale signature that stays with the fish for life. The scale signatures on adults taken from a late-fall aggregation of mountain whitefish near the mouth of Naver Creek strongly suggest that the fish in this aggregation are of mixed origins.

Newly emerged fry concentrate in shallow, quiet water (a habitat they share with young-of-the-year chinook salmon). Typically, such sites are deposition areas and the substrate is fine sand or mud. This habitat preference confines the young-of-the-year to the edges of streams and rivers. Thus, in the main stem Fraser this life-history stage will more often come in contact with shore-hugging contaminant plumes than other life-history stages. Towards the end of their first growing season the young-of-the-year move into slightly deeper, faster water. It is not known where they over-winter.

Juveniles ($1^+$ years of age) also occur throughout most of the major tributaries and the Fraser main stem. The most obvious change in habitat use by juveniles relative to fry is a shift to deeper, faster water. In the main stem Fraser, this habitat shift presumably decreases their chances of encountering contaminants directly, but may not isolate them from exposure to food chain contaminants. Like the young-of-the-year, there are among tributaries growth differences in juveniles that suggest a second summer of residence in their natal stream.

In the Prince George area, most mountain whitefish reach sexual maturity at the end of their third summer ($2^+$ years of age). Consequently, if there are spawning migrations, it is at this age that the newly mature adults should move. Generally, adult foraging behaviour and habitat use are more complex than that of either fry or juveniles. Adults occupy deeper water than juveniles and, in clear tributaries where underwater observations can be made, adults concentrate where shallow riffles or rapids break into deeper scour pools or sweep around large woody debris. At such sites, aggregations of adult mountain whitefish maintain position in the current just off the bottom and forage on the drifting juvenile stages of aquatic insects. They are often associated with rainbow trout but, unlike trout, mountain whitefish rarely make foraging movements towards the surface. Because of the turbidity, underwater observations could not be made in the main stem Fraser but, presumably, the behaviour of main stem adults is similar to that of adults in tributary streams. If so, the use of deeper water by main stem adults should decrease their exposure to shore-hugging contaminant plumes. However, their prey could be a more important route of exposure to contaminants in any case.

One aspect of morphology that appears to influence foraging in adult whitefish is a dimorphism in head shape (Figure 6). In some adults the snout is exceptionally long and pointed. These so-called “pinocchios” forage closer to the bottom and direct a higher proportion of their foraging movements towards the substrate than “normal” mountain whitefish. In addition, pinocchios are slimmer than normals and this produces a significant difference in their apparent condition (length-weight relationship). Since condition often is used as a measure of fish health, the proportion of pinocchios in a sample will bias estimates of fish health; however, these are not sick fish and should be recorded separately from normal mountain whitefish.

Whether there is a resident main stem stock, and whether the practice of sampling tissues from late-fall aggregations biases contaminant exposure estimates, are critical questions. Consequently, special efforts were made to examine seasonal movements and stock structure in the Prince George area. Five methods provided information on stock structure and movement patterns: radio-tagging, traditional attached tags, laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) of scales, molecular markers (*i.e.* Restriction Fragment Length Polymorphisms [RFLP]) and scale growth data.

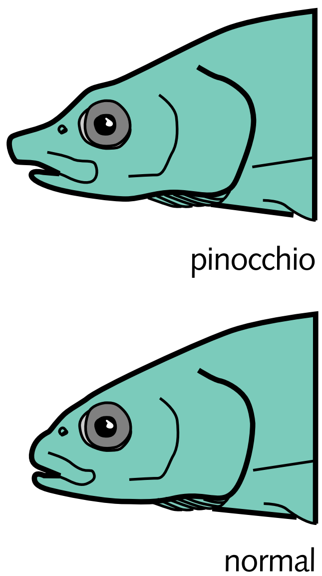


*Figure 6. The head morphology of the pinocchio and normal forms of mountain whitefish.*

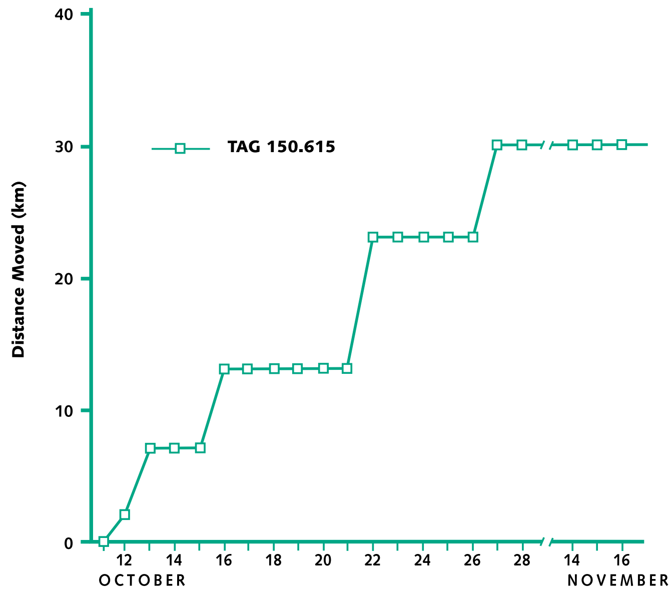


*Figure 7. Example of the fall movements of radio-tagged mountain whitefish.*

Thirteen radio-tags were applied in the late fall of 1995 and mid-April, 1996. The purpose of the fall tags was to examine spawning and over-wintering migrations. The purpose of the spring tags was to document movement from over-wintering sites to summer feeding sites. The fall tags were applied in the Fraser main stem at Prince George and in the Nechako River about one km above its confluence with the Fraser. According to local anglers, mountain whitefish aggregate at the Nechako site in the fall and remain at this site until spring breakup. The fall pattern of movement in both the Fraser and the Nechako fish was similar (Figure 7). In all cases, movement was downstream and proceeded as a series of stops and starts. Typically, tagged fish held position for a few days, then moved rapidly downstream for several kilometres, held position again for a few days and then started down again. They were tracked from October 11 until November 26, or until the tags could no longer be located. The maximum downstream movement before contact was lost was 40 km. Since all of the fall-tagged fish were adults in, or close to, reproductive condition, these downstream movements may be a spawning migration.

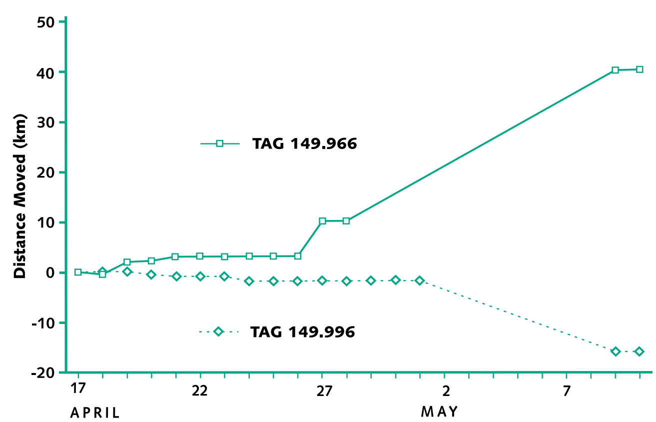


*Figure 8. Examples of the spring movements of radio-tagged mountain whitefish (zero indicates release point; positive values indicate upstream movement, and negative values indicate downstream movements).*

Alternatively, although the tags were the smallest available, they may have been marginal for mountain whitefish and thus the downstream movement could be an artifact. Only five tags were applied in the spring. These were placed on fish angled from the Nechako over-wintering site about one km above the Fraser River. These tags were applied on April 17 and followed until May 11. Like the fall movements, the spring movements proceeded as a series of stops and starts (Figure 8). In this case, however, fish moved upstream into the Chilako River (a Nechako tributary) and downstream into the main stem Fraser. The maximum upstream movement (*i.e.* until contact was lost) was 40 km and the maximum downstream movement was about 15 km.

Although the radio-tag data are limited, they suggest two things. First, that the Nechako site identified as an over-wintering site by local anglers probably is just that—an over-wintering site used by both main stem and tributary fish (Nechako and Chilako). Second, shortly after ice-out, at least some fish move from this site into summer foraging sites in tributary streams and into the main stem Fraser.

Conventional tags were applied in major tributaries (*e.g.* the Bowron, McGregor and Willow rivers) and one minor tributary (Dome Creek), all upstream of Prince George. Dome Creek was chosen because there is a fall aggregation of whitefish near its confluence with the Fraser that was regularly sampled for tissues as a control site in the FRAP fish health assessment program. Thus, if Dome Creek fish were over-wintering at this site, some tags might be recovered during tissue sampling.

Although the number of tags applied in the major tributaries and Dome Creek was relatively small (123), the results of the tag returns are instructive (Table 8). The average time at large for within-season returns was 24 days and all of the within-season returns were within a few metres of the original tagging site. This indicates very little movement during the summer feeding period. Given the low number of tagged fish, the tag returns after one year are startling. Of five fish sampled at the 1995 McGregor River tagging site in 1996, one fish was a recapture from 1995. Similarly, of 14 fish sampled at two tagging sites on Dome Creek in 1997, four were tagged in 1996 at exactly the sites where they were recaptured. These results imply remarkable year-to-year site fidelity in adult mountain whitefish. In Dome Creek, this site fidelity is all the more remarkable since underwater observations and sampling indicated that whitefish had left the tagging areas by the late fall of 1996. It is not known whether they migrated to the main stem Fraser or to the lower

***Table 8.*** *Recaptures of tagged fish (1995–1997).*

| WITHIN SEASON RECAPTURES | | | | |
|---|---|---|---|---|
| LOCALITY | TAGGING DATE | RECAPTURE DATE | ELAPSED TIME (DAYS) | MOVEMENT (m) |
| McGregor | 8/1/95 | 9/20/95 | 50 | 0 |
| Willow | 9/14/95 | 10/24/95 | 41 | 0 |
| Dome | 6/28/96 | 8/5/96 | 38 | 0 |
| Dome | 6/29/96 | 7/1/96 | 2 | 0 |
| Dome | 6/29/96 | 7/19/96 | 20 | 0 |
| Dome | 7/18/96 | 9/9/96 | 72 | 0 |
| Dome | 7/18/96 | 7/18/96 | 0.5 | 0 |
| Dome | 7/18/96 | 8/5/96 | 18 | 0 |
| Dome | 7/19/96 | 8/5/96 | 18 | 0 |
| Dome | 7/19/96 | 7/24/96 | 5 | 0 |
| Dome | 7/19/96 | 7/24/96 | 5 | 0 |
| Dome | 7/19/96 | 8/2/96 | 14 | 0 |
| Dome | 7/24/96 | 7/25/96 | 1 | 0 |
| Dome | 7/24/96 | 9/19/96 | 57 | 0 |
| BETWEEN SEASON RECAPTURES | | | | |
| McGregor | 8/1/95 | 8/1/96 | 365 | 0 |
| Dome | 6/29/96 | 7/30/97 | 396 | 0 |
| Dome | 7/18/96 | 7/30/97 | 378 | 0 |
| Dome | 7/19/96 | 7/30/97 | 377 | 0 |
| Dome | 8/18/96 | 7/31/97 | 357 | 0 |

parts of Dome Creek, but it is clear that on their return migration to summer feeding areas, the tagged individuals return to the exact sites they occupied the previous year. If similar summer foraging site fidelity is typical of main stem fish, then, despite possible spawning and overwintering migrations, they could return annually to contaminated foraging sites.

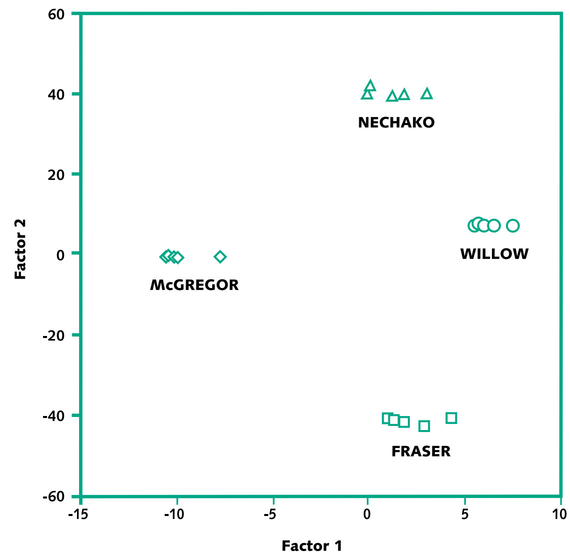


*Figure 9. Principal Components plot based on elemental analyses of mountain whitefish scales from five rivers in the Prince George region.*

Laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) is a technique that allows the assessment of the relative concentrations of various elements in micro-samples. In this case, scales were used as samples since they are calcified and exhibit annular growth (*i.e.* new layers are laid down each growing season). The technique is still in its infancy and the results should be treated with some caution. Still, some of the results are encouragingly consistent with the tagging data. In one analysis the focus (centre) of a scale from five adult individuals from each of four rivers (the main stem Fraser, Nechako, Willow and McGregor) was analyzed for the ratios of 16 elements (normalized to the concentration of $^{48}$Calcium). The fish were sampled during the summer growing season. The results were subjected to Principal Components Analysis and revealed complete separation of the four samples (Figure 9). Since the centre of the scale is laid down in the first growing season, this result implies that the five adult fish in each sample spent their first growing season in the same place—but that the places were different for the four different samples. These results argue that the main stem Fraser and its major tributaries in the Prince George area contain sufficiently distinctive elemental ratios that the portion of the scale laid down in the first growing season can be used to distinguish fish from the main stem and from the different tributaries.

The original intent was to use this initial data to construct a linear discriminant function, and then use this function to classify fall samples taken for contaminant analysis as to stream of origin (*i.e.* to determine if these samples contain a mix of fish of different origins). Unfortunately, without external reference standards of known composition, the technique only provides relative elemental concentrations (normalized to $^{48}$Calcium). Thus, the machine must be recalibrated at every run, and its performance changes over time. Consequently, samples run at different times are not directly comparable and, at its present stage of development, the technique cannot be used to reliably classify fish of unknown origin.

Using the LA-ICPMS technique, however, it was possible to assess the temporal pattern of element exposure. Scales from two adult fish were ablated at eight equally spaced sites from the focus (centre) to the edge of the scale. This was done to determine if there were interpretable changes in the elemental composition in the parts of the scale laid down in different years. Since the eight sites on each scale were sampled consecutively on the same run, the relative concentrations of elements in different parts of the scale are directly comparable. Both of the scales chosen for this analysis showed an abrupt change in the spacing of the circuli in the third or fourth year of life and then a return to the previous circuli spacing pattern. This apparent change in growth rate implies a change in habitat. The change in elemental concentration over the scales was not the same for all elements. Some metals (*e.g.* mercury) steadily increased in concentration from the centre of the scale to the edge, other elements (*e.g.* magnesium) steadily decreased along the same axis, whereas the concentration of still other elements was remarkably variable. A few elements (*e.g.* nickel and rubidium), however, showed a pattern of change in concentration consistent with the circuli pattern on the scale. For these elements there is a clear peak in elemental concentration in the third or fourth year of life followed by a return to the original concentration (Figure 10). One possible interpretation of this pattern is that the fish moved to a new environment, perhaps for spawning or over-wintering, and then returned to the original environment. If this interpretation is correct, it suggests long-term fidelity to a specific elemental environment with occasional short-term shifts to different environments.

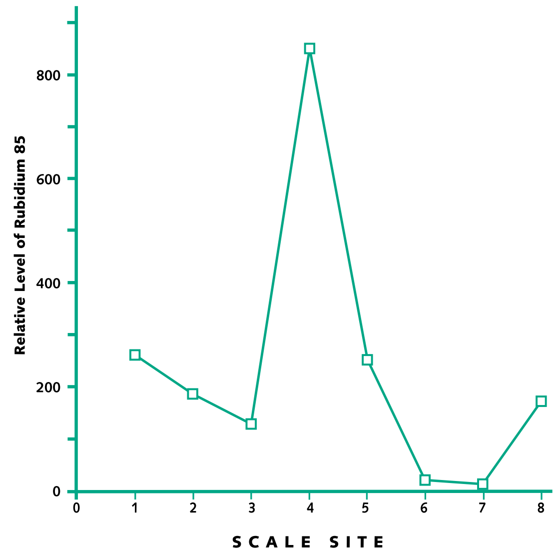


***Figure 10.*** *Relative concentration of $^{85}$rubidium at eight equally spaced intervals across a single adult whitefish scale.*

To determine if there are genetically different stocks of mountain whitefish in the Prince George area, tissue samples from the main stem Fraser and different tributaries were examined for mitochondrial restriction fragment length polymorphisms (RFLP). This technique (Lansman *et al.* 1981) identified six haplotypes in the Prince George area. All sexually reproducing organisms receive one set of nuclear genes from their father and another set from their mother. This allows two forms (alleles) of a gene to coexist in a single organism. In contrast to nuclear DNA, mitochondrial DNA is passed only through the mother. Consequently, each individual possesses only a single set of mitochondrial genes and thus a single allele at each locus. These single alleles are called haplotypes.

Two of the haplotypes identified in mountain whitefish (A and B) were common and geographically widespread, while the other four haplotypes (C, D, E and F) were rare and with more restricted distribution. The frequency of the two common haplotypes varied from site to site but there was no evidence of significant differences in the frequency of the common haplotypes among sites. Interestingly, however, the normal and pinocchio forms of mountain whitefish differed dramatically in the frequency of the two common haplotypes. Haplotype A occurred with about equal frequency in both normals and pinocchios, but haplotype B occurred only in pinocchios. This is clear evidence of a genetic difference between the normal and pinocchio forms of mountain whitefish. How this genetic difference is maintained is unknown, but one possibility is assortative mating. Since mitochondrial haplotypes are passed through the maternal lineage, perhaps normal males rarely, if ever, mate with pinocchio females.

Generally, the frequencies of the rarer haplotypes (C, D, E and F) are too low to permit comparisons among sites. There is, however, one instructive comparison. It is clear that haplotype D is more common in the main stem Fraser than it is in any of the tributaries and, if all of the tributary sites are pooled and compared with the main stem samples, there is a significant ($P<0.05$) difference in the frequency of haplotype D between the tributaries and the main river. Thus, the RFLP analysis suggests the presence of a distinct main stem stock.

In summary, the results of this project indicate that the life history, habitat use and movements of mountain whitefish in the Prince George area are similar to what has been found in other areas (Northcote and Ennis 1994). There is evidence of age-related habitat shifts; complex and individually variable migrations for spawning, over-wintering and summer-foraging sites; different foraging forms; and different stocks. In spite of this biological complexity, mountain whitefish have a number of characteristics that suit them for the role of an indicator species in the Fraser Basin. First, they occur throughout the basin and this permits comparison of samples from pristine sites with samples from sites where the fish are exposed to contaminants. Second, they are sufficiently long-lived (up to 20 years) that there is time for individuals to accumulate contaminants and also time for them to reach a body size that provides sufficient tissue for contaminant analysis. Third, their diet (primarily nymphs and pupae of aquatic insects) is unlikely to be seriously confounded by inputs of terrestrial or aerial contaminants. Fourth, at least some individuals appear to show remarkable fidelity to summer foraging sites. Thus, in spite of evidence from this, and other studies (Pettit and Wallace 1975; Thompson and Davies 1976) for complex spawning, over-wintering, and summer foraging migrations, there is evidence that individual fish return to summer foraging sites that were used in previous years. This suggests that although seasonally some adults move over considerable distances, their patterns of movement can be consistent from year to year. Consequently, on an annual basis, fish that forage in sites exposed to contaminants may return to those sites for a number of summers.

The biggest problem with using mountain whitefish as an indicator species in the main stem Fraser is the difficulty of sampling the species. For much of the year the adults in the main river appear to be dispersed in deep water. They will not enter baited traps, and the depth and turbidity of the water precludes electroshocking from a boat. In tributaries, angling with worms on small hooks is a slow but reliable sampling system for adults and the largest juveniles; however, angling is not effective in the main river. In the Prince George area, the only effective sampling gear is a large seine set from a boat, and even this gear only produces useful catches in the fall when mountain whitefish aggregate near the mouths of tributaries. Furthermore, tagging studies in Idaho (Pettit and Wallace 1975) found that over-wintering aggregations of mountain whitefish were made up of mixed stocks (*i.e.* fish that use different summer foraging sites). In the upper Fraser system, the available evidence supports the hypothesis that fish sampled from fall aggregations represent a mixture of stocks that may have had different histories of exposure to contaminants. This makes the interpretation of contaminant loads in fish from such sites difficult, especially if the samples are pooled or averaged over several fish. Given the difficulty of obtaining adequate samples of adult fish at other times, there is no simple alternative to sampling these fall aggregations.

A method of identifying which stocks individuals belong to is critical to the continued use of mountain whitefish as an indicator species. In other salmonids, the analysis of micro-satellite DNA (Tautz 1989) has proven sensitive enough to distinguish adjacent stocks (Angers *et al.* 1995). Micro-satellite loci consist of repeated short nucleotide sequences. In theory the number of possible repeats is infinite, thus, theoretically, the number of possible alleles at such loci is infinite. In practice, the number of alleles that can be distinguished at a micro-satellite locus is not infinite; however, it is often large and it is this profusion of distinguishable alleles that make microsatellites such a powerful means of detecting genetic differences between populations (Avise 1994). Since micro-satellite analyses are quick, relatively inexpensive and require no more tissue than a small fin clip, they might provide a solution to the mixed stock problem in mountain whitefish.

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***Table 1.*** *Native fishes of the Fraser Basin (48 species), including the eight marine species that regularly enter the river.*

| SCIENTIFIC NAME | COMMON NAME | LIFE HISTORY |
|---|---|---|
| *Lampetra ayresi* | river lamprey | A |
| *Lampetra richardsoni* | western brook lamprey | F |
| *Lampetra tridentata* | Pacific lamprey | A |
| *Acipenser medirostris* | green sturgeon | A |
| *Acipenser transmontanus* | white sturgeon | A, F |
| *Acrocheilus alutaceus* | chiselmouth | F |
| *Couesius plumbeus* | lake chub | F |
| *Hybognathus hankinsoni* | brassy minnow | F |
| *Mylocheilus caurinus* | peamouth chub | F |
| *Ptychocheilus oregonensis* | northern squawfish | F |
| *Rhinichthys cataractae* | longnose dace | F |
| *Rhinichthys falcatus* | leopard dace | F |
| *Richardsonius balteatus* | redside shiner | F |
| *Catostomus catostomus* | longnose sucker | F |
| *Catostomus columbianus* | bridgelip sucker | F |
| *Catostomus commersoni* | white sucker | F |
| *Catostomus macrocheilus* | largescale sucker | F |
| *Catostomus platyrhynchus* | mountain sucker | F |
| *Spirinchus thaleichthys* | longfin smelt | A, F |
| *Thaleichthys pacificus* | eulachon | A |
| *Oncorhynchus clarki clarki* | coastal cutthroat trout | A, F |
| *Oncorhynchus clarki lewisi* | westslope cutthroat trout | F |
| *Oncorhynchus gorbuscha* | pink salmon | A |
| *Oncorhynchus keta* | chum salmon | A |
| *Oncorhynchus kisutch* | coho salmon | A |
| *Oncorhynchus mykiss* | rainbow trout | A, F |
| *Oncorhynchus nerka* | sockeye salmon | A, F |
| *Oncorhynchus tshawytscha* | chinook salmon | A |
| *Salvelinus confluentus* | bull trout | A, F |
| *Salvelinus malma* | Dolly Varden | A, F |
| *Salvelinus namaycush* | lake trout | F |
| *Coregonus clupeaformis* | lake whitefish | F |
| *Prosopium coulteri* | pygmy whitefish | F |
| *Prosopium williamsoni* | mountain whitefish | F |
| *Lota lota* | burbot | F |
| *Gasterosteus aculeatus* | threespine stickleback | A, F |
| *Cottus aleuticus* | coastrange sculpin | C, F |
| *Cottus asper* | prickly sculpin | C, F |
| *Cottus cognatus* | slimy sculpin | F |
| *Cottus rhotheus* | torrent sculpin | F |
| **Marine species:** | | |
| *Clupea pallasi* | Pacific herring | M |
| *Hypomesus pretiosus* | surf smelt | M |
| *Microgadus proximus* | Pacific tomcod | M |
| *Cymatogaster aggregata* | shiner perch | M |
| *Clevelandia ios* | arrow goby | M |
| *Leptocottus armatus* | Pacific staghorn sculpin | M |
| *Synchirus gilli* | manacled sculpin | M |
| *Platichthys stellatus* | starry flounder | M |

*A = anadromous [migrates between the sea and freshwater but spawns in freshwater]; C = catadromous [migrates between the sea and freshwater but spawns in salt or brackish water]; F = freshwater residents; M = marine*

**Table 2.** *The Fraser estuarine fish assemblage (58 species), including five introduced species.*

| SCIENTIFIC NAME | COMMON NAME | LIFE HISTORY | STATUS | ABUNDANCE |
|---|---|---|---|---|
| *Lampetra ayresi* | river lamprey | A | N | ++ |
| *Lampetra richardsoni* | western brook lamprey | F | N | ++ |
| *Lampetra tridentata* | Pacific lamprey | A | N | ++ |
| *Acipenser medirostris* | green sturgeon | A | N | + |
| *Acipenser transmontanus* | white sturgeon | A, F | N | ++ |
| *Alosa sapidissima* | American shad | A | I | + |
| *Clupea pallasi* | Pacific herring | M | N | ++ |
| *Cyprinus carpio* | carp | F | I | ++ |
| *Hybognathus hankinsoni* | brassy minnow | F | N | ++ |
| *Mylocheilus caurinus* | peamouth chub | F | N | +++ |
| *Ptychocheilus oregonensis* | northern squawfish | F | N | +++ |
| *Rhinichthys cataractae* | longnose dace | F | N | ++ |
| *Rhinichthys falcatus* | leopard dace | F | N | + |
| *Richardsonius balteatus* | redside shiner | F | N | +++ |
| *Catostomus catostomus* | longnose sucker | F | N | + |
| *Catostomus macrocheilus* | largescale sucker | F | N | +++ |
| *Ameiurus nebulosus* | brown bullhead | F | I | ++ |
| *Hypomesus pretiosus* | surf smelt | M | N | ++ |
| *Mallotus villosus* | capelin | M | N | ++ |
| *Spirinchus thaleichthys* | longfin smelt | A, F | N | +++ |
| *Thaleichthys pacificus* | eulachon | A | N | +++ |
| *Oncorhynchus clarki clarki* | coastal cutthroat trout | A, F | N | ++ |
| *Oncorhynchus gorbuscha* | pink salmon | A | N | +++ |
| *Oncorhynchus keta* | chum salmon | A | N | +++ |
| *Oncorhynchus kisutch* | coho salmon | A | N | +++ |
| *Oncorhynchus mykiss* | rainbow trout | A, F | N | +++ |
| *Oncorhynchus nerka* | sockeye salmon | A, F | N | +++ |
| *Oncorhynchus tshawytscha* | chinook salmon | A | N | +++ |
| *Salmo salar* | Atlantic salmon | A | I | + |
| *Salvelinus confluentus* | bull trout | A, F | N | ++ |
| *Salvelinus malma* | Dolly Varden | A, F | N | ++ |

| | | | | |
|---|---|---|---|---|
| *Prosopium williamsoni* | mountain whitefish | F | N | ++ |
| *Microgadus proximus* | Pacific tomcod | M | N | + |
| *Aulorhynchus flavidus* | tubesnout | M | N | + |
| *Gasterosteus aculeatus* | threespine stickleback | A, F | N | +++ |
| *Syngnathus griseolineatus* | bay pipefish | M | N | + |
| *Cymatogaster aggregata* | shiner perch | M | N | ++ |
| *Lumpenus sagitta* | Pacific snake prickleback | M | N | ++ |
| *Apodichthys flavidus* | penpoint gunnel | M | N | + |
| *Pholis laeta* | crescent gunnel | M | N | + |
| *Pholis ornata* | saddleback gunnel | M | N | + |
| *Ammodytes hexapterus* | Pacific sandlance | M | N | + |
| *Clevelandia ios* | arrow goby | M | N | ++ |
| *Hexagrammos decagrammus* | kelp greenling | M | N | + |
| *Artedius lateralis* | smoothhead sculpin | M | N | + |
| *Asemichthys taylori* | spinynose sculpin | M | N | + |
| *Cottus aleuticus* | coastrange sculpin | C, F | N | ++ |
| *Cottus asper* | prickly sculpin | C, F | N | +++ |
| *Enophrys bison* | buffalo sculpin | M | N | + |
| *Leptocottus armatus* | Pacific staghorn sculpin | M | N | ++ |
| *Oligocottus maculosus* | tidepool sculpin | M | N | + |
| *Synchirus gilli* | manacled sculpin | M | N | + |
| *Pomoxis nigromaculatus* | black crappie | F | I | ++ |
| *Citharichthys sordidus* | Pacific sanddab | M | N | + |
| *Pleuronectes isolepis* | butter sole | M | N | + |
| *Pleuronectes vetulus* | English sole | M | N | + |
| *Platichthys stellatus* | starry flounder | M | N | +++ |
| *Psettichthys melanostictus* | sand sole | M | N | + |

*A = anadromous [migrates between the sea and freshwater but spawns in freshwater]; C = catadromous [migrates between the sea and freshwater but spawns in salt or brackish water]; F = freshwater residents; M = marine*
*N = native; I = introduced*
*+ = rare; ++ = modestly common; +++ = common*

*Table 3. The fish assemblage (44 species) in the lower river between Mission and the canyon.*

| SCIENTIFIC NAME | COMMON NAME | LIFE HISTORY | STATUS | ABUNDANCE |
|---|---|---|---|---|
| *Lampetra ayresi* * | river lamprey | A | N | ++ |
| *Lampetra richardsoni* * | western brook lamprey | F | N | ++ |
| *Lampetra tridentata* | Pacific lamprey | A | N | ++ |
| *Acipenser medirostris* * | green sturgeon | A | N | + |
| *Acipenser transmontanus* | white sturgeon | A, F | N | ++ |
| *Alosa sapidissima* † | American shad | A | I | + |
| *Carassius auratus* | goldfish | F | I | + |
| *Cyprinus carpio* | carp | F | I | +++ |
| *Hybognathus hankinsoni* | brassy minnow | F | N | +++ |
| *Mylocheilus caurinus* | peamouth chub | F | N | +++ |
| *Pimephales promelas* † | fathead minnow | F | I | ++ |
| *Ptychocheilus oregonensis* | northern squawfish | F | N | +++ |
| *Rhinichthys cataractae* | longnose dace | F | N | +++ |
| *Rhinichthys falcatus* | leopard dace | F | N | ++ |
| *Richardsonius balteatus* | redside shiner | F | N | +++ |
| *Catostomus catostomus* | longnose sucker | F | N | + |
| *Catostmous macrocheilus* | largescale sucker | F | N | +++ |
| *Catostomus columbianus* | bridgelip sucker | F | N | ++ |
| *Catostomus platyrhynchus* | mountain sucker | F | N | + |
| *Ameiurus nebulosus* † | brown bullhead | F | I | ++ |
| *Spirinchus thaleichthys* * | longfin smelt | A, F | N | +++ |
| *Thaleichthys pacificus* * | eulachon | A | N | +++ |
| *Oncorhynchus clarki clarki* * | coastal cutthroat trout | A, F | N | +++ |
| *Oncorhynchus gorbuscha* | pink salmon | A | N | +++ |
| *Oncorhynchus keta* * | chum salmon | A | N | +++ |
| *Oncorhynchus kisutch* | coho salmon | A | N | +++ |
| *Oncorhynchus mykiss* | rainbow trout | A, F | N | +++ |
| *Oncorhynchus nerka* | sockeye salmon | A, F | N | +++ |
| *Oncorhynchus tshawytscha* | chinook salmon | A | N | +++ |
| *Salmo solar* | Atlantic salmon | A | I | + |
| *Salvelinus confluentus* | bull trout | A, F | N | ++ |
| *Salvelinus fontinalis* | brook trout | F | I | ++ |
| *Salvelinus malma* | Dolly Varden | A, F | N | ++ |
| *Salvelinus namaycush* | lake trout | F | T | + |
| *Coregonus clupeaformis* | lake whitefish | F | T | + |
| *Prosopium williamsoni* | mountain whitefish | F | N | +++ |
| *Lota lota* | burbot | F | N | + |
| *Gasterosteus aculeatus* * | threespine stickleback | A, F | N | +++ |
| *Cottus aleuticus* | coastrange sculpin | C, F | N | +++ |
| *Cottus asper* | prickly sculpin | C, F | N | +++ |
| *Perca flavescens* † | yellow perch | F | I | + |
| *Lepomis gibbosus* † | pumpkinseed | F | I | ++ |
| *Micropterus salmoides* † | largemouth bass | F | I | + |
| *Pomoxis nigromaculatus* † | black crappie | F | I | ++ |

*F = freshwater residents; A = anadromous [migrates between the sea and freshwater but spawns in freshwater]; C = catadromous [migrates between the sea and freshwater but spawns in salt or brackish water]; M = marine*
*N = native; I = introduced; T = transplanted*
*+ = rare; ++ = modestly common; +++ = common*
** = native species restricted to the lower river; † = introduced species restricted to lower river*

*Table 4. The fish assemblage (35 species) in the upper river above the canyon.*

| SCIENTIFIC NAME | COMMON NAME | LIFE HISTORY | STATUS | ABUNDANCE |
|---|---|---|---|---|
| *Lampetra tridentata* | Pacific lamprey | A | N | ++ |
| *Acipenser transmontanus* | white sturgeon | F | N | ++ |
| *Acrocheilus alutaceus* * | chiselmouth | F | N | ++ |
| *Carassius auratus* | goldfish | F | I | + |
| *Couesius plumbeus* * | lake chub | F | N | +++ |
| *Cyprinus carpio* | carp | F | I | ++ |
| *Hybognathus hankinsoni* | brassy minnow | F | N | ++ |
| *Mylocheilus caurinus* | peamouth chub | F | N | +++ |
| *Ptychocheilus oregonensis* | northern squawfish | F | N | +++ |
| *Rhinichthys cataractae* | longnose dace | F | N | +++ |
| *Rhinichthys falcatus* | leopard dace | F | N | +++ |
| *Richardsonius balteatus* | redside shiner | F | N | +++ |
| *Catostomus catostomus* | longnose sucker | F | N | +++ |
| *Catostomus columbianus* | bridgelip sucker | F | N | +++ |
| *Catostomus commersoni* * | white sucker | F | N | +++ |
| *Catostomus macrocheilus* | largescale sucker | F | N | +++ |
| *Catostomus platyrhynchus* | mountain sucker | F | N | + |
| *Oncorhynchus clarki lewisi* * | westslope cutthroat trout | F | N | + |
| *Oncorhynchus gorbuscha* | pink salmon | A | N | ++ |
| *Oncorhynchus kisutch* | coho salmon | A | N | ++ |
| *Oncorhynchus mykiss* | rainbow trout | A, F | N | +++ |
| *Oncorhynchus nerka* | sockeye salmon | A, F | N | +++ |
| *Oncorhynchus tshawytscha* | chinook salmon | A | N | +++ |
| *Salvelinus confluentus* | bull trout | F | N | ++ |
| *Salvelinus fontinalis* | brook trout | F | I | ++ |
| *Salvelinus malma* | Dolly Varden | A | N | + |
| *Salvelinus namaycush* *† | lake trout | F | N | ++ |
| *Coregonus clupeaformis* *† | lake whitefish | F | N | ++ |
| *Prosopium coulteri* * | pygmy whitefish | F | N | ++ |
| *Prosopium williamsoni* | mountain whitefish | F | N | +++ |
| *Lota lota* | burbot | F | N | ++ |
| *Cottus aleuticus* | coastrange sculpin | F | N | + |
| *Cottus asper* | prickly sculpin | F | N | +++ |
| *Cottus cognatus* * | slimy sculpin | F | N | ++ |
| *Cottus rhotheus* * | torrent sculpin | F | N | + |

** = native species (or subspecies) originally restricted to the upper river; † = transplanted to lower river basin*
*A = anadromous [migrates between the sea and freshwater but spawns in freshwater]; F = freshwater residents*
*I = introduced; N = native*
*+ = rare; ++ = modestly common; +++ = common*