SITE C FISHERIES STUDIES
ELEMENTAL SIGNATURE PILOT STUDY
-2010 REPORT-

Prepared for

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EXECUTIVE SUMMARY

B.C. Hydro is considering the Peace River Site C Hydroelectric Project (Site C) in north eastern British Columbia as a potential resource option to help meet BC's future electricity needs. B.C. Hydro is taking a stage-by-stage approach to the evaluation of Site C. B.C. Hydro is currently in Stage 3; Environmental and Regulatory Review. Fisheries studies are presently underway to add to existing baseline information and to address data gaps that have been identified.

The purpose of this work is to complete a pilot study to establish whether otolith microchemistry analysis can be used to address data gaps in our knowledge of the Peace River fish community. The objectives of the study are as follows:

1. Test the efficacy of using otolith microchemistry in the Site C study area using otoliths collected from fish located in the Peace River and the Halfway River.
2. Examine existing water chemistry data for the Peace River, Moberly River, and Halfway River to establish whether there is sufficient separation of potential chemical signatures.
3. Complete the analytical procedure on a sample of otoliths collected from each of two target species (Arctic grayling and mountain whitefish) from the Halfway River and the Peace River.
4. Document whether the Halfway River is a source of recruitment of fish collected from the Peace River for each of the two target species.
5. Document use of the Halfway River by adult fish for each of the two target species.
6. Document the age of sampled fish.

We examined 82 fish otoliths (42 mountain whitefish, 40 Arctic grayling) collected from the Peace River and Halfway River, and compared the elemental signatures of Strontium:Calcium (Sr:Ca) and Barium:Calcium (Ba:Ca) to measured water chemistries from these systems. Next we identified the proportional relationship between otolith and water chemistries for both Arctic grayling and mountain whitefish and predicted the recruitment habitat and first summer rearing habitat for each species. Peace River Arctic grayling appear to recruit from the Moberly River watershed. Halfway River Arctic grayling recruit from the Peace River watershed and habitats not measured for water chemistry (unknown). Mountain whitefish recruit from both the Halfway and Peace Rivers as well as from unknown habitats. Most of the mountain whitefish were rearing in the Peace and Halfway Rivers during their first summer.

Our work demonstrates that the elemental signature method can be applied to investigate fish life history strategies in the Site C study area. As such, otolith microchemistry analysis can be used to address data gaps in our knowledge of the Peace River fish community. Main findings are as follows:

1. The elemental signature method was an effective technique when applied to otoliths collected from fish located in the Peace River and the Halfway River.
2. Water chemistry data for the Peace River, Moberly River, and Halfway River provided sufficient separation of potential chemical signatures.
3. The Moberly River appears to be a major source of recruitment for Peace River Arctic grayling.
4. The Halfway River and Peace River appear to be major sources of recruitment for Peace River Arctic grayling.
5. Unknown sources of recruitment also were identified for Arctic grayling and mountain whitefish collected from the Halfway River and the Peace River.
6. The elemental signature method can be used to document the age of younger Arctic grayling and younger mountain whitefish collected from the Peace River and the Halfway River.

ACKNOWLEDGEMENTS

This report was produced for Bruce Mattock of B.C. Hydro Site C team.

Earthtone Environmental Ltd. would like to acknowledge Rick Pattenden of Mainstream Aquatics Ltd. for the technical support he provided during preparation of this report. In addition, Brent Mossop of B.C. Hydro had enough confidence in our experimental approach to recommend us to work on this new and interesting project. Finally, Bruce Mattock of B.C. Hydro provided the water chemical data for the Peace, Halfway and Moberly Rivers.

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1.0 INTRODUCTION

1.1 BACKGROUND

B.C. Hydro is considering the Peace River Site C Hydroelectric Project (Site C) in north eastern British Columbia (BC) as a potential resource option to help meet BC's future electricity needs. B.C. Hydro is taking a stage-by-stage approach to the evaluation of Site C. B.C. Hydro is currently in Stage 3, Environmental and Regulatory Review. Fisheries studies are presently underway to add to existing baseline information and to address data gaps in order to assist in completion of Stage 3.

A number of Peace River tributaries may provide important spawning and early rearing habitat for several fish populations that occur in the mainstem Peace River. Movements between the Peace River mainstem and tributaries have, or are currently being evaluated using:

1. Radio telemetry (e.g., AMEC and LGL 2010a, 2010b).
2. Full- or partial-spanning fish fences for upstream and downstream migrants (Mainstream 2009),
3. The re-capture of fish in tributaries that were marked in the Peace River (e.g., Mainstream 2010, Mainstream and Gazey 2011).
4. Capture of downstream migrants in rotary screw traps (Maintream 2011a).
5. Inferences based the seasonal abundance and distribution of fish life stages in the Peace River and in tributaries (e.g., Mainstream 2010).

It is not known if a single tributary, multiple tributaries, entrainment from upstream from the Peace Canyon Dam, or a combination therein are recruitment sources for the Peace River fish community. Arctic grayling are thought to recruit from the Moberly River; however, clumped distributions around tributary confluences suggest recruitment of juvenile Arctic grayling from several tributaries. Mountain whitefish are known to spawn in the Moberly River and Halfway River, as well as the mainstem Peace River. Like Arctic grayling, concentrations of juvenile mountain whitefish have been documented around tributary confluences suggesting recruitment of fish from these systems.

A second point of interest is the potential need for fish to pass through the proposed Site C dam to access spawning tributaries. Arctic grayling, bull trout, and mountain whitefish that reside downstream of the dam site may enter the Pine River to spawn, which eliminates the need to pass Site C. If fish must access upstream tributaries then the dam would block upstream movement without mitigation.

There are numerous methods to determine migration, rearing areas, recruitment and spawning locations of fish. Inclined plane trap, beach seine, visual observations, and minnow traps are common fish capture methods because they provide estimates of juvenile migration timing and stock size (Fedorenko *et al.*

1983; Delaney *et al.* 1982). Within the study area, boat electrofisher, fish fences, and rotary screw traps have been employed as fish capture methods and radio telemetry has been used to describe fish movements.

Problems have been associated with these techniques that may bias results. For example, Fedorenko *et al.* (1983) stated that their results were biased due to variation in trapping effort, trapping efficiency based on gear use, debris in the river, and selection of capture sites. Additionally, other techniques such as physically tagging animals can reveal inherent biases. Tagging programs often end up concentrating on the re-captured, non-mobile portion of the population (migrating fish often leave the study area), or on the members that are physically large enough to receive tags. Moreover, some individuals susceptible to injury from handling may experience higher mortality rates resulting directly from the application of physical tags. A relatively new method that has been shown to be effective for discriminating habitat use by freshwater and marine fish is analyzing otoliths using laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS). This procedure has recently been used successfully to discriminate stream location in cutthroat trout (Wells *et al.* 2003) and also in Arctic grayling (*Thymallus arcticus*) (Clarke *et al.* 2007a,b).

Otoliths, which are calcified bony structures of the inner ear, function in the senses of balance and hearing (Popper *et al.* 2005). They are primarily composed of calcium carbonate (CaCO3) while K, Sr, Na, N, S, Cl, Ba, P, and other trace elements are the minor elements within the otolith (Campana 1999). Concentrations of specific elements may differ between freshwater systems (e.g., tributaries versus Peace River). Differences in water chemistry are consistently reflected in the trace elements of Sr, Zn, Pb, Mn, Fe, and Ba that are incorporated into the otolith (Campana 1999). Because otoliths are metabolically inert and permanently retain elements incorporated through daily growth, entire individual life histories can be recorded in the structure (Campana and Neilson 1985). It is then possible to analyze the otolith to determine a specific life history using Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS).

Elemental concentration in otoliths can vary based on three mechanisms:

1. Maternal influence in elemental deposition from yolk into the core of progeny (Kalish 1990),
2. In physiological active elements such as Zn, concentrations can vary seasonally due to metabolism (Milner 1982; Bradley and Sprague 1985; Clarke and Telmer 2008); and,
3. In non-physiological elements (e.g. Ca, Ba, Sr) variation is dependent on spatial differences in water chemistry (usually as a result of migration).

Spatial differences in the chemistry of freshwaters largely reflect differences in age and composition of the underlying bedrock. These differences result in variation among stream chemistries, but also provide a stable chemical signature for each river system. Consistency within river systems is well described by Taylor & Hamilton (1994) who examined 25 years of water chemistry data on the Saskatchewan River system and showed that element ratios remain consistent over time. Further support for the consistency in water chemistry is the stability of Sr, Ba, and Mn measured across otoliths of slimy sculpins (Clarke *et al.* 2004). Slimy sculpins are considered to be non-migratory and the elemental concentrations maintained a flat profile for 2–5 years depending on the age of the sculpin. The lack of changes in elemental signature across much of the otolith indicates that chemical signatures have been stable for at least 5 years for the tributaries that were sampled in the Williston Watershed (Clarke 2004).

LA-ICPMS is a technique that utilizes a narrow laser beam to scan the surface of a solid object (e.g. fish otolith). This technique has gained popularity in the fact that LA-ICPMS has the ability to analyze concentrations of single or multiple trace elements at high precision (Sanborn and Telmer 2003). Other benefits of this technique include little to no sample preparation, few sample size limitations, and low probability of contamination (Sanborn and Telmer 2003). A number of studies have used LA-ICPMS towards fisheries research, including stock discrimination and identification (Rooker *et al.* 2003), migratory and environmental history (Arai *et al.* 2007; Clarke *et al.* 2007a, b), age of fish based on seasonal variation in elemental signature of the water (Clarke *et al.* 2007c), and fish physiology (Melancon *et al.* 2005; Arai and Hirata 2006).

1.2 PURPOSE AND OBJECTIVES

The purpose of this work is to complete a pilot study to establish whether otolith microchemistry analysis can be used to address data gaps in our knowledge of the Peace River fish community. The objectives of the study are as follows:

1. Test the efficacy of using otolith microchemistry in the Site C study area using otoliths collected from fish located in the Peace River and the Halfway River.
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5. Document use of the Halfway River by adult fish for each of the two target species.
6. Document the age of sampled fish.

1.3 STUDY AREA AND SAMPLES

The study area for water chemistry sample collections included the Peace River, Halfway River, downstream of the Cameron River confluence, and the Moberly River (Figure 1.1).

The study area for otolith collections included sections of the Halfway River and Peace River (Figure 1.1). Halfway River fish were collected between the Chowade River confluence and the Cameron River confluence, or approximately 110 km to 40 km upstream of the Peace River. All Peace River mountain whitefish were collected in Section 3, which is located from 5 km to 15 km downstream of the Halfway River confluence. Peace River Arctic grayling were collected from Section 3 (n = 5), Section 5 (n = 14), and Section 6 (n = 1). Section 5 is located from 1 km to 15 km downstream of the Moberly River confluence; and Section 6 is located from 1 km to 17 km downstream of the Pine River confluence.

In total, 40 Arctic grayling and 42 mountain whitefish otoliths collected by Mainstream Aquatics Ltd. were provided for the pilot study (Tables 1.1 and 1.2, Appendix A).

Table 1.1 Number of otolith samples collected by species, waterbody, and section area, 2010 Site C Sample Collection for Elemental Signature Pilot Study.

Waterbody	**Section**	**Arctic grayling**		**Mountain whitefish**		**Total**	**Total**
		Collected	**Submitted**	**Collected**	**Submitted**	**Collected**	**Submitted**
Halfway River	One	8	8	9	9	17	17
	Two	1	1	1	1	2	2
	Three	4	4	4	4	8	8
	Four	2	2	1	1	3	3
	Five	3	3	2	2	5	5
	Six	2	2	4	4	6	6
	Subtotal	*20*	*20*	*21*	*21*	*41*	*41*
Peace River	One	0	0	7	0	7	0
	Three	7	5	28	21	35	26
	Five[a]	16	14	16	0	32	14
	Six	1	1	0	0	1	1
	Subtotal	*24*	*20*	*51*	*21*	*75*	*41*
Total		**44**	**40**	**72**	**42**	**116**	**82**

[a] Rotary screw trap P01 is located within Section 5 of the Peace River

Table 1.2. Biological characteristics of target fish species collected from the Halfway River and Peace River, 2010 Site C Sample Collection for Elemental Signature Pilot Study.

Waterbody	Species	Fork Length (mm)		
		n	Mean	Range
Halfway River	Arctic grayling	20	204.7	155 - 285
	Mountain whitefish	21	242.2	164 - 322
Peace River	Arctic grayling	24	233.7	162 - 356
	Mountain whitefish	51	314.6	97 - 478

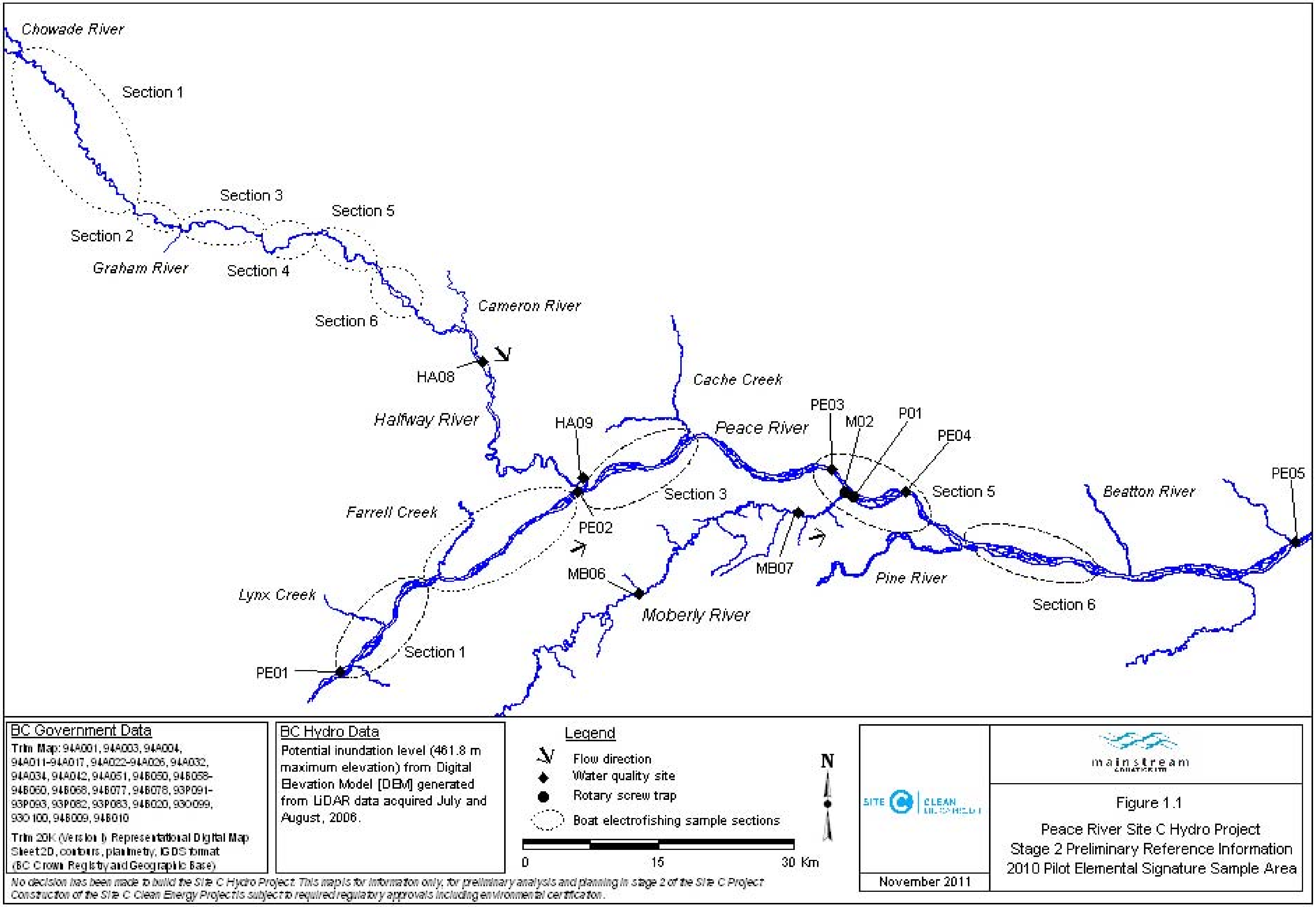

Figure 1.1
Peace River Site C Hydro Project
Stage 2 Preliminary Reference Information
2010 Pilot Elemental Signature Sample Area

2.0 METHODS

2.1 OTOLITH COLLECTIONS

Fish otolith collections were made opportunistically during other Site C fisheries investigations that included the Pilot Rotary Screw Trap Study (Mainstream 2011a), Halfway and Moberly River Study (Mainstream 2011b), and the Peace River Inventory (Mainstream 2011c). Additional samples were collected during the Water License Requirement Peace River Fish Index Study that was occurring concurrently to the Site C fisheries investigations (Mainstream and Gazey 2011).

Standard fish capture methods were used (Bonar *et al.* 2009). On the Halfway and Peace Rivers, the majority of fish were collected using jetboat or inflatable boat based electrofishers. A smaller number of samples were collected using rotary screw traps located on the Peace River and the Moberly River.

Target fish were euthanized and otolith removal was accomplished following procedures described by Mackay *et al.* (1990). Once otoliths were removed, they were cleaned of any residual tissue (i.e., gelatinous membrane or blood) using fresh water. Samples were then air dried and placed in labelled envelopes. At the end of the field program, otoliths were transferred into labelled cryogenic vials padded with cotton and stored until submission to Earthtone Environmental R&D.

2.2 OTOLITH ANALYSES

Otolith preparation was conducted using standard methodology by Earthtone Environmental R&D Inc. (Clarke *et al.* 2007a). Samples were cleaned in deionized water, then embedded in epoxy (Buehler Epoxy-Cure Resin), which adds strength to the otolith preventing breakage. The otoliths, along with the epoxy covering, were then scored with a scalpel and sectioned using an isomet saw (Buehler). Secondary epoxy embedding was accompanied by placing the sectioned otolith into acrylic tubing where more epoxy was added to secure the otolith. The core was exposed by polishing the otolith with adhesive-backed lapping paper in 320, 600, and 1200 grit sizes (Buehler, Carbimet). To achieve a highly polished surface, otoliths were moistened with 0.25 μm diamond suspension spray (Buehler, Metadi Supreme) and polished with 2500 grit pads (Buehler, Texmet). LA-ICPMS was accomplished at the School of Earth and Ocean Sciences, University of Victoria, using the UP-213 Laser Ablation System (New Wave Research) attached to an X Series II ICP-MS (Thermo Electron Corporation).

Prior to scanning, background data was collected for 20 seconds to separate the background signal from otolith elemental chemistry. Polished otoliths were probed with the laser in regions of the otolith that corresponded to maternal growth (core), early juvenile rearing, and the location of capture. Regions were probed using a continuous line scan. Finally, PlasmaLab (version 2.5.3.280, Thermo Electron 2003) software was used for data collection and reduction. Data reduction involves integration of data over a 10 ms dwell time where isotopes are measured consecutively. The laser travels at 5 um/s and each elemental concentration (e.g. 86 Sr) is measured every 10 ms. The data points are then averaged over a 10 um section of the continuous line scan (or every 2 seconds).

Mean Sr:Ca and Ba:Ca ratios were calculated for three regions of each otolith. The first region examined was the core of the otolith which is composed of maternal Sr:Ca and Ba:Ca. This reflects the maternal yolk incorporation into the juvenile otolith core – revealing the most recent habitat occupied by the maternal parent. The second region of the otolith that was examined was the portion that represents the first summer rearing habitat of each fish. (see Donohoe *et al.* 2008, Figure 2.1). Finally, measured elemental ratios were determined at the edge of the otoliths for each individual, which should correspond to measured water chemistries at each capture location unless fish have recently migrated.

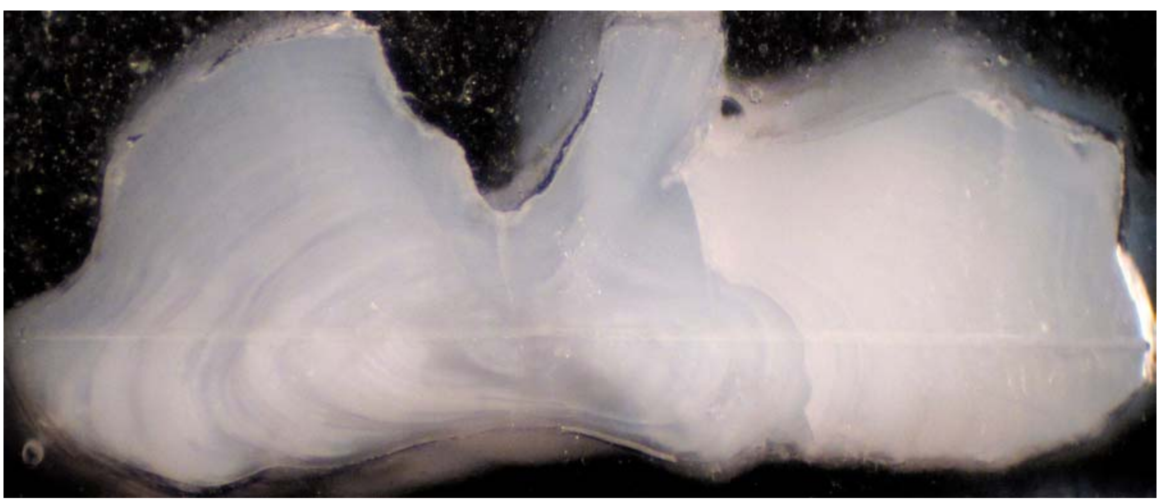

Figure 2.1 Representative sectioned and polished mountain whitefish otolith. The laser scan travelled across the entire surface of the otolith and through the otolith core.

Age was determined by microanalysis for all of the Arctic grayling and mountain whitefish examined in this study. Elemental signature fluctuations can estimate age reliably for bull trout, Arctic grayling, and rainbow trout to age 4; this technique becomes less accurate when annuli become more tightly spaced as otoliths get larger and older (Clarke and Telmer 2008). Halden *et al.* (2000) determined that seasonal deposition of Zn in Arctic char otoliths correlates to annulus formation. Milner (1982), as well as Bradley and Sprague (1985), suggest that metabolic rate influences Zn deposition in fish otoliths. Seasonal summer temperatures likely positively influence the uptake and production of Zn, while colder winter temperatures would represent times when lower levels of Zn uptake occur (Halden *et al.* 2000). Clarke *et al.* (2004) also determined that oscillations of Zn present in fin-rays of 15 bull trout represent yearly increments because ages estimated using Zn:Ca ratios corresponded well to independent age estimates provided by North/South Consulting who used traditional ageing techniques. Halden *et al.* (2000) noted that the incorporation of Zn into Arctic char otoliths decreases with age. The results of Halden *et al.* (2000) are also consistent with other studies examining Zn uptake by fish (Milner 1982; Bradley and Sprague 1985; Campbell and Stokes 1985). Our ageing convention is Age 0, Age 1, Age 2 etc. where an age 0 fish is from 1 to 364 days of age.

Dissolved Sr (mg/L) and Ba (mg/L) water chemistries measured in 2008 (Golder 2009) were provided by Bruce Mattock (B.C. Hydro). Arctic grayling and mountain whitefish capture locations corresponded well with Peace River water sampling sites; however, water sampling for the Halfway River occurred downstream of the fish collection sites and downstream of the confluence of a major tributary (Cameron River).

The trace metal chemistry in otoliths has been related to the trace metal chemistry in water using an incorporation coefficient (Wells *et al.* 2003; Clarke *et al.* 2007b). The incorporation coefficient refers to the proportion of element/Ca incorporated into the otolith from the water. The coefficient is calculated as the molar ratio in the otolith over the molar ratio in the water (e.g. [(Sr (μmol):Ca(mol)$_{otolith}$] / [(Sr:Ca$_{water}$]). The raw data obtained from the otolith scans were expressed as parts per million. These values were converted to the equivalent units of the water analysis by stoichiometric conversion of $CaC0_3$ using a molecular weight conversion of Ca as 40% of the assumed $CaCO_3$ composition of the otolith. We used the Peace River Sr and Ba (mg/L) water samples to develop the incorporation coefficient for both Arctic grayling and mountain whitefish. We used 18/20 Peace River Arctic grayling (excluded 2 outliers – Gr23 and Gr34) and 20/21 Peace River mountain whitefish (excluded M23). Fish were excluded because their elemental ratios were significantly different than other fish captured at the same site suggesting recent immigration from a discrete location. The incorporation coefficients were used to calculate the expected otolith elemental concentrations (river specific) based on the measured water chemistries for each river examined.

Next, we used the measured water chemistries (a mean of all sampling periods to reduce variance) and the determined incorporation coefficients to create a spatial map of expected otolith chemistries for each river examined (five Peace, two Moberly, and two Halfway sites). We used all of the measurements for water chemistry sampled from February to October 2008 in order to allow for seasonal variation in water chemistry (57 sample points mapped). Finally, we used the mean chemistries measured at the edge of the otolith (these values should represent the habitat where the fish were captured) for all of the Arctic grayling and mountain whitefish collected from Halfway River sites 1-6 (to estimate water chemistries for these sites).

For each fish we used Zn:Ca ratios to estimate the region of the otolith that represented the natal area, (the maternal rearing area and first habitat), the first summer rearing period, and the location of capture (edge of the otolith).

These values for each fish (n = 82) were then plotted on our chemical map for each life history stage.

We then rebuilt a continuous age-specific life-history for four Arctic grayling and four mountain whitefish. We used the Sr:Ca and Ba:Ca concentrations measured in each otolith from Age 0 until capture. Changes in Sr:Ca and Ba:Ca concentration were used to help identify chemically unique habitats in the study area (this highlights the need for further water sampling). The life histories for each fish begin at the core and extend to the period of time when the fish was captured and killed. Measured water chemistries were plotted for each age-specific life-history in an effort to track each fish throughout its life.

3.0 RESULTS

Representative line scans of Sr:Ca, Ba:Ca, and Mn:Ca ratios for a Halfway River Arctic grayling (Gr) and a Halfway River mountain whitefish (Mw) are presented in Figures 3.1 and 3.2, respectively. Sr:Ca and Ba:Ca concentrations did fluctuate throughout each individual's life history suggesting some movements within and between watersheds.

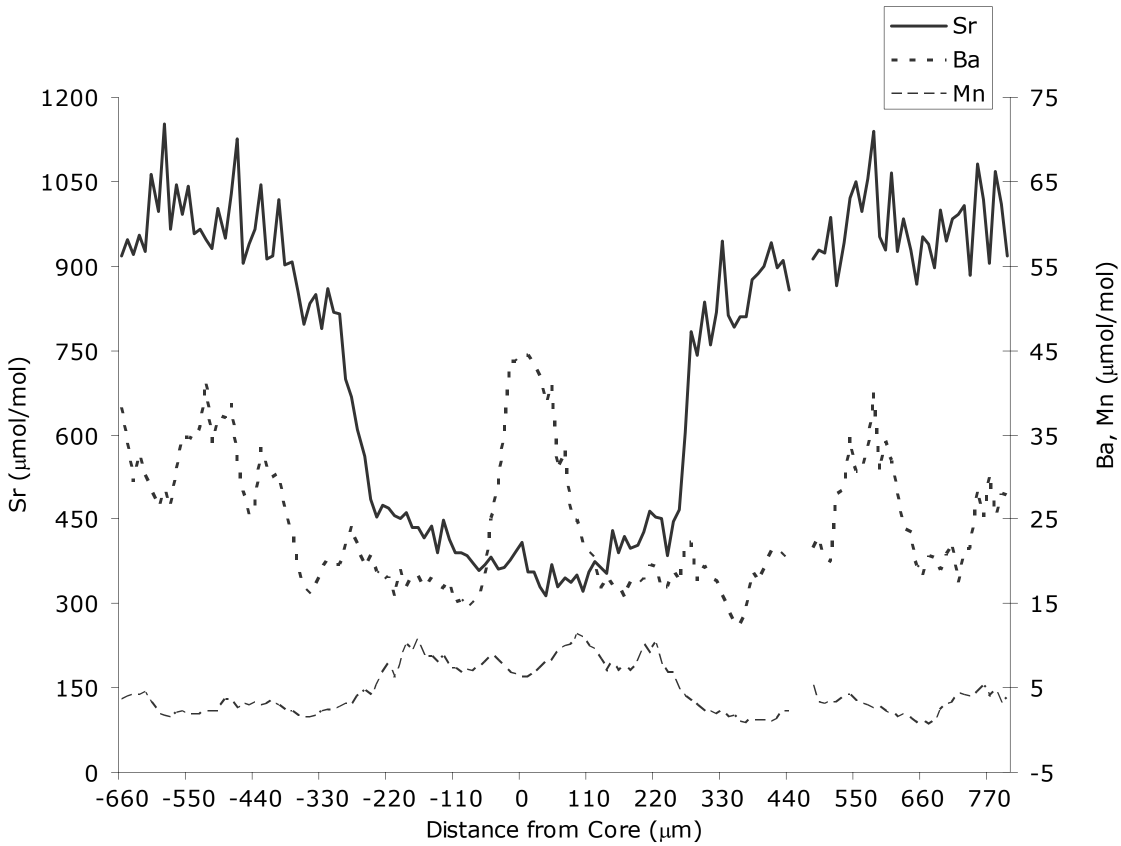

Figure 3.1 Representative life-history profile for a Halfway River Arctic grayling according to Sr, Ba, and Mn measured in the otolith. The centre of the otolith core is located at 0 µm on the x-axis. Elemental concentrations are mirrored extending out from the core to the edge of the otolith. One side of the profile is longer due to growth patterns observed in fish otoliths.

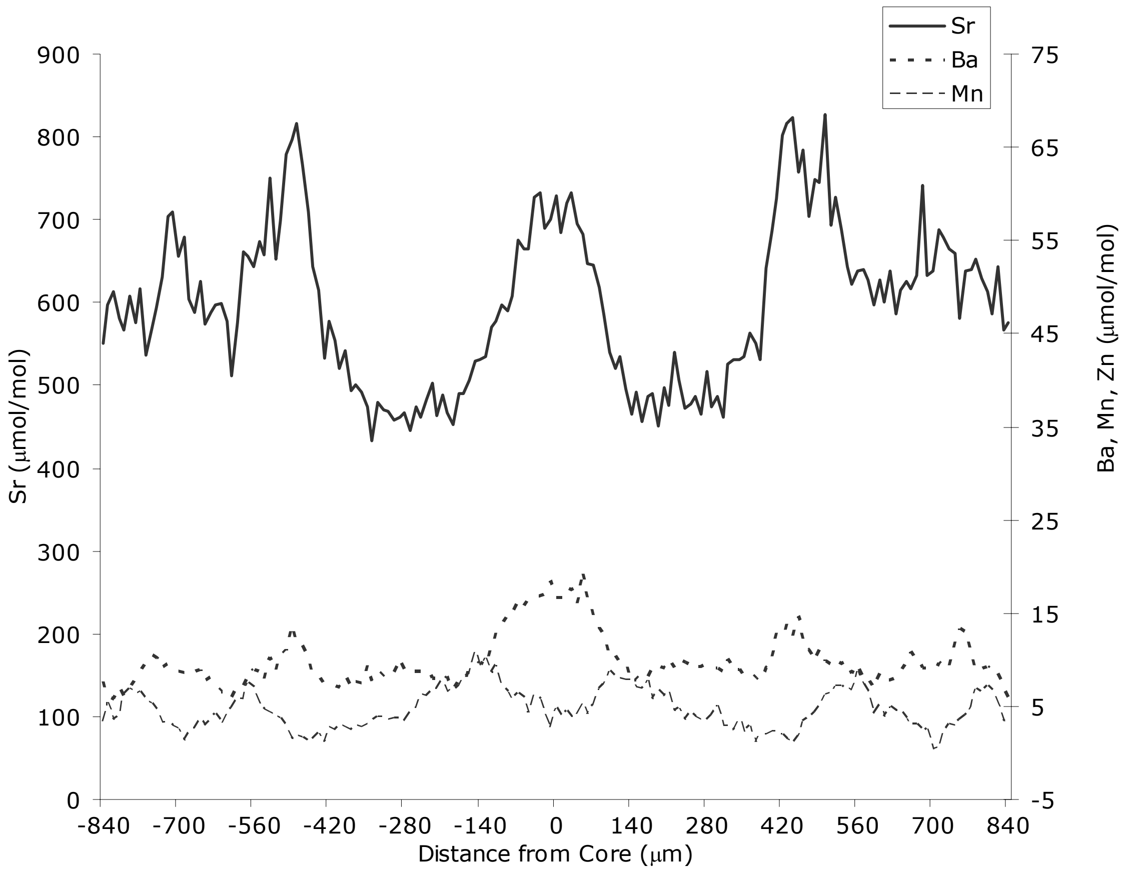

Figure 3.2 Representative life-history profile for a Halfway River mountain whitefish according to Sr, Ba, and Mn measured in the otolith. The centre of the otolith core is located at 0 μm on the x-axis. Elemental concentrations are mirrored extending out from the core to the edge of the otolith.

Water chemistry data that was provided for the Halfway, Peace, and Moberly Rivers showed considerable spatial variability for both Sr:Ca and Ba:Ca. The lower Halfway River was higher in Sr:Ca than the Peace River but there was some minor overlap in water chemistries. The Moberly River has unique water chemistry when compared to both the Halfway and Peace Rivers (Tables 3.1 and 3.2). As well, the Peace and Moberly Rivers were remarkably consistent for all sampling locations, both spatially and temporally. The Sr:Ca and Ba:Ca did vary seasonally in the Halfway River (possibly due to seasonal discharge volume differences from the Cameron River). Finally, the estimated water chemistries corresponded well to the measured water chemistries. Interestingly, estimated Ba:Ca was higher using Arctic grayling otoliths than it was for mountain whitefish otoliths (Table 3.1).

Table 3.1 Average otolith elemental values for each site are provided. Expected water chemistries were determined using the incorporation coefficients developed using Peace River Arctic grayling and mountain whitefish otoliths. Expected water chemistries were then compared to measured water chemistries for each site (average values over all seasons are provided).

Location	**n**	**Capture Sr:Ca (µmol/mol)**	**Standard Deviation (µmol/mol)**	**Capture Ba:Ca (µmol/mol)**	**Standard Deviation (µmol/mol)**	**Expected Sr:Ca water chemistry**	**Measured Sr:Ca water chemistry**	**Expected Ba:Ca water chemistry**	**Measured Ba:Ca water chemistry**
Arctic grayling									
Peace 3	5	636.9	21.3	14.5	2.0	0.00152	0.00153	0.00036	0.00035
Peace 5	14	640.2	30.3	12.1	1.4	0.00152	0.00150	0.00030	0.00035
Peace 6	1	587.4	0.0	20.3	0.0	0.00140	N/A	0.00051	N/A
Halfway 1	8	912.4	62.2	21.9	6.3	0.00217	N/A	0.00055	N/A
Halfway 2	1	850.6	0.0	19.8	0.0	0.00203	N/A	0.00049	N/A
Halfway 3	4	776.1	49.9	21.1	5.8	0.00185	N/A	0.00053	N/A
Halfway 4	2	766.3	19.5	28.9	5.9	0.00182	N/A	0.00072	N/A
Halfway 5	3	780.9	60.0	13.7	0.3	0.00186	N/A	0.00034	N/A
Halfway 6	2	748.8	42.4	18.2	1.8	0.00178	N/A	0.00045	N/A
Mountain whitefish									
Peace 3	21	541.5	80.0	9.9	4.3	0.00151	0.00153	0.00031	0.00035
Halfway 1	9	682.3	58.5	9.9	3.6	0.00191	N/A	0.00031	N/A
Halfway 2	1	804.7	0.0	5.9	0.0	0.00225	N/A	0.00018	N/A
Halfway 3	4	601.6	64.5	6.1	0.8	0.00168	N/A	0.00019	N/A
Halfway 4	1	544.1	0.0	5.8	0.0	0.00152	N/A	0.00018	N/A
Halfway 5	1	568.2	0.0	4.7	0.0	0.00159	N/A	0.00014	N/A
Halfway 6	4	547.6	24.8	5.3	0.6	0.00153	N/A	0.00016	N/A

Table 3.2 Measured water Sr, Ba, and Ca (mg/L) concentrations for the Peace, Halfway, and Moberly Rivers and expected otolith chemistries based on the incorporation coefficient developed with Peace River water and otolith elemental Sr:Ca and Ba:Ca. The incorporation coefficients were 0.42 and 0.36 for Sr:Ca (Arctic grayling [Gr] and mountain whitefish [Mw], respectively) and 0.037 and 0.032 for Ba:Ca (Gr and Mw, respectively).

Location	**Date**	**Sr (ppm)**	**Ba (ppm)**	**Ca (ppm)**	**Sr:Ca**	**Ba:Ca**	**Expected Gr Otolith Sr:Ca (µmol/mol)**	**Expected Otolith Gr Ba:Ca (µmol/mol)**	**Expected Mw Otolith Sr:Ca (µmol/mol)**	**Expected Otolith Mw Ba:Ca (µmol/mol)**
Peace 1	25/02/2008	0.079	0.027	28.6	0.0013	0.0003	529.3	10.9	451.3	8.8
	08/05/2008	0.104	0.031	29.0	0.0016	0.0003	689.0	12.4	587.4	10.0
	10/06/2008	0.094	0.030	28.2	0.0015	0.0003	641.8	12.5	547.2	10.1
	11/06/2008	0.096	0.031	28.6	0.0015	0.0003	644.9	12.7	549.8	10.3
	08/07/2008	0.092	0.029	26.3	0.0016	0.0003	673.5	12.8	574.3	10.3
	26/08/2008	0.075	0.027	25.4	0.0014	0.0003	568.0	12.2	484.3	9.9
	26/08/2008	0.080	0.027	25.9	0.0014	0.0003	596.4	12.3	508.5	9.9
	28/10/2008	0.070	0.026	24.4	0.0013	0.0003	548.8	12.4	467.9	10.0
	28/10/2008	0.073	0.027	24.9	0.0013	0.0003	560.9	12.7	478.3	10.2
Peace 2	25/02/2008	0.081	0.028	28.2	0.0013	0.0003	549.1	11.4	468.2	9.2
	05/05/2008	0.094	0.033	29.5	0.0015	0.0003	610.9	13.2	520.8	10.7
	13/06/2008	0.104	0.032	29.2	0.0016	0.0003	684.3	12.9	583.4	10.4
	10/07/2008	0.091	0.031	26.5	0.0016	0.0003	659.0	13.7	561.9	11.0
	27/08/2008	0.077	0.028	26.0	0.0013	0.0003	566.0	12.6	482.6	10.2
	31/10/2008	0.075	0.028	25.3	0.0013	0.0003	566.5	12.8	483.0	10.3
Peace 3	08/05/2008	0.111	0.038	29.7	0.0017	0.0004	718.0	15.1	612.2	12.2
	11/06/2008	0.122	0.045	34.4	0.0016	0.0004	681.4	15.3	580.9	12.4
	09/07/2008	0.106	0.036	30.1	0.0016	0.0003	676.6	13.9	576.9	11.2
	09/07/2008	0.106	0.036	30.9	0.0016	0.0003	659.1	13.7	561.9	11.0
	28/08/2008	0.079	0.030	26.8	0.0013	0.0003	562.7	12.9	479.8	10.4
	30/10/2008	0.075	0.029	26.2	0.0013	0.0003	552.2	12.9	470.8	10.4
Peace 4	25/02/2008	0.094	0.029	29.3	0.0015	0.0003	613.7	11.6	523.3	9.3
	08/05/2008	0.099	0.036	29.9	0.0015	0.0004	637.4	14.2	543.5	11.5
	11/06/2008	0.135	0.047	36.3	0.0017	0.0004	714.5	15.0	609.2	12.1

Location	Date	Sr (ppm)	Ba (ppm)	Ca (ppm)	Sr:Ca	Ba:Ca	Expected Gr Otolith Sr:Ca (µmol/mol)	Expected Otolith Gr Ba:Ca (µmol/mol)	Expected Mw Otolith Sr:Ca (µmol/mol)	Expected Otolith Mw Ba:Ca (µmol/mol)
	09/07/2008	0.099	0.034	29.9	0.0015	0.0003	637.4	13.4	543.5	10.8
	28/08/2008	0.086	0.033	28.0	0.0014	0.0003	588.7	13.6	501.9	11.0
	30/10/2008	0.076	0.029	25.7	0.0014	0.0003	568.9	13.0	485.0	10.5
Peace 5	26/02/2008	0.093	0.029	28.7	0.0015	0.0003	624.6	11.9	532.5	9.6
	08/05/2008	0.062	0.032	18.3	0.0015	0.0005	649.9	20.6	554.1	16.6
	09/05/2008	0.070	0.038	18.2	0.0018	0.0006	740.0	24.6	630.9	19.8
	11/06/2008	0.106	0.053	32.7	0.0015	0.0005	622.8	18.8	531.0	15.2
	09/07/2008	0.096	0.040	28.7	0.0015	0.0004	641.3	16.4	546.8	13.2
	28/08/2008	0.086	0.035	28.5	0.0014	0.0004	578.4	14.4	493.1	11.6
	30/10/2008	0.078	0.032	26.7	0.0013	0.0003	557.7	13.8	475.5	11.1
Moberly 6	27/02/2008	0.071	0.132	34.8	0.0009	0.0011	394.2	44.3	336.1	35.8
	27/02/2008	0.068	0.130	35.1	0.0009	0.0011	372.7	43.2	317.8	34.9
	06/05/2008	0.067	0.124	29.7	0.0010	0.0012	435.3	48.7	371.2	39.4
	13/06/2008	0.058	0.113	23.7	0.0011	0.0014	468.5	55.7	399.5	44.9
	11/07/2008	0.050	0.104	25.3	0.0009	0.0012	376.6	48.0	321.1	38.8
	29/08/2008	0.055	0.106	28.3	0.0009	0.0011	372.7	43.7	317.8	35.3
	29/10/2008	0.055	0.104	29.3	0.0009	0.0010	360.6	41.4	307.5	33.5
Moberly 7	06/05/2008	0.073	0.100	32.8	0.0010	0.0009	429.9	35.6	366.6	28.7
	13/06/2008	0.061	0.112	26.3	0.0011	0.0012	444.9	49.7	379.3	40.1
	11/07/2008	0.056	0.110	29.4	0.0009	0.0011	365.9	43.7	312.0	35.3
	29/08/2008	0.070	0.116	35.9	0.0009	0.0009	376.7	37.7	321.2	30.5
	29/10/2008	0.079	0.116	41.0	0.0009	0.0008	369.2	33.0	314.8	26.7
Halfway 8	07/05/2008	0.107	0.050	32.2	0.0015	0.0005	638.4	18.1	544.3	14.6
	12/06/2008	0.229	0.115	68.9	0.0015	0.0005	638.5	19.5	544.4	15.7
	10/07/2008	0.248	0.074	55.7	0.0020	0.0004	855.4	15.5	729.3	12.5
	27/08/2008	0.216	0.077	60.8	0.0016	0.0004	682.5	14.8	581.9	11.9
	31/10/2008	0.272	0.077	71.1	0.0017	0.0003	735.0	12.6	626.7	10.1

Location	Date	Sr (ppm)	Ba (ppm)	Ca (ppm)	Sr:Ca	Ba:Ca	Expected Gr Otolith Sr:Ca (µmol/mol)	Expected Otolith Gr Ba:Ca (µmol/mol)	Expected Mw Otolith Sr:Ca (µmol/mol)	Expected Otolith Mw Ba:Ca (µmol/mol)
Halfway 9	25/02/2008	0.309	0.085	72.0	0.0020	0.0003	824.5	13.8	703.0	11.2
	08/05/2008	0.100	0.067	30.5	0.0015	0.0006	629.9	25.8	537.1	20.8
	12/06/2008	0.196	0.060	53.5	0.0017	0.0003	703.8	13.0	600.1	10.5
	10/07/2008	0.238	0.071	56.0	0.0019	0.0004	816.5	14.8	696.2	12.0
	27/08/2008	0.216	0.075	60.1	0.0016	0.0004	690.5	14.6	588.7	11.8
	31/10/2008	0.273	0.076	71.9	0.0017	0.0003	729.5	12.3	622.0	9.9

Both Arctic grayling and mountain whitefish sampled in the Halfway River were captured further up the watershed in respect to the location of the water sampling sites. Sr:Ca and Ba:Ca concentrations measured at the edge of each otolith (representative of capture site) were converted to *estimated* water chemistries for the upper Halfway River. This suggests higher Sr:Ca in the area where fish were captured (above the Cameron River confluence) when compared to measured water chemistries in the lower Halfway River (Table 3.2). The incorporation coefficients determined using Peace fish otoliths and water chemistry were 0.42 and 0.36 for Sr:Ca (Gr and Mw respectively) and 0.037 and 0.032 for Ba:Ca (Gr and Mw, respectively).

Age according to Zn:Ca ratios was determined for each fish to help identify age-specific migration patterns (Table 3.3). Zn:Ca ratios used to age the fish in this study suggest that ages range from 1+ to 3+ for Arctic grayling and 2 to 8 for mountain whitefish. An example illustration is presented in Figure 3.3.

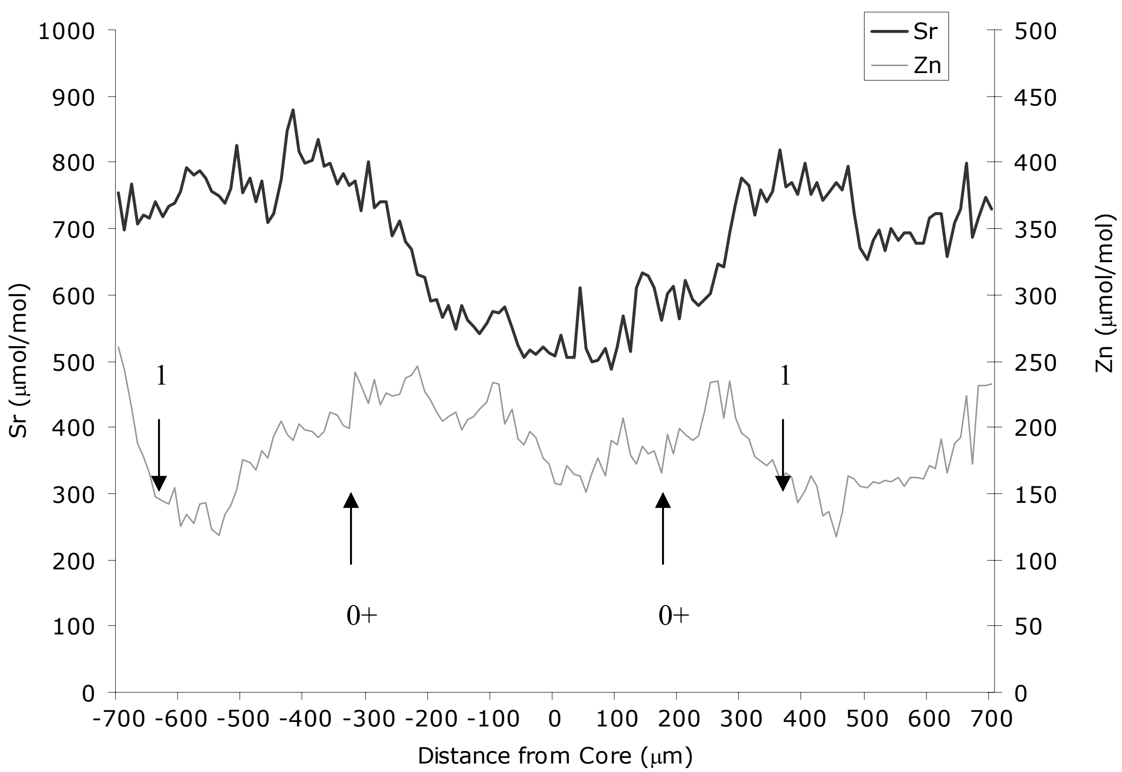

Figure 3.3 Representative Zn profile for a Halfway River Arctic grayling with an age of 1+ years. The top of the peaks represents summer (0+) when Zn is being incorporated at a higher rate than winter. The 2nd summer is characterized by the beginning of the last peak which starts at 600 and -600 µm on the x-axis.

Table 3.3 Biological attributes for each fish sampled. Measured otolith chemistries for the capture, first summer rearing, and natal portion of each otolith are provided. Estimated ages according to Zn:Ca are presented.

Lab ID	Sample Label	River	Section	Fork Length	Capture Sr:Ca	Capture Ba:Ca	Natal Sr:Ca	Natal Ba:Ca	First Summer Sr:Ca	First Summer Ba:Ca	Zn:Ca Age
Arctic grayling											
GR17	A10006017	HALFWAY	1	229	1022.4	15.3	467.8	27.5	506.4	31.9	2+
GR18	A10006018	HALFWAY	1	211	944.0	16.4	635.4	45.0	317.5	16.7	2+
GR19	A10006019	HALFWAY	1	214	907.4	21.2	341.4	53.8	322.2	27.2	2+
GR20	A10006020	HALFWAY	1	215	929.0	28.0	516.5	23.2	572.2	32.3	2+
GR1	A10006001	HALFWAY	1	188	933.3	33.0	358.7	30.7	378.5	18.5	1+
GR2	A10006002	HALFWAY	1	198	811.4	25.2	525.6	26.1	532.5	36.6	1+
GR3	A10006003	HALFWAY	1	221	861.6	18.9	483.4	54.6	494.1	53.0	2+
GR4	A10006004	HALFWAY	1	217	890.3	16.9	645.0	45.1	437.6	31.8	2+
GR5	A10006005	HALFWAY	2	217	850.6	19.8	650.7	34.3	894.0	37.1	2+
GR6	A10006006	HALFWAY	3	156	848.7	29.3	402.1	26.4	849.0	28.8	1+
GR7	A10006007	HALFWAY	3	200	768.1	20.5	396.6	35.3	410.9	48.6	1+
GR8	A10006008	HALFWAY	3	208	739.7	17.9	335.4	14.5	325.4	9.5	2+
GR9	A10006009	HALFWAY	3	233	747.8	16.5	721.2	68.2	661.8	52.2	2+
GR10	A10006010	HALFWAY	4	155	752.6	24.8	287.4	6.6	812.0	23.6	1+
GR11	A10006011	HALFWAY	4	162	780.1	33.1	674.7	33.9	793.1	51.0	1+
GR12	A10006012	HALFWAY	5	254	757.9	13.3	375.1	28.2	454.6	35.8	3+
GR13	A10006013	HALFWAY	5	191	735.9	13.7	517.4	34.5	768.9	19.9	1+
GR14	A10006014	HALFWAY	5	285	849.0	14.0	445.2	24.5	429.8	24.5	3+
GR15	A10006015	HALFWAY	6	161	718.8	16.9	614.4	20.6	326.2	52.4	1+
GR16	A10006016	HALFWAY	6	178	778.8	19.5	271.5	8.7	284.0	7.0	1+
GR22	A10011002	PEACE	3	299	620.2	12.1	644.3	52.0	627.1	48.7	3+
GR27	A10011008	PEACE	3	248	629.6	13.4	599.2	164.7	406.0	52.9	2+
GR23	A10011003	PEACE	3	196	883.0	16.5	464.5	86.6	426.3	31.6	2+
GR34	A10011015	PEACE	3	176	840.2	14.2	300.3	19.2	989.2	19.5	1+
GR24	A10011004	PEACE	3	180	660.9	16.5	375.4	44.0	989.7	41.2	2+
GR28	A10011009	PEACE	5	212	662.3	10.0	433.3	80.8	340.0	39.7	2+
GR38	A10011019	PEACE	5	232	677.7	14.1	368.4	66.6	445.3	65.2	2+
GR25	A10011006	PEACE	5	230	622.4	11.1	430.6	69.0	614.9	26.1	2+
GR29	A10011010	PEACE	5	218	561.7	11.2	409.5	79.1	650.2	27.2	2+
GR36	A10011017	PEACE	5	195	687.0	12.1	392.1	45.7	458.5	59.3	2+
GR39	A10011020	PEACE	5	244	649.2	11.6	474.4	62.7	453.7	48.0	2+
GR40	A10011021	PEACE	5	217	652.6	12.1	426.2	54.3	429.3	49.4	2+
GR26	A10011007	PEACE	5	229	634.1	10.0	416.8	77.9	685.0	18.3	2+
GR30	A10011011	PEACE	5	241	632.6	11.6	411.7	50.2	411.3	46.0	2+

Lab ID	Sample Label	River	Section	Fork Length	Capture Sr:Ca	Capture Ba:Ca	Natal Sr:Ca	Natal Ba:Ca	First Summer Sr:Ca	First Summer Ba:Ca	Zn:Ca Age
GR31	A10011012	PEACE	5	235	638.6	12.4	389.0	61.9	415.1	72.5	2+
GR33	A10011014	PEACE	5	222	634.2	13.1	402.9	53.1	665.8	24.2	2+
GR21	A10005001	PEACE	5	198	640.8	12.8	402.4	64.8	418.7	59.1	2+
GR32	A10011013	PEACE	5	162	388.8	31.1	393.5	88.5	419.8	72.0	1+
GR37	A10011018	PEACE	5	222	629.4	15.0	393.0	89.0	460.1	84.0	2+
GR35	A10011016	PEACE	6	185	587.4	20.3	427.0	78.6	906.0	22.4	1+
Mountain whitefish											
M1	M10006001	HALFWAY	1	310	658.0	7.1	892.7	15.4	608.2	6.9	6
M17	M10006017	HALFWAY	1	164	657.9	7.2	603.1	16.5	597.8	8.2	2
M18	M10006018	HALFWAY	1	190	709.3	6.0	628.0	16.7	537.2	8.2	2
M19	M10006019	HALFWAY	1	283	699.6	8.5	566.1	12.5	535.9	10.8	5
M2	M10006002	HALFWAY	1	248	634.3	6.0	236.0	14.8	228.0	13.1	4
M20	M10006020	HALFWAY	1	210	720.5	5.4	610.3	8.3	599.1	8.4	3
M21	M10006021	HALFWAY	1	279	667.1	8.2	671.0	13.4	576.8	8.4	4
M3	M10006003	HALFWAY	1	195	594.9	6.5	712.2	17.0	494.9	8.3	2
M4	M10006004	HALFWAY	1	211	798.6	5.6	752.1	11.6	543.2	6.5	4
M5	M10006005	HALFWAY	2	320	804.7	5.9	609.4	7.5	468.8	7.9	7
M6	M10006006	HALFWAY	3	302	619.1	5.8	574.3	14.3	493.2	8.3	6
M7	M10006007	HALFWAY	3	198	685.4	6.3	408.5	16.7	375.0	14.6	3
M8	M10006008	HALFWAY	3	204	552.1	6.1	804.3	14.0	513.0	6.4	3
M9	M10006009	HALFWAY	3	269	549.6	7.1	616.9	11.9	505.3	8.0	6
M10	M10006010	HALFWAY	4	182	544.8	6.1	581.0	18.9	460.8	6.2	2
M11	M10006011	HALFWAY	5	255	568.2	4.7	539.9	13.0	566.7	8.0	4
M12	M10006012	HALFWAY	5	322	882.0	7.0	489.2	9.6	540.9	8.8	8
M13	M10006013	HALFWAY	6	264	521.2	5.5	515.9	8.3	563.4	9.3	4
M14	M10006014	HALFWAY	6	235	568.6	5.0	630.4	11.2	566.3	7.6	3
M15	M10006015	HALFWAY	6	232	569.0	4.7	684.5	14.2	512.6	6.8	3
M16	M10006016	HALFWAY	6	214	531.7	6.0	570.1	15.7	528.3	8.0	3
M22	M10011001	PEACE	3	212	436.9	7.0	492.9	10.4	405.9	8.2	2
M23	M10011002	PEACE	3	311	762.3	21.8	444.3	8.4	459.3	10.1	6
M24	M10011003	PEACE	3	321	464.3	5.1	596.7	14.0	523.4	8.2	7
M25	M10011004	PEACE	3	322	564.0	10.5	283.8	26.4	302.9	31.9	7
M26	M10011005	PEACE	3	220	461.1	6.6	441.2	15.2	453.9	6.8	3
M27	M10011006	PEACE	3	245	503.5	9.3	506.2	12.3	445.7	7.4	3
M28	M10011007	PEACE	3	248	463.5	7.3	451.9	35.8	407.8	10.7	3
M29	M10011008	PEACE	3	287	484.8	9.2	533.6	12.3	477.6	7.5	4
M30	M10011009	PEACE	3	330	674.8	21.0	400.7	15.3	291.9	8.3	5

Lab ID	Sample Label	River	Section	Fork Length	Capture Sr:Ca	Capture Ba:Ca	Natal Sr:Ca	Natal Ba:Ca	First Summer Sr:Ca	First Summer Ba:Ca	Zn:Ca Age
M31	M10011010	PEACE	3	262	413.0	9.1	605.9	14.6	447.1	8.0	3
M32	M10011011	PEACE	3	265	548.6	8.5	469.0	16.6	402.2	7.9	3
M33	M10011012	PEACE	3	314	518.3	5.7	434.0	6.4	465.1	7.8	5
M34	M10011013	PEACE	3	328	559.4	12.7	407.2	12.0	382.9	8.5	6
M35	M10011014	PEACE	3	319	604.1	11.3	535.7	8.9	419.1	7.3	6
M36	M10011015	PEACE	3	307	594.7	10.1	463.6	5.3	503.0	10.8	5
M37	M10011016	PEACE	3	294	540.3	8.4	480.3	9.2	477.5	8.4	4
M38	M10011017	PEACE	3	273	543.6	10.8	581.7	15.7	474.1	12.2	4
M39	M10011018	PEACE	3	306	584.8	7.5	522.4	13.0	484.5	9.3	4
M40	M10011019	PEACE	3	304	566.1	10.7	542.0	19.0	522.6	8.4	5
M41	M10011020	PEACE	3	271	537.3	10.4	391.3	8.7	404.2	7.6	4
M42	M10011021	PEACE	3	284	546.7	6.4	522.7	14.2	536.9	8.4	4

For the three watersheds examined there was considerable chemical separation between the Moberly and both the Peace and Halfway Rivers. There was some minor overlap between the lowest Halfway River water chemistry sites and the Peace River water chemistry sites. Additionally, there was minor spatial and temporal variation for water chemistry collected, but separation between watersheds was still clear (Figure 3.4).

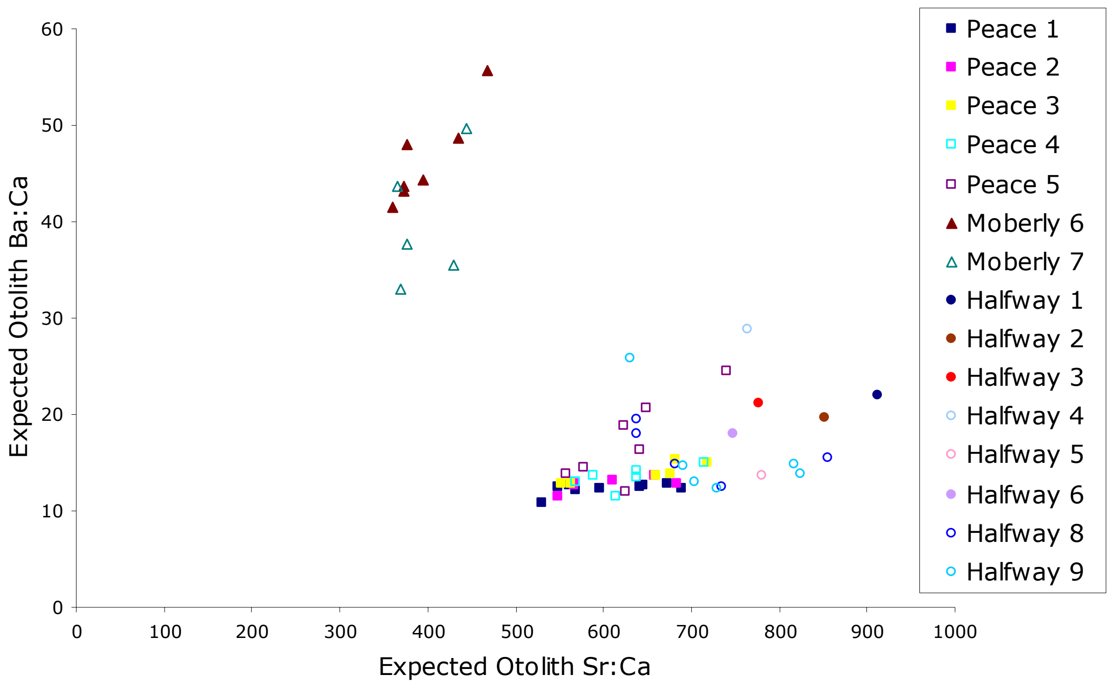

Figure 3.4 Spatial map of expected otolith Sr:Ca and Ba:Ca concentrations based on measured water chemistries (converted using incorporation coefficients) for the Peace, Moberly, and Halfway (Site 8 and 9) Rivers. Halfway River sections 1 to 6 are represented by average Sr:Ca and Ba:Ca concentrations measured at the edge of the otolith for all of the Arctic grayling from each section.

Sr:Ca and Ba:Ca concentrations measured at the edge of Arctic grayling otoliths correlated well to measured water chemistries in the Peace River for all fish examined. Halfway River Arctic grayling showed more variation in otolith chemistry (similar to measured water chemistries) (Figure 3.5).

Otolith chemistries measured in the natal portion of the otolith core for Peace River Arctic grayling suggest recruitment from the Moberly River watershed. One Peace River grayling had a very high Ba:Ca ratio and appears to have recruited from outside of the study area (in terms of location where water chemistries were measured). Halfway River Arctic grayling show more variation in recruitment origin but it appears that at minimum six individuals recruited from the Moberly River watershed (Figure 3.6).

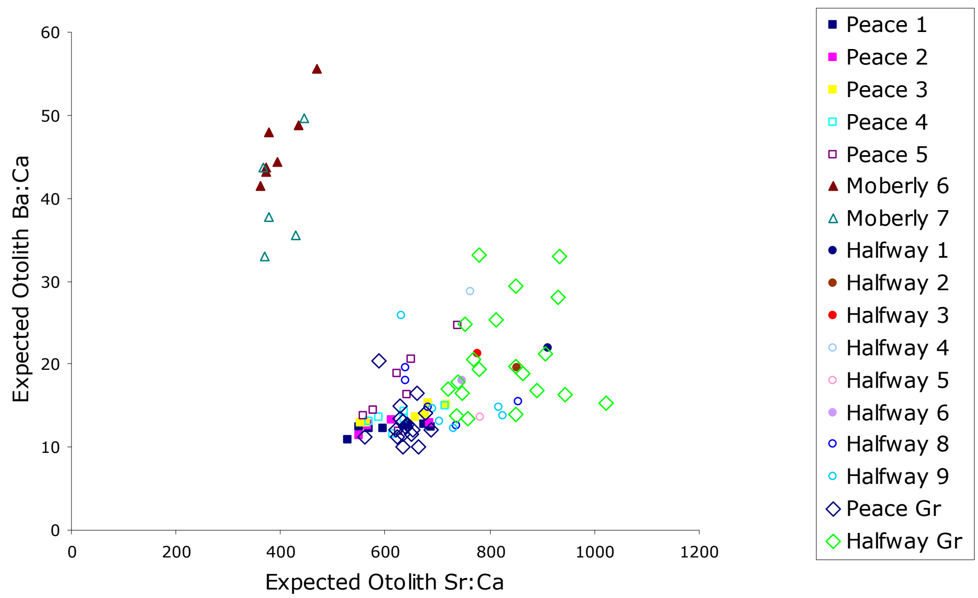

Figure 3.5 Arctic grayling Sr:Ca and Ba:Ca concentrations measured at the edge of each otolith and plotted on the spatial map of expected otolith chemistries.

Otolith concentrations measured in the otolith core that represent the first summer habitat show that most of the Arctic grayling sampled remain in chemically similar habitats to their natal streams, albeit with more variation. A small number of fish appear to have migrated to chemical habitats similar to the Peace and Halfway Rivers in their first summer (Figure 3.7). There appears to be considerable variation in habitat use for Halfway River grayling during their early rearing period based on the examined samples.

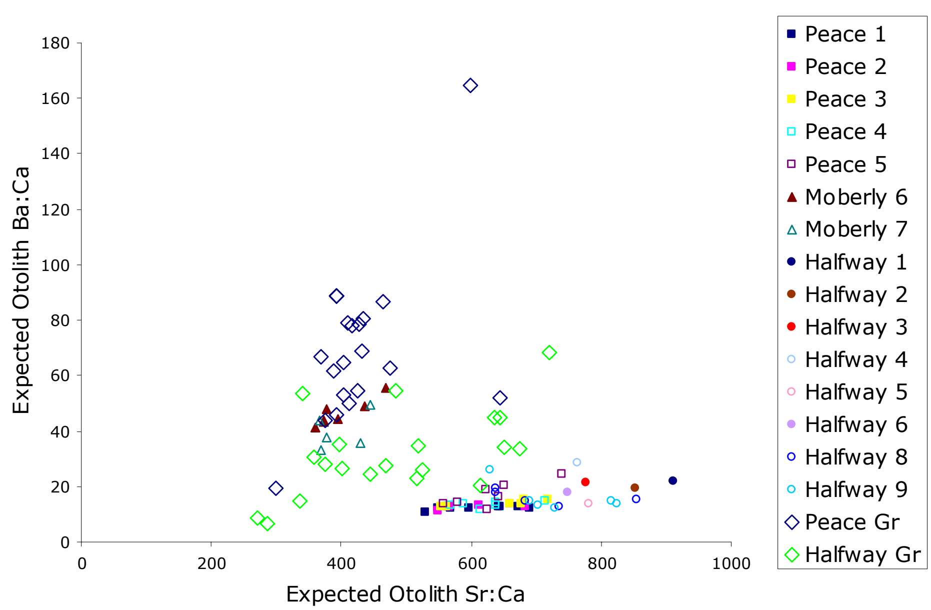

Figure 3.6 Arctic grayling Sr:Ca and Ba:Ca concentrations measured in the natal portion of each otolith and plotted on the spatial map of expected otolith chemistries. Most of the Arctic grayling appear to recruit from outside of their capture locations, with a large proportion recruiting from the Moberly watershed or a chemically similar habitat.

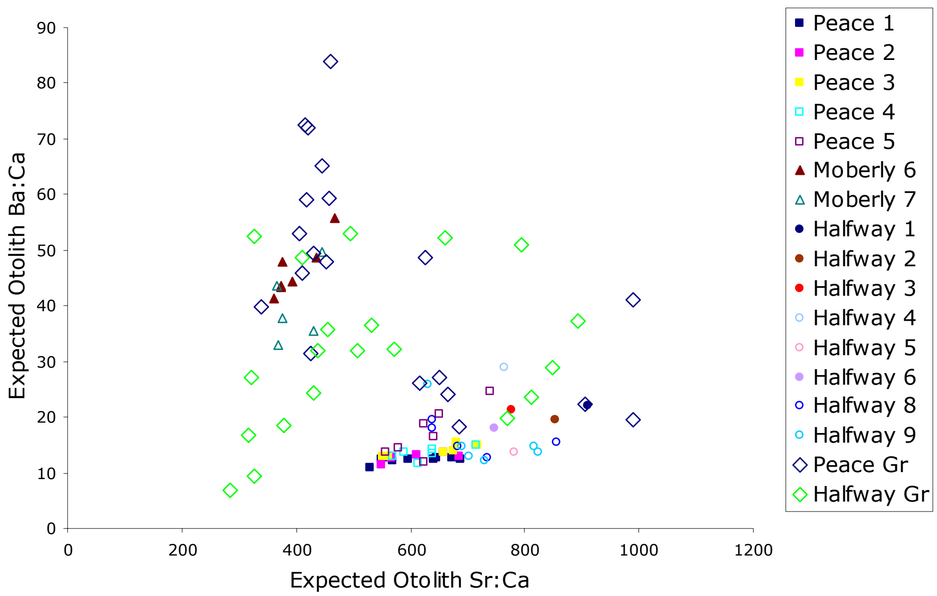

Figure 3.7 Arctic grayling Sr:Ca and Ba:Ca concentrations measured in the portion of each otolith that represents their first summer. Most of the Arctic grayling appear to remain in their natal stream at age 0+ but some appear to have migrated to the Peace and Halfway Rivers.

Similar to Arctic grayling, otolith chemistries measured at the edge of the otolith for mountain whitefish correlated well to expected and measured water chemistries for all of the fish sampled. Expected otolith Ba:Ca for fish captured above the Cameron River suggest lower river Ba:Ca than what was determined from Arctic grayling (Table 3.2, Figure 3.8).

In contrast to the Arctic grayling, only two mountain whitefish sampled in this study appear to be recruiting from the Moberly River watershed. Recruitment for mountain whitefish appears to occur mainly in the Peace and Halfway Rivers, with some other tributaries not measured for water chemistry (Figure 3.9).

Otolith concentrations measured in the otolith core that represent the first summer habitat of mountain whitefish show that most fish have moved into the Peace River with the exception of one Peace whitefish that migrated to, or remained in the Moberly River (Figure 3.10). There does appear to be separation between Peace and Halfway mountain whitefish. Halfway mountain whitefish could be rearing below the confluence of the Peace and Halfway Rivers or the lower portion of the Halfway mainstem.

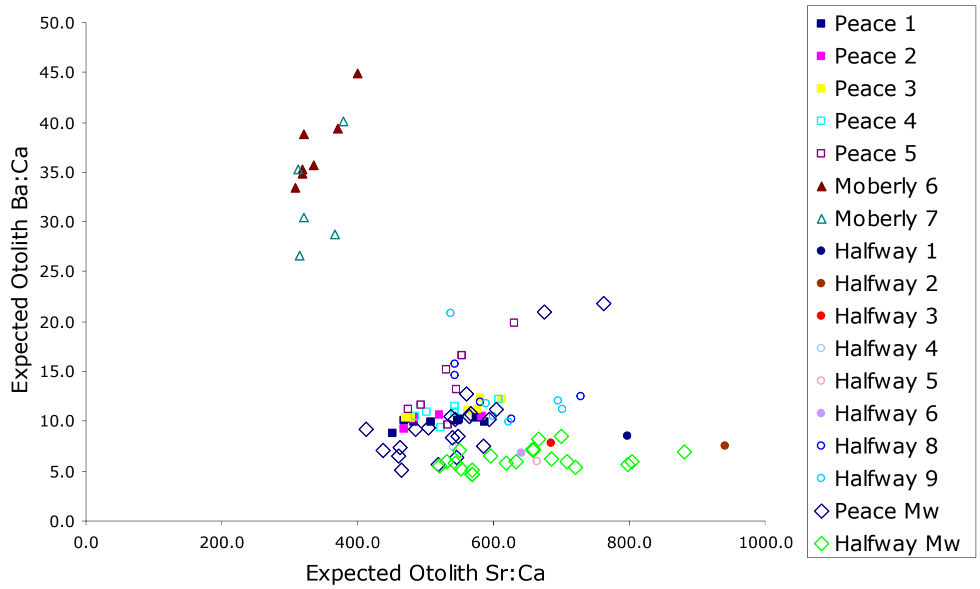

Figure 3.8 Mountain whitefish Sr:Ca and Ba:Ca concentrations measured at the edge of each otolith and plotted on the spatial map of expected otolith chemistries. The estimated water chemistries for Halfway sites 1-6 were slightly lower for Ba:Ca using mountain whitefish otoliths but very similar for Sr:Ca when compared to Arctic grayling otoliths.

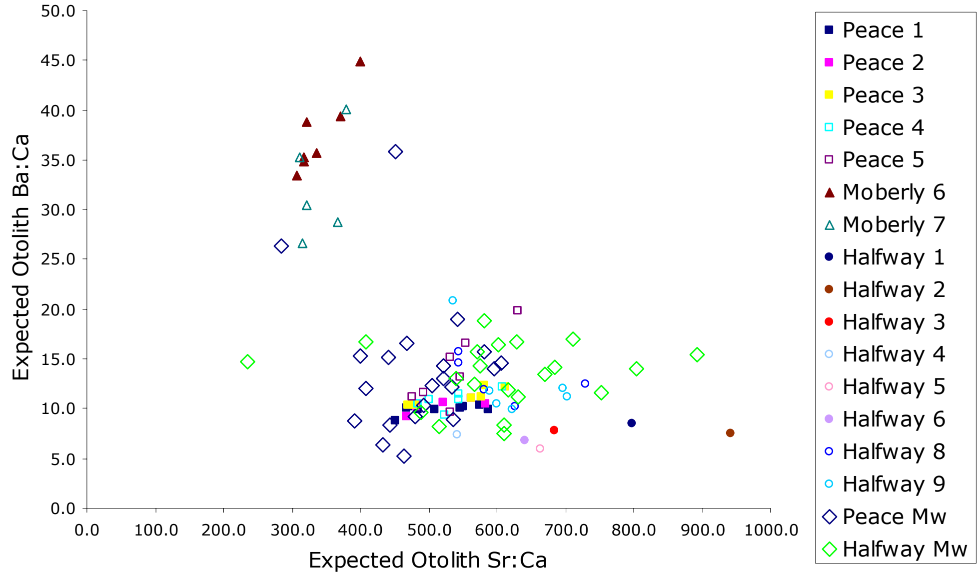

Figure 3.9 Mountain whitefish Sr:Ca and Ba:Ca concentrations measured in the natal portion of each otolith and plotted on the spatial map of expected otolith chemistries.

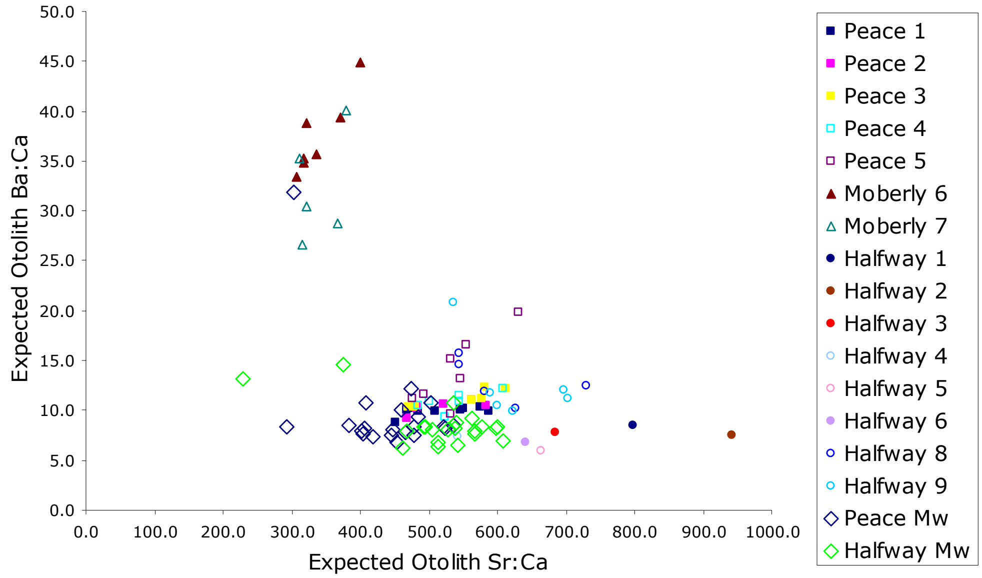

Figure 3.10 Mountain whitefish Sr:Ca and Ba:Ca concentrations measured in the portion of each otolith that represents their first summer. Most of the mountain whitefish appear to have migrated to (or remained in) the Peace River during their first summer or fall. One mountain whitefish (M30) appears to have migrated to, or remained in, the Moberly River. There does appear to be habitat separation for Peace and Halfway mountain whitefish.

Rebuilt life-histories (starting from the area of recruitment) to the time of capture for Halfway River Arctic grayling suggest that early rearing is occurring in tributaries not measured for water chemistry. Recruitment location is defined as the habitat where individual fish first emerged from the gravel because we used the maternally incorporated signature as the starting point. During the spring or summer (near the end of their first year) Arctic grayling appear to be migrating to the Halfway River where they remained until capture. The variation exhibited by each fish within the Halfway is likely attributed to in-river migrations and temporal variation in water chemistry (Figures 3.11 and 3.12).

Peace River Arctic grayling are for the most part recruiting from the Moberly River and migrating to the Peace River at the end of their first year (spring), or during their second summer. Once Peace River Arctic grayling have entered the Peace River they appear to remain there until at least age 3+ (oldest fish sampled in this study (Figures 3.13 and 3.14).

Arctic grayling 23 is an example of one of two Peace River grayling that exhibited a different life-history than the remaining 18 fish sampled. Both fish appear to recruit from the Moberly River but have rearing habitats that are similar to the Halfway River (Figure 3.14). The two individuals were captured in the same stream reach and either recently emigrated from the Halfway River, or recently emigrated from a tributary with very similar water chemistry to the Halfway River.

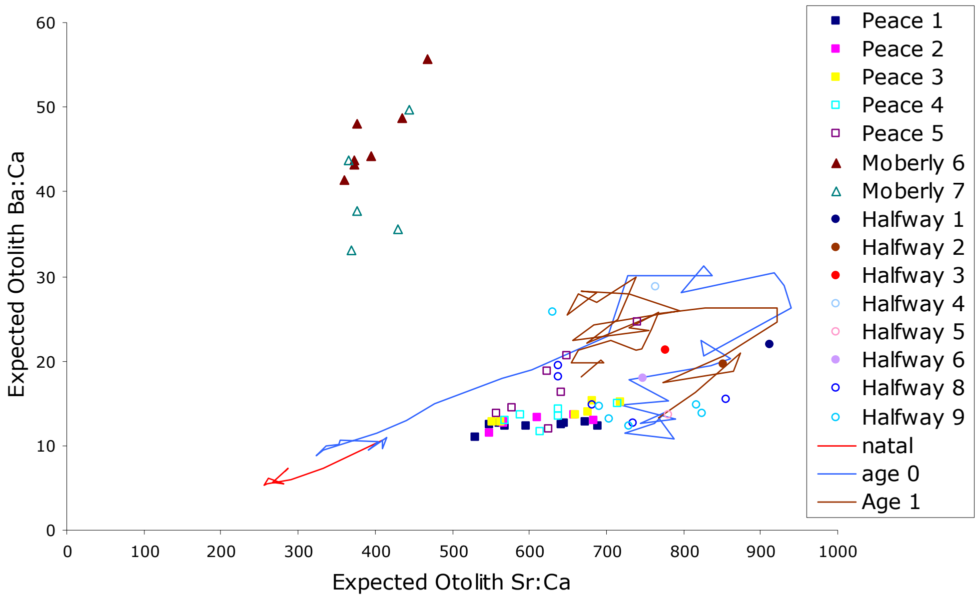

Figure 3.11 Complete life-history plot for a Halfway River Arctic grayling (Gr10). This individual appears to have recruited outside of the habitats measured for water chemistry. At age 0+ Gr10 migrated to the Halfway River where it remained until capture.

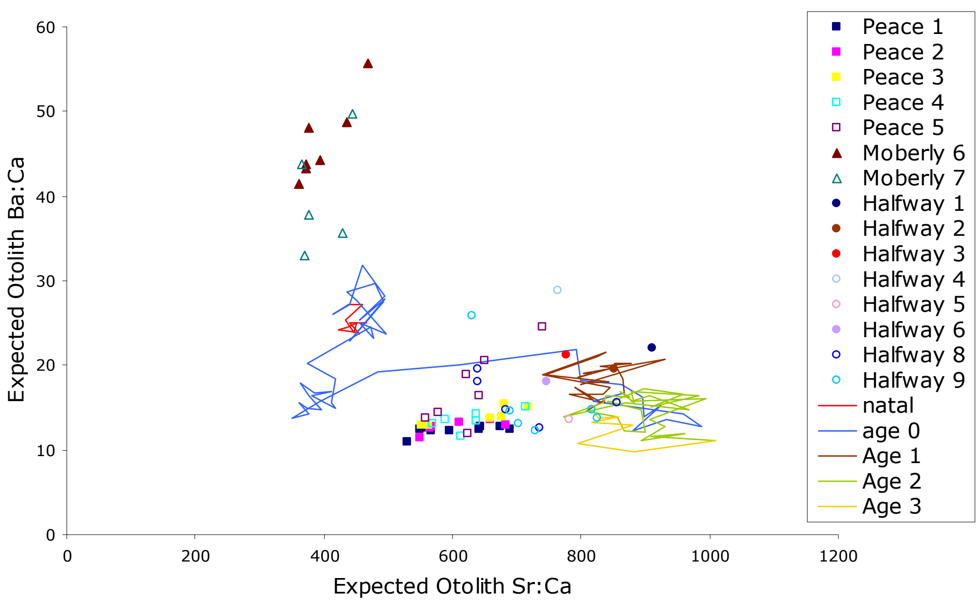

Figure 3.12 Complete life-history plot for a Halfway River Arctic grayling (Gr14). This individual appears to have recruited outside of the habitats measured for water chemistry. At age 0+ Gr14 migrated to the Halfway River where it remained until capture.

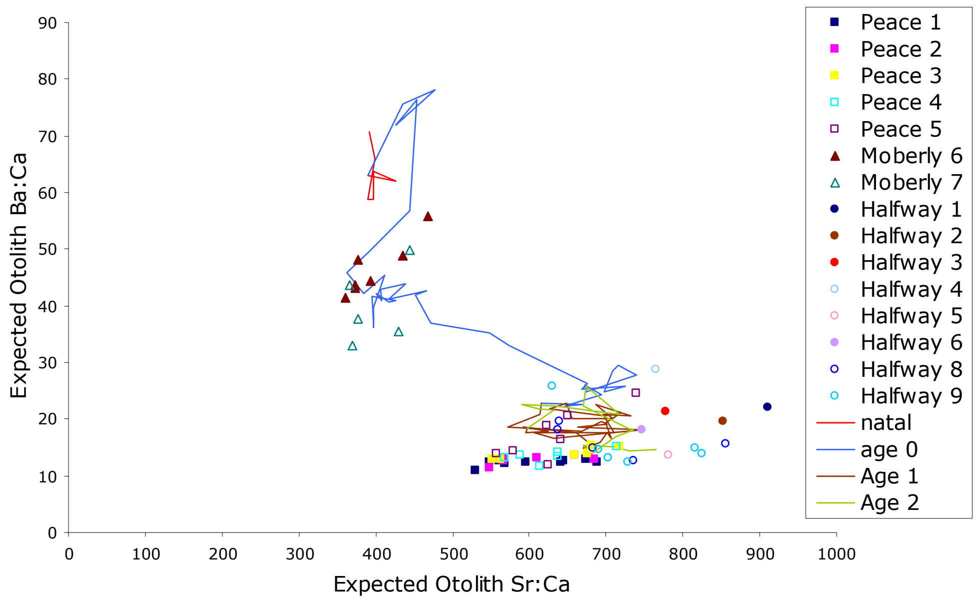

Figure 3.13 Complete life-history plot for a Peace River Arctic grayling (Gr21). This individual appears to have recruited outside of the habitats measured for water chemistry but may have migrated into the Moberly River at age 0+ before migrating to the Peace River where it remained until capture.

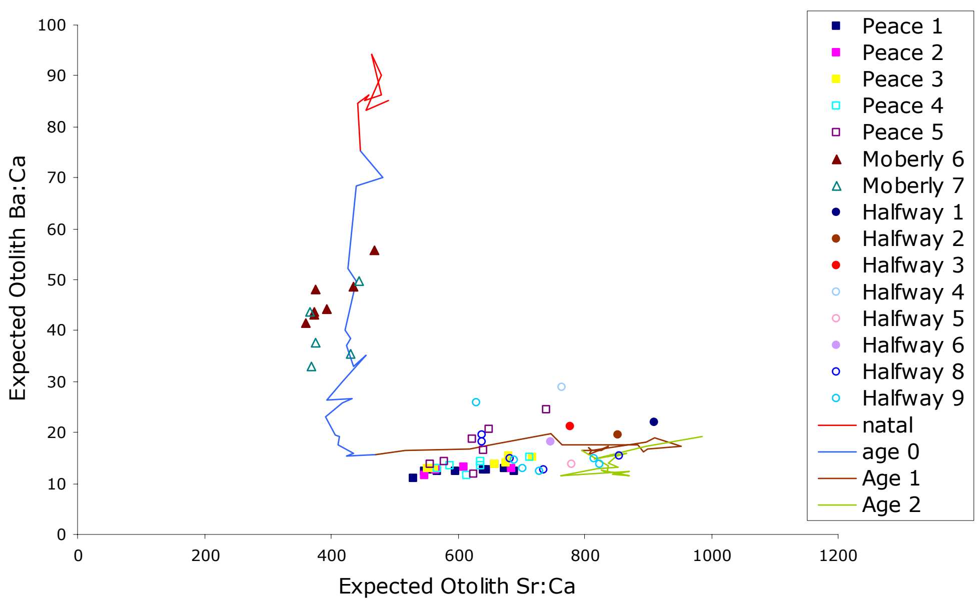

Figure 3.14 Complete life-history plot for a Peace River Arctic grayling (Gr23). This individual appears to have recruited outside of the habitats measured for water chemistry but may have migrated into the Moberly River at age 0+ before migrating to what appears to be the Halfway River where it remained until capture. This individual was captured in the Peace River but had a Sr:Ca concentration representative of the Halfway River. One other individual (Gr34) captured in the same Peace River location demonstrated this life-history.

Both Peace and Halfway River mountain whitefish recruit from the mainstem Halfway and Peace Rivers but a large number are also recruiting from outside of the study area (measured water chemistries). Most of the whitefish start rearing in either the Halfway or Peace River during their first summer and remain there for their entire life histories (Figures 3.15 to 3.18). There is some evidence for habitat use outside of measured water chemistries but the habitats are similar to the Peace River water chemistry make-up. Habitat use could be occurring immediately below tributaries to the Peace (affecting local water chemistry) or in tributaries to the Peace not examined in this study.

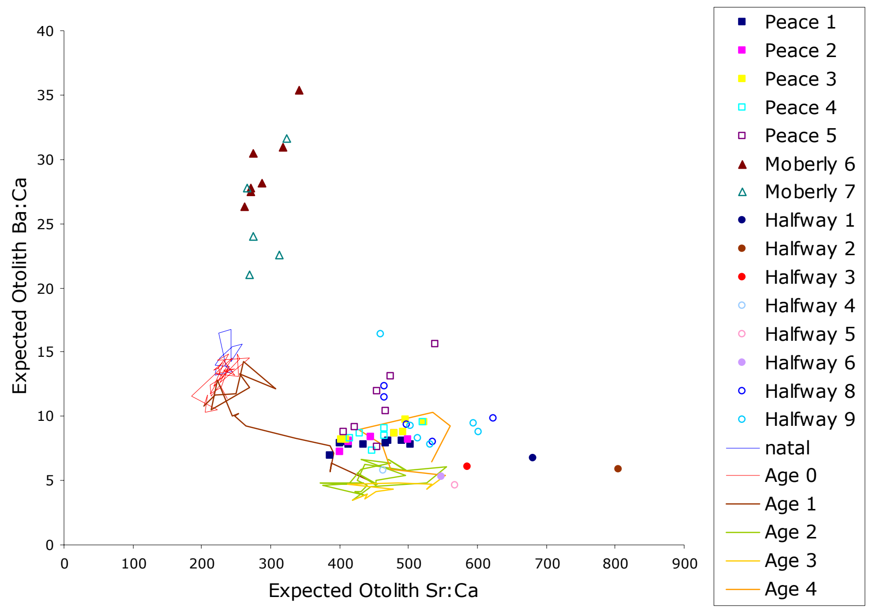

Figure 3.15 Complete life-history plot for a Halfway River mountain whitefish (M2). This individual appears to have recruited outside of the habitats measured for water chemistry. At age 1 this individual likely migrated to the Halfway River (lower Ba:Ca than the Peace) where it remained until capture. This individual does appear to migrate into the Peace River in its 4th year before moving back into the Halfway.

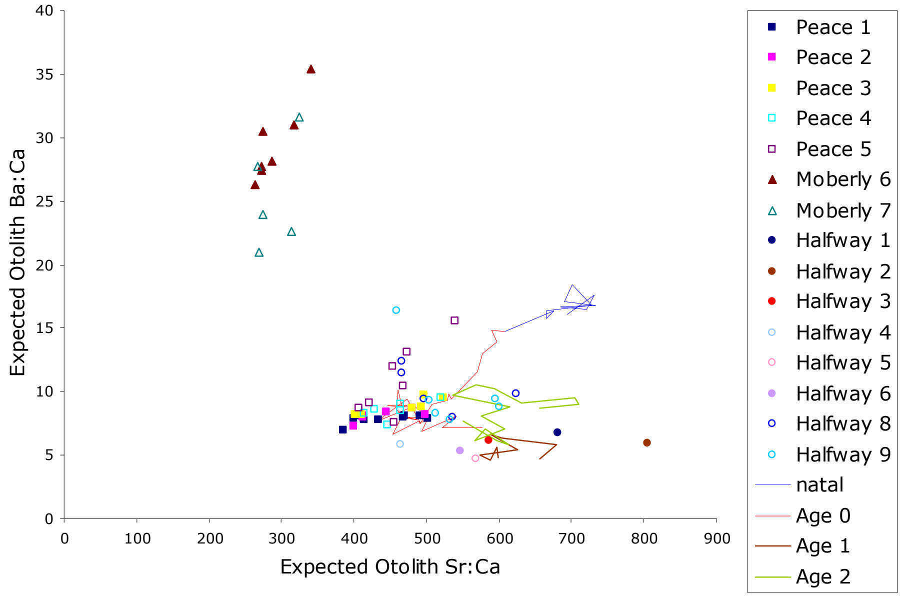

Figure 3.16 Complete life-history plot for a Halfway River mountain whitefish (M3). This individual appears to have recruited outside of the habitats measured for water chemistry. At age 0 this individual likely migrated to the Halfway River but it appears to spend time in both the Peace and Halfway Rivers.

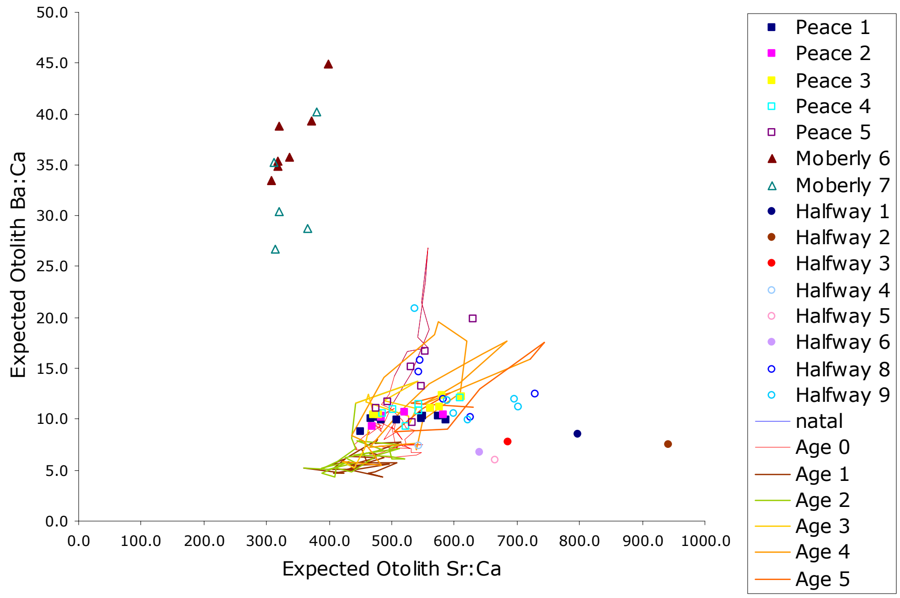

Figure 3.17 Complete life-history plot for a Peace River mountain whitefish (M40). This individual appears to have recruited in the Peace River, and reared in the Peace until it was captured. The lower left portion of the track indicates movement into a habitat not measured for water chemistry (tributary or mouth of tributary).

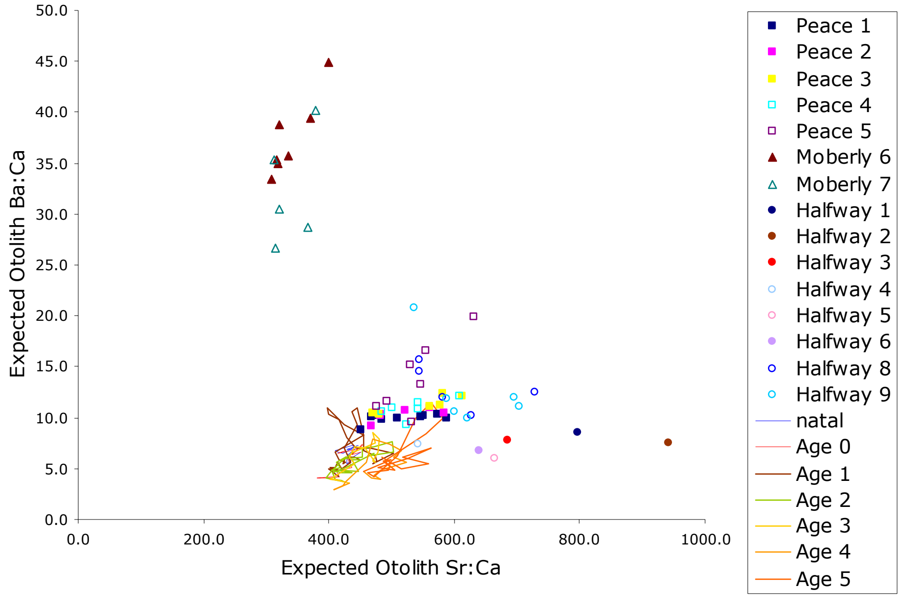

Figure 3.18 Complete life-history plot for a Peace River mountain whitefish (M33). This individual appears to have recruited outside of the habitats measured for water chemistry (same habitat as M40). Expected Sr:Ca suggest Peace River rearing for most of this individual's life but Ba:Ca is lower than expected.

4.0 DISCUSSION

The main finding of this work is that discrete and stable water chemical signatures exist for the Peace and Moberly Rivers and these watersheds are useful for further examination of fish life-history to help assess potential effects of the Site C project. The Halfway River showed some variability in water chemistry below the Cameron River, but this would be quantifiable through an examination of more years of data. Regardless, both otolith and water chemistry signatures are different between the Halfway (particularly above the Cameron River) and Peace Rivers samples. This suggests a good model describing habitat use of Peace watershed fishes could be developed with further sampling of both otolith and water chemistry.

We identified unknown habitats used by both Arctic grayling and mountain whitefish in our study but a lack of water chemistry data inhibits quantitative classifications. The results from the Sr:Ca concentrations measured in both Arctic grayling and mountain whitefish otoliths suggest decreasing concentrations of Sr:Ca in the Halfway River in a downstream direction. The measured water chemistries in lower portions of the Halfway do overlap with Peace River water chemistries but fish were not sampled in these areas of the Halfway River. On the other hand, estimated water chemistries for the Halfway River (sites 1-6) using otoliths for captured fish suggest that there is good chemical separation between the Halfway River (above the confluence of the Cameron River), and the Peace River. For the Peace River, otolith and water chemistry data suggests a very homogenous chemical environment. We are confident we can assign future samples to the Peace River, but any fish movements up and down the Peace River would be difficult to discern. The Moberly River was unique chemically and movements to this watershed by fish could be detected.

A large peak in Sr:Ca at the core of the otolith has previously been demonstrated to represent a marine maternal signature. Differences in those levels in the core have also been used to differentiate between progeny of anadromous and resident rainbow trout (Zimmerman and Reeves 2002; Donohoe *et al.* 2008) and bull trout (Brenkman *et al.* 2007). Originally, Kalish (1990) found that Sr:Ca ratios in the core of rainbow trout would reflect the composition of the ambient water where the maternal parent matured. To take the work of Kalish (1990) one step further, the Sr:Ca measured in the otolith core can be used to identify the maturing area of the maternal parent in freshwater fish (Clarke and Telmer 2008; Korman *et al.* 2009). The core (natal area) constitutes both ambient water chemistry of the developing otolith and maternal contribution (adult rearing area). The ratio changes as the yolk is used up by the developing fish eventually reflecting only ambient water chemistry near the outer portion of the core (we examine the core spatially so we can identify the specific area that reflects maternal composition). Most of the Arctic grayling in the sample appear to be recruiting from the Moberly River watershed and moving into the

Peace, and or, Halfway Rivers during their second spring or summer (age 1 to 1+). Mountain whitefish, on the other hand, appear to be recruiting from the Peace River, Halfway River, and some unknown tributaries before moving into the mainstem Peace and Halfway Rivers during their first summer. Only two of 40 mountain whitefish examined in this study appear to have recruited from the Moberly River.

Two Arctic grayling (23 and 34, considered outliers) were captured in Section 3 of the Peace River and had elemental concentrations measured at the edge of the otolith that reflected expected Halfway River values. There are three possible explanations for this observation. The first possibility is that these two fish recently migrated from the Halfway River into Section 3 of the Peace River. One weakness with the use of LA-ICPMS is that we cannot observe the last month of a fish's life. Although the 10 um resolution for the laser used to ablate these otoliths corresponds to approximately 1 week of otolith growth, shorter-term signals can still be detected. The magnitude of the change in concentration is less for short-term changes due to target mixing, but it is still clearly observable. This is known from the analysis of otoliths in chemical tagging experiments where fish are exposed to elevated Sr concentrations for just a few hours. In such analysis, a beam resolution of 50 um was able to clearly detect exposures of just 6 h (Telmer *et al.*, 2006). *However,* material deposited onto the otolith just before death is difficult to analyse because it is right at the edge of the target. A short end-of-life signal by the nature of its location in the otolith is difficult to observe. A second possibility is that the specific location these fish were captured in the Peace River differs in water chemistry from the other locations sampled. This scenario seems unlikely given the volume of water moving through this system. The third possibility is that these two individuals recently emigrated from a tributary that has similar water chemistry to the Halfway River. Further water sampling of tributaries used by Arctic grayling will be needed to explore this possibility further.

Zn:Ca ratios were used to estimate the ages of both Arctic grayling and mountain whitefish in this study and to determine age at specific migrations. Halden *et al.* (2000) determined that seasonal deposition of Zn in Arctic char otoliths correlates to annulus formation. Milner (1982), as well as Bradley and Sprague (1985), suggest that metabolic rate influences Zn deposition in fish otoliths. Seasonal summer temperatures likely positively influence the uptake and production of Zn, while colder winter temperatures would represent times when lower levels of Zn uptake occur (Halden *et al.* 2000). Clarke *et al.* (2004) also determined that oscillations of Zn present in fin-rays of bull trout represent yearly increments. In that study, ages estimated using Zn:Ca ratios corresponded well to independent age estimates using traditional ageing techniques.

Halden *et al.* (2000) noted that the incorporation of Zn into Arctic char otoliths decreases with age. These results are also consistent with other studies examining Zn uptake by fish (Milner 1982; Bradley and

Sprague 1985; Campbell and Stokes 1985; Clarke and Telmer 2008). We have noted that Zn:Ca is often more concentrated on one side of the otolith than the other. The imperfect symmetry of otoliths, particularly for metabolically controlled elements that are more strongly uptaken in the protein matrix of otoliths (e.g. Zn), results in a higher concentration on one side of the otolith than the other; due to a higher concentration of endolymphatic fluid. The more compressed side of the otolith is always lower in Zn. The combination of these factors makes ageing more difficult, particularly for slow growing species and for older ages.

Our results for the Peace and Halfway Rivers indicate that LA-ICPMS is a valid technique for determination of life-history characteristics and behaviours of fishes in these watersheds. Previous work has shown that elemental signatures are directly proportional to water chemistry (Wells *et al.* 2003 for cutthroat trout; Clarke *et al.* 2004 for slimy sculpins; Clarke *et al.* 2007a for Arctic grayling). The data examined in this report suggests that otoliths of fishes from these watersheds are also proportional to water chemistry and there appears to be sufficient heterogeneity between rivers to assess fish movement and rearing patterns. The results are not surprising, as recent work in other British Columbia watersheds has revealed significant heterogeneity among freshwater habitats (Clarke *et al.* 2004; Clarke *et. al* 2007a; Clarke and Telmer 2008).

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5.0 SUMMARY

Our work demonstrates that the elemental signature method can be applied to investigate fish life history strategies in the Site C study area. As such, otolith microchemistry analysis can be used to address data gaps in our knowledge of the Peace River fish community. Main findings are as follows:

1. The elemental signature method was an effective technique when applied to otoliths collected from fish located in the Peace River and the Halfway River.
2. Water chemistry data for the Peace River, Moberly River, and Halfway River provided sufficient separation of potential chemical signatures.
3. The Moberly River appears to be a major source of recruitment for Peace River Arctic grayling.
4. The Halfway River and Peace River appear to be major sources of recruitment for Peace River Arctic grayling.
5. Unknown sources of recruitment were identified for Arctic grayling and mountain whitefish collected from the Halfway River and the Peace River.
6. The elemental signature method can be used to document the age of younger Arctic grayling and younger mountain whitefish collected from the Peace River and the Halfway River.

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APPENDIX

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APPENDIX A
Sample Collection Data

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Appendix A - Elemental signature otolith sample collection data, Site C 2010 Elemental Signature Pilot Study.

SampleLabel	Project	River	Section	Site	Method	NAD	Zone	Easting	Northing	Date	FishID	Species	ForkLength	Comments
A10005001	10005	Peace	5	LF0508	Large fish boat EF	83	10	638430	6227150	15-Jul-10	7973	GR	198	2 otoliths (2 whole)
A10006001	10006	Halfway	1	HSF0101	Small fish boat EF	83	10	537211	6269851	6-Aug-10	8	GR	188	2 otoliths (1 whole, 1 with tip broken)
A10006002	10006	Halfway	1	HSF0104	Small fish boat EF	83	10	538961	6267982	6-Aug-10	12	GR	198	2 otoliths (whole)
A10006003	10006	Halfway	1	HSF0104	Small fish boat EF	83	10	538961	6267982	6-Aug-10	14	GR	221	2 otoliths (whole)
A10006004	10006	Halfway	1	HSF0106	Small fish boat EF	83	10	539947	6266476	6-Aug-10	16	GR	217	2 otoliths (1 whole, 1 with tip broken)
A10006005	10006	Halfway	2	HSF0201	Small fish boat EF	83	10	542694	6264626	6-Aug-10	19	GR	217	2 otoliths (1 whole, 1 with tip broken)
A10006006	10006	Halfway	3	HSF0206	Small fish boat EF	83	10	548135	6262658	7-Aug-10	21	GR	156	2 otoliths (2 whole)
A10006007	10006	Halfway	3	HSF0303	Small fish boat EF	83	10	552248	6263101	7-Aug-10	27	GR	200	2 otoliths (1 whole, 1 broken)
A10006008	10006	Halfway	3	HSF0305	Small fish boat EF	83	10	554662	6262938	7-Aug-10	29	GR	208	2 otoliths (both with broken tip)
A10006009	10006	Halfway	3	HSF0305	Small fish boat EF	83	10	554662	6262938	7-Aug-10	30	GR	233	2 otoliths (2 whole)
A10006010	10006	Halfway	4	HSF0401	Small fish boat EF	83	10	557359	6260332	8-Aug-10	33	GR	155	2 otoliths (2 whole)
A10006011	10006	Halfway	4	HSF0404	Small fish boat EF	83	10	561016	6261633	8-Aug-10	34	GR	162	2 otoliths (2 whole)
A10006012	10006	Halfway	5	HSF0501	Small fish boat EF	83	10	565080	6261802	9-Aug-10	41	GR	254	2 otoliths (2 whole)
A10006013	10006	Halfway	5	HSF0502	Small fish boat EF	83	10	565937	6261213	9-Aug-10	42	GR	191	2 otoliths (2 whole)
A10006014	10006	Halfway	5	HSF0502	Small fish boat EF	83	10	565937	6261213	9-Aug-10	43	GR	285	2 otoliths (2 whole)
A10006015	10006	Halfway	6	HSF0601	Small fish boat EF	83	10	571978	6256458	10-Aug-10	47	GR	161	2 otoliths (2 whole)
A10006016	10006	Halfway	6	HSF0602	Small fish boat EF	83	10	572366	6255398	10-Aug-10	48	GR	178	2 otoliths (2 whole)
A10006017	10006	Halfway	1	HSF1103	Small fish boat EF	83	10	530231	6281579	4-Aug-10	72	GR	229	1 otolith (broken in two pieces)
A10006018	10006	Halfway	1	HSF1201	Small fish boat EF	83	10	533021	6278772	5-Aug-10	80	GR	211	otoliths submitted
A10006019	10006	Halfway	1	HSF1205	Small fish boat EF	83	10	534961	6273497	5-Aug-10	88	GR	214	2 otoliths (1 whole, 1 with edge broken)
A10006020	10006	Halfway	1	HSF1206	Small fish boat EF	83	10	535717	6272311	5-Aug-10	101	GR	215	2 otoliths (1 whole, 1 with broken tip)
A10011002	10011	Peace	3	303	Large fish boat EF	83	10	602930	6233597	24-Aug-10	131	GR	299	2 otoliths (2 whole)
A10011003	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	386	GR	196	2 otoliths (2 whole)
A10011004	10011	Peace	3	316	Large fish boat EF	83	10	607974	6234928	25-Aug-10	613	GR	180	1 otolith (small part of edge broken off)
A10011006	10011	Peace	5	502	Large fish boat EF	83	10	630954	6229298	10-Sep-10	6126	GR	230	2 otoliths (2 whole)
A10011007	10011	Peace	5	512	Large fish boat EF	83	10	634872	6230026	11-Sep-10	6488	GR	229	2 otoliths (2 whole)
A10011008	10011	Peace	3	303	Large fish boat EF	83	10	602930	6233597	14-Sep-10	7083	GR	248	2 otoliths (2 whole)
A10011009	10011	Peace	5	501	Large fish boat EF	83	10	630016	6229305	16-Sep-10	8030	GR	212	2 otoliths (2 whole)
A10011010	10011	Peace	5	502	Large fish boat EF	83	10	630954	6229298	16-Sep-10	8134	GR	218	2 otoliths (1 whole, 1 with tip broken)
A10011011	10011	Peace	5	512	Large fish boat EF	83	10	634872	6230026	17-Sep-10	8348	GR	241	2 otoliths (2 whole)
A10011012	10011	Peace	5	510	Large fish boat EF	83	10	635555	6230048	17-Sep-10	8395	GR	235	2 otoliths (2 whole)
A10011013	10011	Peace	5	508	Large fish boat EF	83	10	638432	6227150	17-Sep-10	8492	GR	162	2 otoliths (1 whole, 1 with tip broken)
A10011014	10011	Peace	5	510	Large fish boat EF	83	10	635555	6230048	20-Sep-10	8493	GR	222	2 otoliths (2 whole)
A10011015	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	19-Sep-10	8815	GR	176	2 otoliths (both with broken tips)

Appendix A - Elemental signature otolith sample collection data, Site C 2010 Elemental Signature Pilot Study.

SampleLabel	Project	River	Section	Site	Method	NAD	Zone	Easting	Northing	Date	FishID	Species	ForkLength	Comments
A10011016	10005	Peace	6	SF0616	Small fish boat EF	83	10	654559	6221624	19-Jul-10	13474	GR	185	2 otoliths (2 whole)
A10011017	10011	Peace	5	505	Large fish boat EF	83	10	631540	6229590	20-Sep-10	8647	GR	195	2 otoliths (1 whole, 1 with tip broken)
A10011018	10011	Peace	5	508	Large fish boat EF	83	10	638432	6227150	17-Sep-10	8684	GR	222	2 otoliths (1 whole, 1 with tip broken)
A10011019	10011	Peace	5	504	Large fish boat EF	83	10	630560	6229543	23-Sep-10	9168	GR	232	2 otoliths (2 whole)
A10011020	10011	Peace	5	509	Large fish boat EF	83	10	633704	6229905	23-Sep-10	9201	GR	244	2 otoliths (2 whole)
A10011021	10011	Peace	5	509	Large fish boat EF	83	10	633704	6229905	23-Sep-10	9205	GR	217	2 otoliths (2 whole)
M10006001	10006	Halfway	1	HSF0101	Small fish boat EF	83	10	537211	6269851	6-Aug-10	2526	MW	310	2 otoliths (1 with broken tip, 1 broken)
M10006002	10006	Halfway	1	HSF0103	Small fish boat EF	83	10	538291	6268412	6-Aug-10	2541	MW	248	2 otoliths (2 whole)
M10006003	10006	Halfway	1	HSF0106	Small fish boat EF	83	10	539947	6266476	6-Aug-10	2576	MW	195	2 otoliths (2 whole)
M10006004	10006	Halfway	1	HSF0107	Small fish boat EF	83	10	540759	6265884	6-Aug-10	2582	MW	211	2 otoliths (both broken)
M10006005	10006	Halfway	2	HSF0201	Small fish boat EF	83	10	542694	6264626	6-Aug-10	2596	MW	320	2 otoliths (both with broken tips)
M10006006	10006	Halfway	3	HSF0301	Small fish boat EF	83	10	550242	6263341	7-Aug-10	2636	MW	302	2 otoliths (both broken)
M10006007	10006	Halfway	3	HSF0303	Small fish boat EF	83	10	552248	6263101	7-Aug-10	2670	MW	198	2 otoliths (both with broken tips)
M10006008	10006	Halfway	3	HSF0306	Small fish boat EF	83	10	556804	6261915	7-Aug-10	2702	MW	204	2 otoliths (1 whole, 1 broken)
M10006009	10006	Halfway	3	HSF0306	Small fish boat EF	83	10	556804	6261915	7-Aug-10	2703	MW	269	2 otoliths (2 whole)
M10006010	10006	Halfway	4	HSF0402	Small fish boat EF	83	10	558258	6259894	8-Aug-10	2719	MW	182	2 otoliths (both with broken tips)
M10006011	10006	Halfway	5	HSF0501	Small fish boat EF	83	10	565080	6261802	9-Aug-10	2794	MW	255	2 otoliths (1 broken, 1 broken into pieces)
M10006012	10006	Halfway	5	HSF0503	Small fish boat EF	83	10	566845	6260696	9-Aug-10	2825	MW	322	2 otoliths (1 with broken tip, 1 broken)
M10006013	10006	Halfway	6	HSF0602	Small fish boat EF	83	10	572366	6255398	10-Aug-10	2898	MW	264	2 otoliths (both broken tips)
M10006014	10006	Halfway	6	HSF0602	Small fish boat EF	83	10	572366	6255398	10-Aug-10	2899	MW	235	2 otoliths (both broken tips)
M10006015	10006	Halfway	6	HSF0603	Small fish boat EF	83	10	573091	6254729	10-Aug-10	2910	MW	232	2 otoliths (1 with broken tip, 1 broken)
M10006016	10006	Halfway	6	HSF0605	Small fish boat EF	83	10	574571	6253088	10-Aug-10	2921	MW	214	2 otoliths (both with broken tips)
M10006017	10006	Halfway	1	HSF1102	Small fish boat EF	83	10	529094	6283298	4-Aug-10	3176	MW	164	2 otoliths (1 whole, 1 broken)
M10006018	10006	Halfway	1	HSF1104	Small fish boat EF	83	10	531791	6280216	4-Aug-10	3213	MW	190	2 otoliths (1 with broken tip, 1 broken)
M10006019	10006	Halfway	1	HSF1203	Small fish boat EF	83	10	533980	6275853	5-Aug-10	3236	MW	283	2 otoliths (both with broken tips)
M10006020	10006	Halfway	1	HSF1205	Small fish boat EF	83	10	534961	6273497	5-Aug-10	3267	MW	210	2 otoliths (both with broken tips)
M10006021	10006	Halfway	1	HSF1206	Small fish boat EF	83	10	535717	6272311	5-Aug-10	3286	MW	279	2 otoliths (both with broken tips)
M10011001	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	259	MW	212	2 otoliths (2 whole)
M10011002	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	261	MW	311	2 otoliths (1 with tip broken, 1 broken)
M10011003	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	14-Sep-10	7279	MW	321	2 otoliths (both with broken tips)
M10011004	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	267	MW	322	2 otoliths (1 with tip broken, 1 broken)
M10011005	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	285	MW	220	2 otoliths (both with broken tips)
M10011006	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	295	MW	245	2 otoliths (1 whole, 1 broken in half)
M10011007	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	303	MW	248	2 otoliths (1 whole, 1 with broken tip missing)

Appendix A - Elemental signature otolith sample collection data, Site C 2010 Elemental Signature Pilot Study.

SampleLabel	Project	River	Section	Site	Method	NAD	Zone	Easting	Northing	Date	FishID	Species	ForkLength	Comments
M10011008	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	338	MW	287	2 otoliths (1 with tip broken, 1 broken in half)
M10011009	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	269	MW	330	1 otolith (1 with tip broken and missing)
M10011010	10011	Peace	3	302	Large fish boat EF	83	10	601597	6233232	14-Sep-10	7025	MW	262	2 otoliths (both with broken tips)
M10011011	10011	Peace	3	302	Large fish boat EF	83	10	601597	6233232	14-Sep-10	7034	MW	265	2 otoliths (1 whole, 1 broken in half)
M10011012	10011	Peace	3	302	Large fish boat EF	83	10	601597	6233232	14-Sep-10	7035	MW	314	2 otoliths (both with broken tips)
M10011013	10011	Peace	3	301	Large fish boat EF	83	10	602606	6233198	14-Sep-10	7079	MW	328	2 otoliths (both with broken tips, 1 tip missing)
M10011014	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	24-Aug-10	266	MW	319	2 otoliths (both with broken tips)
M10011015	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	14-Sep-10	7281	MW	307	2 otoliths (1 whole, 1 broken in half)
M10011016	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	14-Sep-10	7283	MW	294	2 otoliths (1 whole, 1 with tip broken)
M10011017	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7419	MW	273	2 otoliths (1 with tip broken, 1 broken)
M10011018	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7420	MW	306	2 otoliths (both with broken tips)
M10011019	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7421	MW	304	2 otoliths (both with broken tips)
M10011020	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7422	MW	271	2 otoliths (2 whole)
M10011021	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7423	MW	284	2 otoliths (1 with tip broken, 1 broken in half)
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	3-Sep-10	3236	GR	94	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	14-Sep-10	3478	GR	192	2 otoliths ; both rostrums broken off
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3551	MW	108	1 otolith ; rostrum broken off
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3552	GR	95	2 otoliths ; 1 good, 1 missing rostrum
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3554	GR	110	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3555	GR	87	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3556	GR	93	2 otoliths ; 1 good, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3557	GR	84	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3558	MW	92	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3559	MW	86	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3560	MW	101	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3561	MW	144	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	16-Sep-10	3562	MW	108	1 otolith ; broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3596	MW	193	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3597	GR	99	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3598	GR	98	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3599	GR	102	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3600	GR	95	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3601	GR	95	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3602	GR	93	2 otoliths ; good condition

Appendix A - Elemental signature otolith sample collection data, Site C 2010 Elemental Signature Pilot Study.

SampleLabel	Project	River	Section	Site	Method	NAD	Zone	Easting	Northing	Date	FishID	Species	ForkLength	Comments
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3603	GR	100	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3604	GR	89	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3605	GR	95	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3606	GR	101	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3607	MW	93	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3608	MW	96	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3609	MW	94	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3610	MW	97	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3611	MW	99	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	17-Sep-10	3612	MW	106	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	22-Sep-10	3662	GR	93	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	23-Sep-10	3706	MW	92	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	24-Sep-10	3715	GR	115	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3859	MW	91	2 otoliths ; both rostrums broken off
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3860	MW	93	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3861	GR	93	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3862	GR	106	1 otolith ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3863	GR	79	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3864	GR	87	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	5-Oct-10	3865	GR	88	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	6-Oct-10	3906	MW	98	2 otoliths ; both rostrums broken off
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	6-Oct-10	3907	MW	89	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	6-Oct-10	3908	MW	96	1 otolith ; broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	7-Oct-10	3969	MW	106	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	7-Oct-10	3971	MW	101	2 otoliths ; good condition
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	7-Oct-10	3972	MW	98	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	7-Oct-10	3973	MW	87	2 otoliths ; 1 good condition, 1 broken
Not submitted	10004	Moberly	Lower	M02	Rotary screw trap	83	10	628564	6230033	7-Oct-10	3974	MW	99	2 otoliths ; 1 good condition, 1 broken
Not submitted	10011	Peace	1	113	Large fish boat EF	83	10	570510	6212043	26-Aug-10	1073	MW	327	2 otoliths; 1 aged, 1 good condition.
Not submitted	10011	Peace	1	112	Large fish boat EF	83	10	570686	6212472	26-Aug-10	1125	MW	300	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	1	103	Large fish boat EF	83	10	567401	6208075	27-Aug-10	1438	MW	348	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	1	110	Large fish boat EF	83	10	569302	6211053	30-Aug-10	2100	MW	304	2 otoliths; 1 aged,1 broken in half.
Not submitted	10011	Peace	1	112	Large fish boat EF	83	10	570686	6212472	7-Sep-10	4802	MW	345	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	1	102	Large fish boat EF	83	10	567497	6208907	13-Sep-10	6844	MW	259	2 otoliths; 1 aged, 1 rostrum broken off.

Appendix A - Elemental signature otolith sample collection data, Site C 2010 Elemental Signature Pilot Study.

SampleLabel	Project	River	Section	Site	Method	NAD	Zone	Easting	Northing	Date	FishID	Species	ForkLength	Comments
Not submitted	10011	Peace	1	102	Large fish boat EF	83	10	567497	6208907	13-Sep-10	6845	MW	332	2 otoliths; 1 aged, 1 good condition.
Not submitted	10011	Peace	3	302	Large fish boat EF	83	10	601597	6233232	1-Sep-10	2795	MW	478	2 otoliths; 1 aged,1 tip broken off.
Not submitted	10011	Peace	3	312	Large fish boat EF	83	10	608047	6235753	9-Sep-10	6033	GR	237	2 otoliths; 1 good, 1 rostrum broken off.
Not submitted	10011	Peace	3	305	Large fish boat EF	83	10	604640	6233426	14-Sep-10	7315	MW	377	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7415	MW	357	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7417	MW	358	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7418	MW	358	2 otoliths; 1 aged, 1 good condition.
Not submitted	10011	Peace	3	306	Large fish boat EF	83	10	605586	6233750	14-Sep-10	7424	MW	364	2 otoliths; 1 aged, 1 broken in half.
Not submitted	10011	Peace	3	310	Large fish boat EF	83	10	607691	6235034	15-Sep-10	7912	MW	370	2 otoliths; 1 aged, 2 broken pieces.
Not submitted	10011	Peace	3	314	Large fish boat EF	83	10	605400	6233321	24-Aug-10	12579	GR	322	1 otolith; good condition.
Not submitted	10011	Peace	5	507	Large fish boat EF	83	10	633099	6229489	28-Aug-10	1790	GR	352	2 otoliths; 1 good, 1 rostrum broken off.
Not submitted	10011	Peace	5	510	Large fish boat EF	83	10	635555	6230048	29-Aug-10	1886	MW	347	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	5	515	Large fish boat EF	83	10	637591	6228192	29-Aug-10	1933	MW	410	2 otoliths; 1 aged, 1 broken.
Not submitted	10011	Peace	5	513	Large fish boat EF	83	10	637433	6228125	29-Aug-10	1963	MW	392	2 otoliths; 1 aged, 1 broken.
Not submitted	10011	Peace	5	514	Large fish boat EF	83	10	637735	6227647	29-Aug-10	1999	MW	380	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	5	514	Large fish boat EF	83	10	637735	6227647	29-Aug-10	2005	MW	412	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	5	508	Large fish boat EF	83	10	638432	6227150	29-Aug-10	2025	MW	415	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10004	Peace	5	P01	Rotary screw trap	83	10	629559	6229483	17-Sep-10	3631	MW	97	2 otoliths ; good condition
Not submitted	10011	Peace	5	504	Large fish boat EF	83	10	630560	6229543	3-Sep-10	3632	MW	469	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	5	502	Large fish boat EF	83	10	630954	6229298	3-Sep-10	3712	MW	282	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	5	502	Large fish boat EF	83	10	630954	6229298	16-Sep-10	8133	MW	359	2 otoliths; 1 aged,1 broken in half.
Not submitted	10011	Peace	5	505	Large fish boat EF	83	10	631540	6229590	16-Sep-10	8176	MW	277	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	5	505	Large fish boat EF	83	10	631540	6229590	16-Sep-10	8177	MW	262	2 otoliths; 1 aged, 1 broken in half.
Not submitted	10011	Peace	5	507	Large fish boat EF	83	10	633099	6229489	16-Sep-10	8244	MW	253	2 otoliths; 1 aged, 1 half of an otolith.
Not submitted	10011	Peace	5	507	Large fish boat EF	83	10	633099	6229489	16-Sep-10	8245	MW	293	2 otoliths; 1 aged,1 broken.
Not submitted	10011	Peace	5	509	Large fish boat EF	83	10	633704	6229905	16-Sep-10	8273	MW	270	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	5	513	Large fish boat EF	83	10	637433	6228125	17-Sep-10	8460	MW	228	2 otoliths; 1 aged, 1 rostrum broken off.
Not submitted	10011	Peace	5	510	Large fish boat EF	83	10	635555	6230048	20-Sep-10	8683	GR	356	2 otoliths; good condition.