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Life history analysis of chinook salmon (*Oncorhynchus tshawytscha*) from lakes Mapourika and Paringa, West Coast, South Island, New Zealand, by otolith microchemistry

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Executive summary

Otolith microchemistry is an established technique for determining fish migrations between the sea and freshwater. The aim of our study was to determine life history patterns of chinook salmon collected from rivers and lake tributaries along the West Coast of the South Island, New Zealand using otolith microchemistry. Specifically, we compared relative concentrations of barium and strontium in salmon otoliths as a proxy of fresh and seawater migration and related this to individual fish ages. Using this approach, fish migrations between the sea and freshwater are often determined by changing patterns in strontium (Sr) and barium (Ba) concentrations across the otolith growth axis. Time spent in the sea is characterised by high relative strontium and low barium concentrations, whereas freshwater phases have relatively higher barium and low strontium concentrations. When fish move from the sea to freshwater or vice versa a pronounced change in relative concentrations is usually seen.

Ten chinook salmon were collected as carcasses or by fishing from the Hokitika and Taramakau rivers, Lake Mapourika and its tributary, MacDonalds Creek, and Lake Paringa and its tributary, Windbag Stream. A previous preliminary report investigated otoliths from 11 salmon captured in tributaries of lakes Mapourika and Paringa during 2008. This study showed lower $^{87}Sr/^{86}Sr$ ratios (0.707-0.709) that were interpreted as freshwater residence and higher ratios (0.710-0.712) that suggested sea residence. This approach uses strontium isotopic ratios instead of Sr and Ba elemental concentrations to determine freshwater and marine occupancy. Ratios of $^{88}Sr/V$ (vanadium) were also examined, and showed a reciprocal relationship to ratios of $^{87}Sr/^{86}Sr$. All 11 otoliths examined from 2008 showed freshwater rearing followed by a period of marine residence of varying length.

Chinook salmon in our study showed a wide variety of life histories, and microchemical analysis of the otoliths partly confirmed the presumed life history of each salmon. The freshwater phase was evident from strontium concentrations, expressed as $^{86}Sr/^{43}Ca$ x 1000, of between 100 and 400 and variable barium concentrations of between 2 to 8 expressed as $^{137}Ba/^{43}Ca$ x 1000. The marine phase was characterised by high strontium concentrations of 500 to 900, with low barium concentrations, generally less than 2. Five individuals from the Hokitika and Taramakau rivers, MacDonalds Creek (L. Mapourika), and Windbag Stream (L. Paringa) exhibited normal chinook salmon life histories with early rearing in freshwater followed by an extensive period of growth to adulthood in the sea. Most salmon from MacDonalds Creek showed extensive freshwater residence, and two of these were lake-locked, with exclusively freshwater residence. A further two fish collected in May 2012 from MacDonalds Creek had lived most of their life in freshwater but showed evidence of a brief period in the sea late in life at ages 2 and 3 year respectively. Curiously, one fish from MacDonalds Creek had apparently entered a marine environment, possibly an estuary, just before its recovery as a carcass.

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Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) were introduced to New Zealand in the early 1900s. A self-supporting run was established from the McCloud River in California that were released into the Hakataramea River, a tributary of the Waitaki River in North Otago. From there, chinook salmon became established in other eastern South Island rivers, notably the Rangitātā, Rakaia and Waimakariri. Small salmon runs also exist on the West Coast of the South Island. A viable self-reproducing population became established in lakes Mapourika and Paringa, West Coast, South Island, and whether the population is supported by lake-locked or sea-run adults has been the subject of speculation. Previous data (unpblished data, Rasmus Gabrielsson, Cawthron Institute, Nelson) summarised and analysis of otoliths from 11 salmon captured in tributaries of lakes Mapourika and Paringa during 2008. These data showed lower $^{87}Sr/^{86}Sr$ ratios (0.707-0.709) that were interpreted as freshwater residence and higher ratios (0.710-0.712) that suggested sea residence (Appendix 1). Ratios of $^{88}Sr/V$ (vanadium) were also examined, and showed a reciprocal relationship to ratios of $^{87}Sr/^{86}Sr$. All 11 otoliths examined from 2008 showed freshwater rearing followed by a period of marine residence of varying length (unpublished data).

Using an alternative approach, fish movements between the sea and freshwater can also be distinguished by tracking changes in elemental concetrations of strontium and barium across the otolith growth axis (Campana, 1999). Given that otolith growth occurs daily and in part is made up of elemental constituents taken up from the water (Kalish 1990), it is possible to track fish movements across different water masses (Limburg 1995; Tzeng 1996;Tzeng et al 2006). In general, time spent at sea can be characterised by high relative strontium and low barium concentrations, whereas freshwater phases have relatively higher barium and low strontium concentrations. When fish move from the sea to freshwater or vice versa a pronounced change in relative concentrations in the otolith is usually seen.

The aim of our study was to determine life history patterns of chinook salmon collected from rivers along the West Coast of the South Island, New Zealand using otolith microchemistry techniques. Specifically, we compared relative concentrations of barium and strontium in salmon otoliths as a proxy of fresh and seawater migration and related this to individual ages. While a laser ablation instrument coupled to a multi-collector mass spectrometer is required to determine ^{87}Sr and ^{86}Sr concentrations, we analysed elemental concentrations of strontium and barium using a single collector mass spectrometer based in the Waikato Mass Spectrometry Facility at the University of Waikato. As our data are based on otolith line scan analyses, we used relative concentrations rather than absolute concentrations. This does not change the life history interpretations compared to absolute abundance measurements.

Methods

Sample collection

Ten chinook salmon were collected as carcasses or by fishing from the Hokitika and Taramakau rivers, Lake Mapourika and its tributary, MacDonalds Creek, and Lake Paringa and its tributary, Windbag Stream (Fig. 1). Locations and method of collection are shown in Table 1, together with the presumed life history at the time of collection and before otolith analysis.

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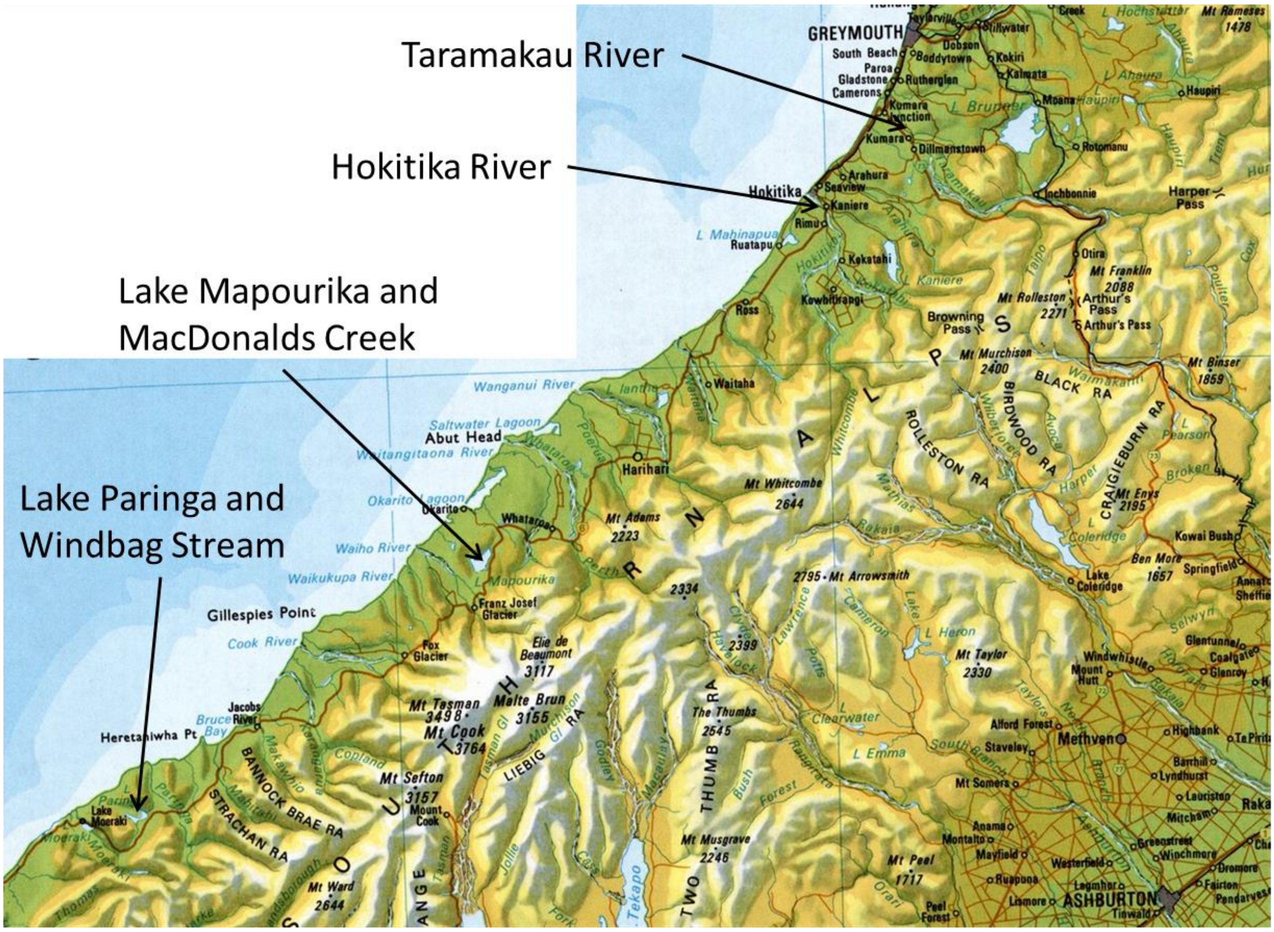

Figure 1. Sample collection locations of chinook salmon from lakes Mapourika and Paringa and their tributaries and the Taramakau River, West Coast, South Island, New Zealand.

Otolith preparation

Of the ten otoliths analysed, seven had been mounted on individual petrographic slides and polished ready for laser ablation by the West Coast Fish and Game Council. The remaining three otoliths were rinsed in ultra-pure milli-Q water then soaked in 3% hydrogen peroxide for 3 min, rinsed in milli-Q water again, then soaked in 2% nitric acid for 15 s. Otoliths were then rinsed thoroughly in mill-Q water again to dissolve any residual acid then drained and left to air dry in a fume hood overnight.

The otoliths were embedded (grove end facing up) in K36 epoxy resin contained within silicon moulds and left to set overnight before being sectioned transversely using a low-speed diamond head Beuhler Isomet saw. Thin sections of the otolith were then mounted onto petrographic slides using Crystal Bond thermo-setting glue, then polished using firstly 2400 micron wetted paper and finally finished using 4000 micron paper to expose the otolith nucleus. All 10 otoliths were mounted on a single petrographic slide then analysed by laser ablation ICP-MS.Laser instrumentation

Otolith microchemical analysis was carried out with a New Wave Research, Perkin Elmer Elan SCIEX DRCII laser ablation inductively coupled mass spectrometer (ICP-MS) with a Nd-YAG shortwave 213-nm laser. A total suite of 12 isotopes (^{7}Li, ^{25}Mg, ^{27}Al, ^{42}Ca, ^{43}Ca, ^{55}Mn, ^{66}Zn, ^{85}Rb, ^{86}Sr, ^{87}Sr, ^{88}Sr, ^{137}Ba) were analysed both in otoliths and NIST (National Institute of Standards and Technology) standard reference material (SRM) 612 the concentrations of which 50 elements are known. The laser was operated in Q-switched time resolved mode and NIST612 was used to standardise the machine output in counts per second as well for calibration.

ICP-MS optimisation and machine sensitivity

Elemental interferences produced by the presence of oxygen in the ICP-MS instrument, carrier gas transport lines, or on samples may result in combinations of oxygen with different elements causing an interference reading on other isotopes. To account for this and optimise the instrument a continuous line scan was run across the NIST612 at a scan speed of 10 µm/s, repetition rate of 10 Hz, output power of 60%, spot size of 60 µm, for 2 min. The ICP-MS was tuned during the 2-min line scan by manually adjusting the nebuliser gas flow to give a ThO+/Th+ ratio of ≈ 1%. Once this was achieved it was assumed that oxide interferences were negligible and otolith sample analysis could begin. During the same analyses a sensitivity check was also carried out by monitoring Th+/U+ ratios, until counts were >20,000 indicating that machine sensitivity was relatively high. For this study, gas flow was generally acceptable between 0.5- 0.7 L/min. This was carried out at the start of each day's run using NIST612 placed in the sample chamber with a single batch of 10 otoliths and purged with an argon carrier gas for 15 mins.

Calibration and data acquisition

Otoliths were analysed in conjunction with NIST 612 standards. Salmon otoliths were analysed using a continuous line scan at a travelling speed of 10 µm/s, repetition rate of 10 Hz, output power of 60%, spot size of 30 µm, which traversed the otolith growth axis from the nucleus to the dorsal edge for approximately 5 minutes (depending on otolith size). The concentration of trace elements in NIST612 is homogeneous (Pearce et al, 1997). Consequently, elemental concentrations (ppm) from NIST612 were standardised to internal ICP-MS machine standards using ^{42}Ca. Because laser ablation signals are notorious for being unstable over prolonged periods of use, NIST612 was analysed before, in the middle, and at the end of each otolith run.

Age determination

Salmon were aged from sections of the otoliths used for laser ablation. These were already mounted on glass slides by the time they arrived at our lab, and the sections were rather thick for straightforward age determination. Nevertheless, we attempted to age each otolith and to determine the radius at which each annual increment occurred with an ocular graticule in a dissecting stereo microscope. The radius of each line scan used in the laser ablation was proportioned to the radius and increment measurement so that the same relative positions of each increment could be calculated (Table 2). These annual increments are plotted on the laser results (Fig. 2).

Results

The chinook salmon in this study showed a wide variety of life histories, and microchemical analysis of the otoliths partly confirmed the presumed life history of each salmon (Table 1). The freshwater phase was evident from strontium concentrations, expressed as $^{86}Sr/^{43}Ca$ x 1000, of between 100 and 400 and variable barium concentrations of between 2 to 8 expressed as $^{137}Ba/^{43}Ca$ x 1000.

The marine phase was characterised by high strontium concentrations of 500 to 900, with low barium concentrations, generally less than 2 (Fig. 2). Five fish (IDs 88, 89, 93, 94, and 95) from the Hokitika and Taramakau rivers, MacDonalds Creek (L. Mapourika), and Windbag Stream (L. Paringa) exhibited normal chinook salmon life histories with early rearing in freshwater followed by an extensive period of growth to adulthood in the sea. Most salmon from MacDonalds Creek showed extensive freshwater residence, and two of these were lake-locked, with exclusively freshwater residence (Fish IDs 90 and 92).

A further two fish collected in May 2012 from MacDonalds Creek (ID 96 and 97) had lived most of their life in freshwater, presumably Lake Paringa, but showed evidence of a brief period in the sea late in life at ages 2 and 3 year respectively (Fig. 2). Curiously, one fish from MacDonalds Creek (ID 91) had apparently entered a marine environment, possibly an estuary, just before its recovery as a carcass.

Table 1. Date and location of capture of 10 chinook salmon from the West Coast of the South Island, New Zealand.

Fish	Capture location			Capture date	Capture	Sex	Length	Age	Presumed	Life history by
ID	Water body	Latitude (°S)	Longitude (°E)		method		(mm)	(years)	life history	otolith analysis
88	Hokitika River	42.90376	170.97006	17-Mar-10	Fishing	Male	810	3	Sea run	Sea run
89	Taramakau River	42.45149	171.27429	3-Jun-11	Carcass	Female	730	3	Sea run	Sea run
90	MacDonalds Creek	43.31127	170.24375	12-May-11	Carcass	Female	510	3	Lake resident	Lake resident
91	MacDonalds Creek	43.31127	170.24375	19-May-11	Carcass	Female	510	3	Lake resident	Lake resident
92	MacDonalds Creek	43.31127	170.24375	19-May-11	Carcass	Female	460	3	Lake resident	Lake resident
93	MacDonalds Creek	43.31127	170.24375	19-May-11	Carcass	Female	720	4	Sea run	Sea run
94	Lake Paringa	43.71735	169.41304	26-Mar-11	Fishing	Female	630	3	Sea run	Sea run
95	Windbag Stream	43.74767	169.38886	11-May-11	Carcass	Male	750	3	Sea run	Sea run
96	MacDonalds Creek	43.31127	170.24375	17-May-12	Carcass	Male	390	2	Lake resident	Late sea run
97	MacDonalds Creek	43.31127	170.24375	17-May-12	Carcass	Female	490	3	Lake resident	Late sea run

Table 2. Age and annual increment determined from otoliths of 10 chinook salmon from the West Coast of the South Island, New Zealand.

Fish ID	Capture location	Capture date	Analysis date	Length (mm)	Age (years)	Otolith length (mm)	Annual increment (year)	Increment distance from nucleus (mm)
88	Hokitika River	17-Mar-10	19-Feb-13	810	3+	5.86	1	1.12
							2	1.77
							3	2.60
							otolith edge	3.26
89	Taramakau River	3-Jun-11	19-Feb-13	730	3+	5.60	1	1.29
							2	1.73
							3	2.22
							otolith edge	3.06
90	MacDonalds Creek	12-May-11	19-Feb-13	510	3+	4.45	1	1.59
							2	2.05
							3	2.62
							otolith edge	2.96
91	MacDonalds Creek	19-May-11	14-Jun-13	510	3+	4.40	1	0.93
							2	1.36
							3	1.70
							otolith edge	2.25
92	MacDonalds Creek	19-May-11	19-Feb-13	460	3+	4.76	1	1.36
							2	1.81
							3	2.21
							otolith edge	2.62
93	MacDonalds Creek	19-May-11	19-Feb-13	720	4+	4.76	1	1.28
							2	1.70
							3	2.34
							4	2.43
							otolith edge	2.98
94	Lake Paringa	26-Mar-11	14-Jun-13	630	3+	4.92	1	0.93
							2	1.30
							3	1.95
							otolith edge	2.39
95	Windbag Stream	11-May-11	14-Jun-13	750	3+	4.71	1	1.63
							2	2.09
							3	2.65
							otolith edge	2.79
96	MacDonalds Creek	17-May-12	19-Feb-13	390	2+	3.93	1	1.43
							2	2.28
							otolith edge	2.69
97	MacDonalds Creek	17-May-12	14-Jun-13	490	3+	4.82	1	0.87
							2	1.39
							3	2.01
							otolith edge	2.44

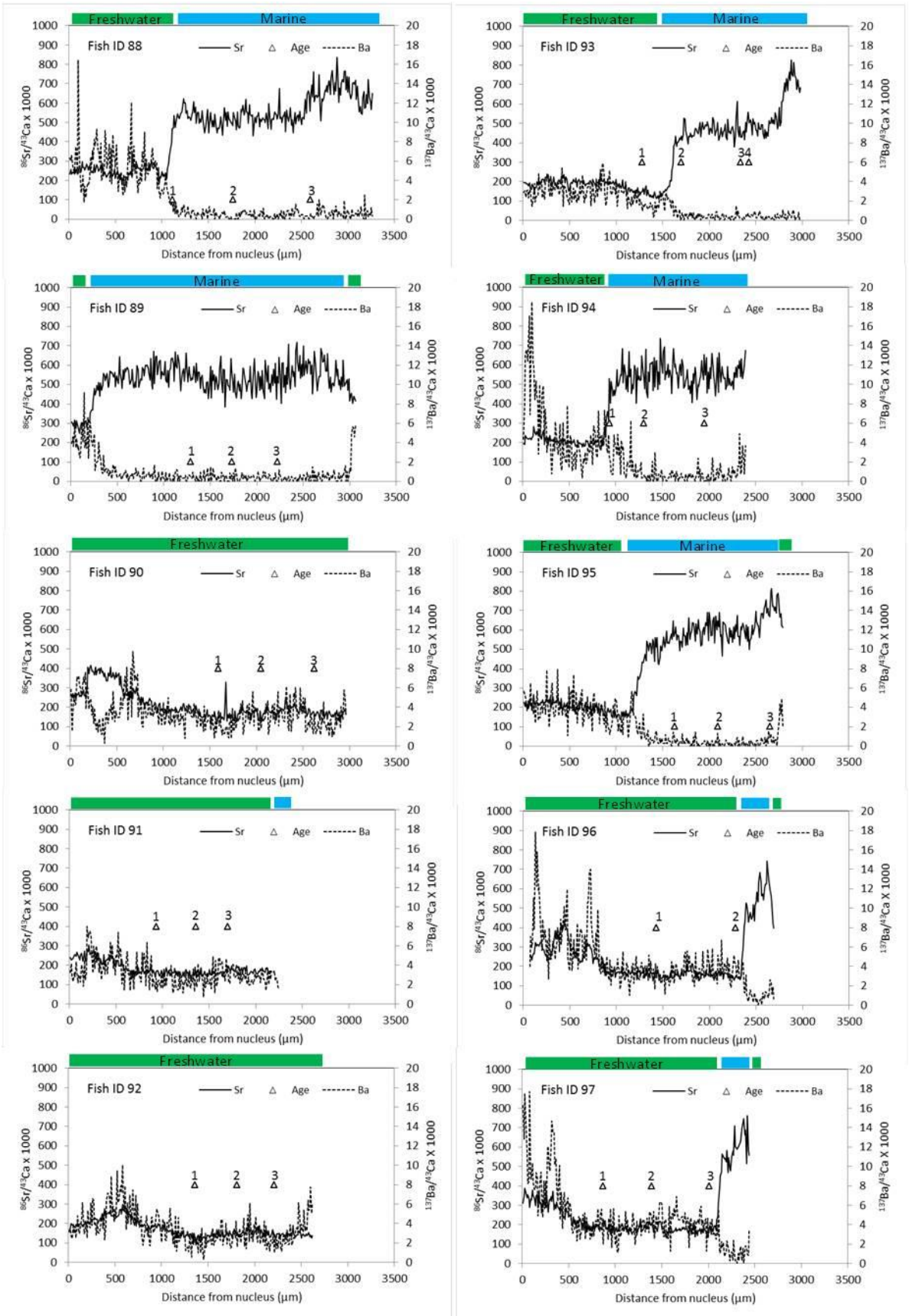

Figure 2. Life histories of 10 West Coast chinook salmon shown by variation in otolith strontium (Sr) and barium (Ba) concentrations (counts per second relative to calcium (Ca)) measured by laser ablation ICP-MS. Bars above each graph indicate freshwater (green ■) and marine (blue ■) residence.

Discussion

Although only a small number of fish were analysed in this study, otolith microchemical analysis of Chinook salmon (*Oncorhynchus tshawytscha*) collected along the West Coast of the South Island, provided some insight on the early rearing and migratory stages of salmon from these locations. On the basis of known relationships between barium and strontium in otoliths with regards to fish movements between sea water and fresh water (Campana 1999; Kalish 1990; Tzeng, 1996), we demonstrated that barium and strontium can be used to differentiate chinook salmon growth between these environments. This approach has already been widely used in determining anadromy in salmonids overseas (e.g., Secor et al 1995; Zimmerman and Ratliff 1999, Zimmerman and Reeves 2000), and in New Zealand to trace adult rainbow trout from two Rotorua Lakes back to spawning tributaries (Riceman 2006), as well as determine diadromy in New Zealand's galaxiids (Baker and Hicks 2003, Hicks et al. 2005, Tana and Hicks 2012), or identify koi carp spawning locations within the Waikato River (Blair and Hicks 2012). In the present study, salmon on the West Coast of the South Island, New Zealand, appear to have diverse life histories.

Five fish from the Hokitika and Taramakau rivers, MacDonalds Creek (L. Mapourika), and Windbag Stream (L. Paringa) exhibited typical anadromous growth patterns that involve growth and maturity at sea, followed by spawning and rearing in fresh water (about 12 months). Notably, two salmon from MacDonalds Creek showed no association with the sea suggesting they had spent early growth and maturity within freshwater possibly moving between the MacDonalds Creek and Lake Mapourika. Similarly, some salmon exhibited a "dash to the sea" late in life, for no longer than 6 or so months, before returning to spawn.

Acknowledgements

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Appendix 1. Otolith scan of a 5-year old 920- mm male chinook salmon from McDonald Creek captured on 20 May 2008. Source: Modified from unpblished data, Rasmus Gabrielsson, Cawthron Institute, Nelson.