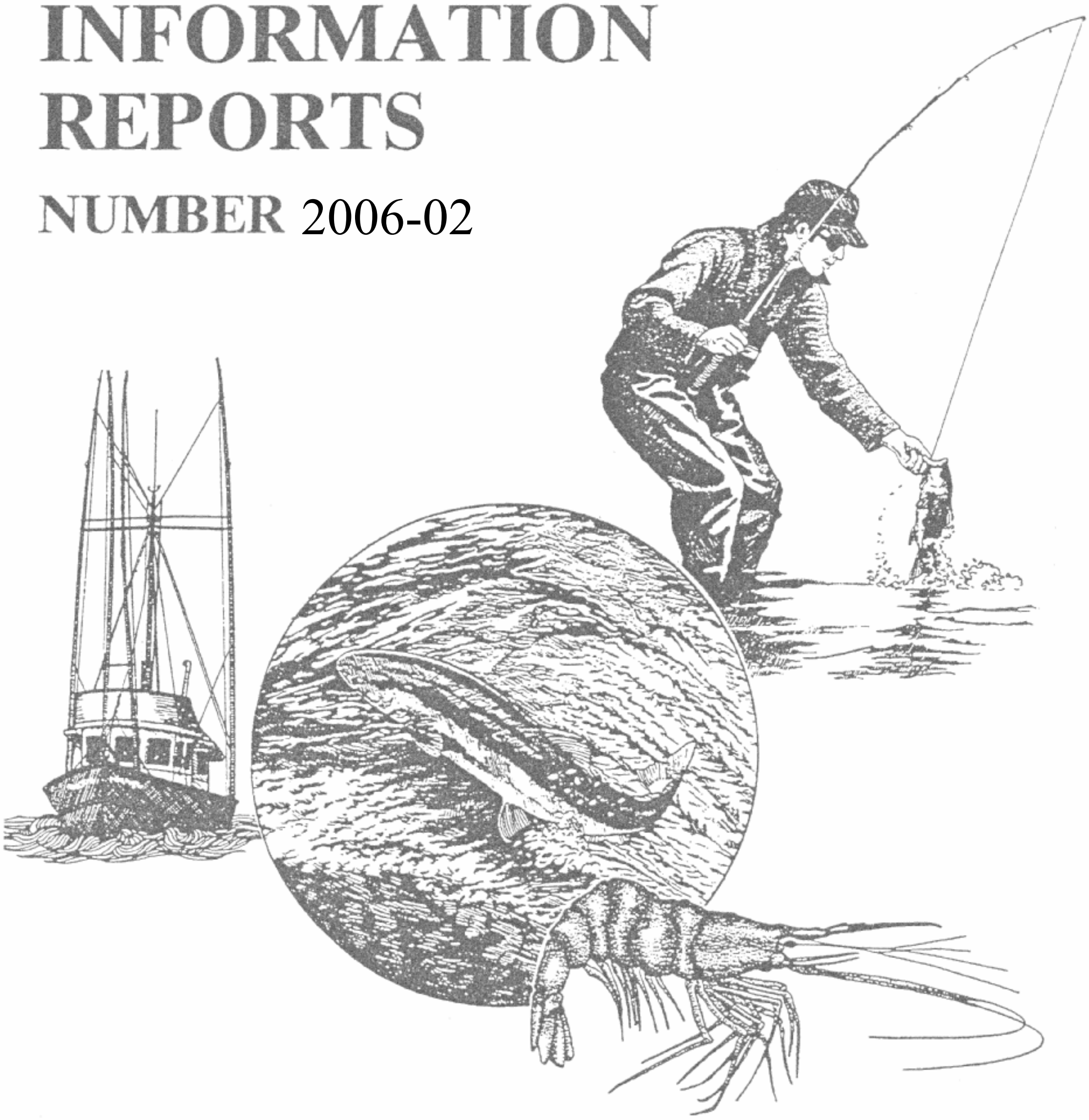
INFORMATION REPORTS

NUMBER 2006-02



FISH DIVISION

Oregon Department of Fish and Wildlife

Analysis of factors potentially inflating the marine survival estimate of coho salmon (*Oncorhynchus kisutch*) at Mill Creek, Yaquina River, central Oregon coast

Analysis of factors potentially inflating the marine survival estimate of coho salmon (*Oncorhynchus kisutch*) at Mill Creek, Yaquina River, central Oregon coast

James Ray and Steven L. Johnson
Oregon Department of Fish and Wildlife, NW Region Research

Eric Volk

ADFG
Commercial Fisheries Division
Anchorage, AK

Oregon Department of Fish and Wildlife
Corvallis Research Lab, 28655 Hwy 34
Corvallis, OR 97333

July 2006

Table of Contents

ABSTRACT

Scale and otolith analyses were used to determine if high marine survival estimates observed for coho salmon at an Oregon Department of Fish and Wildlife Life Cycle Monitoring Project site are inflated by 1) adult coho that reared as juveniles in other tributaries straying to the site, or 2) coho dispersing out of the site as fry, rearing in nearby salt marsh habitat, then returning to the site to contribute to the adult population. Scale analysis indicated that adult straying from other tributaries in the basin was unlikely to be contributing to the high marine survival estimate at the site. Scale analysis also indicated no evidence that coho fry rearing in nearby salt marshes were smolting as age-0+ fish and returning to contribute to the adult spawner population. Analyses of otolith strontium profiles were unable to distinguish differences in habitat use for fish reared in freshwater and marsh habitat because of aberrantly high ambient strontium to calcium abundance in the freshwater environment. Therefore the method was unsuitable for determining if coho fry rearing in nearby salt marshes were smolting as age-1+ fish and returning to contribute to the adult spawner population.

INTRODUCTION

Since 1997, the Oregon Department of Fish and Wildlife (ODFW) has been conducting life cycle monitoring research on salmonid fishes (genus *Oncorhynchus*) in several coastal river basins as part of the Oregon Plan for Salmon and Watersheds. An important focus of this project is to monitor coho salmon populations at two key stages in their life history; when they return to freshwater as spawning adults, and when they migrate to the ocean as juveniles (smolts). The two main objectives of this monitoring are to; 1) estimate the abundance of spawning adult salmon and downstream migrating smolts and 2) estimate the marine and freshwater survival rates of coho populations.

On the central Oregon coast, Life Cycle Monitoring Project (LCMP) sites are located in three main river basins: Alsea, Siletz and Yaquina. Mill Creek, a tributary of the Yaquina River, represents a unique monitoring site due to the presence of a 0.06^2 km reservoir, which is situated 4 km upstream of the Mill Creek/Yaquina River confluence. Mill Creek enters the main-stem Yaquina River approximately 18 km upstream from the ocean. This area of the Yaquina River is tidal and subsequently the first kilometer of Mill Creek is also tidally influenced, both hydrologically and to a lesser extent chemically. Mill Creek is a second order stream with approximately 7.2 km of habitat accessible to coho salmon. Of this habitat 3 km are situated below the dam and 4.2 km are located above the reservoir, where the creek divides into two forks (Figure 1). The riparian habitat is dominated by Red alder (*Alnus rubra*) with some Douglas-fir (*Pseudotsuga menziesii*) and Sitka spruce (*Picea sitchensis*) further upstream. The substrate consists mainly of medium-large gravels with some cobble and small boulder. The majority of the coho in Mill Creek spawn in the 4.2 km of habitat available in the two forks above the reservoir, although some spawning does take place below the dam. A fish ladder provides passage around the reservoir dam, which is a complete barrier to adult salmon upstream migration. A juvenile trap is situated directly downstream of the dam. The life cycle monitoring project samples the coho salmon population that spawns and rears above the dam, and does not sample fish that spawn and rear below it.

Shortly after coho fry emerge from the gravel, many disperse downstream into the reservoir. As in other coastal basins that contain large lentic habitat units, the reservoir is thought to promote growth rates for juvenile coho salmon, and consequently coho salmon smolts from Mill Creek tend to be larger than smolts sampled from other monitoring sites on the central Oregon coast (Figure 2). Coho salmon reared in the reservoir typically migrate to the ocean as age-1+ smolts, and there is little evidence that the good rearing conditions result in fish migrating to the ocean as age-0+ fish. Additionally, there is no evidence that coho salmon rearing in Mill Creek Reservoir smolt at age-2+, a life history pattern that has been observed in larger coastal lake systems on the central Oregon coast.

LCMP research has shown that the marine survival rates of coho salmon at Mill Creek are often much higher than the marine survival rates of coho salmon from other mid-coast Oregon stream systems (Figure 3). In part, these high survival rates could be attributed to the large size of the smolts migrating from the Mill Creek Reservoir. However, it is also possible that coho salmon juveniles that reared in other tributaries of the Yaquina River stray into Mill Creek when they return as adults, resulting in an inflated estimate of marine survival.

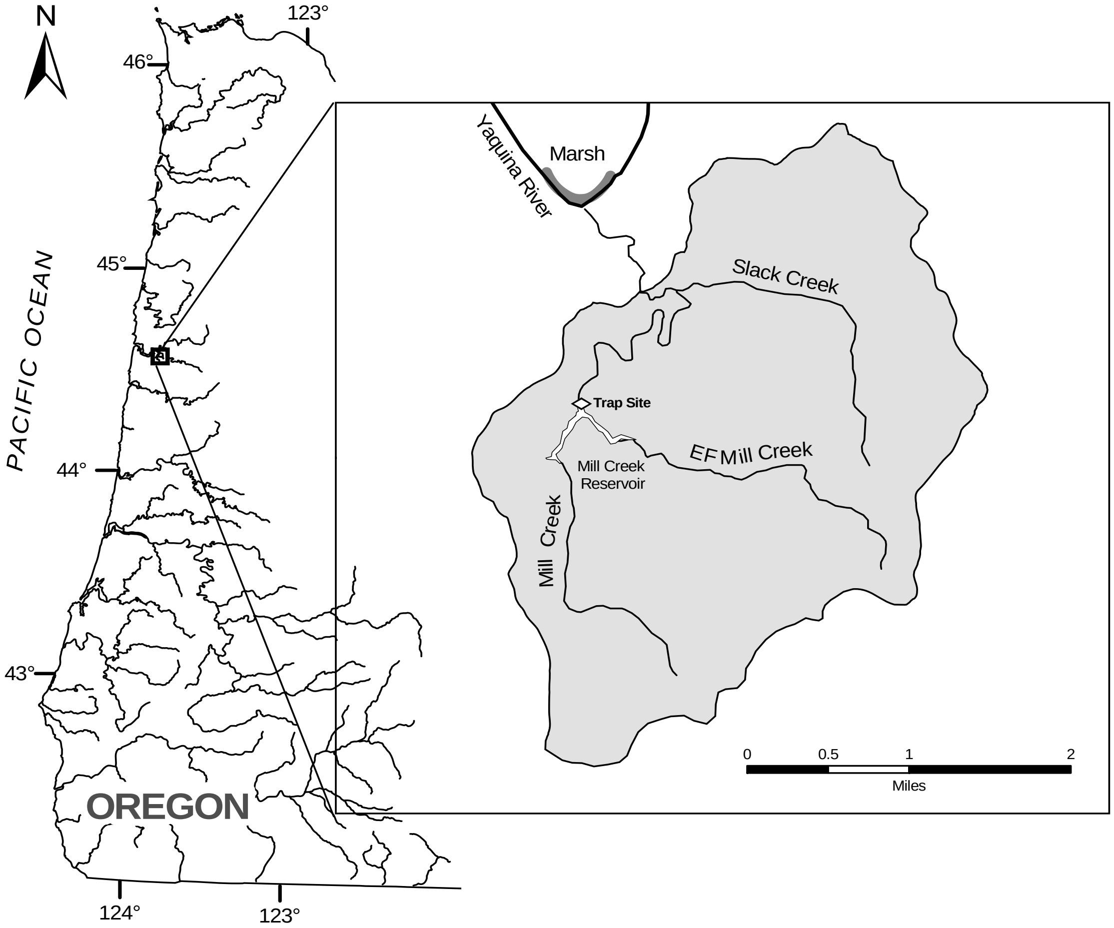


Figure 1: Map showing the Mill Creek drainage area including the reservoir, trapping site and the Mill Creek Marsh.

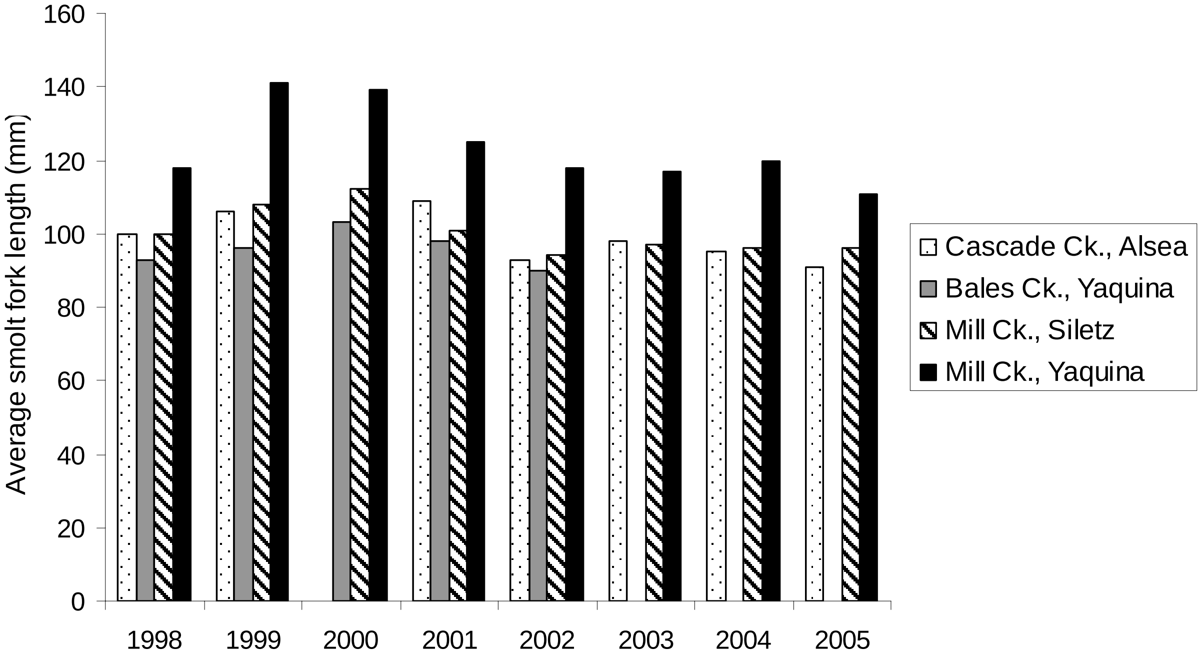


Figure 2: Average fork length of coho salmon smolts at four mid-coast LCMP monitoring sites for the outmigrant years 1998-2005 where available. Data for Cascade Creek is not presented for 2000 because fewer than 10 smolts were captured at the trap that spring.

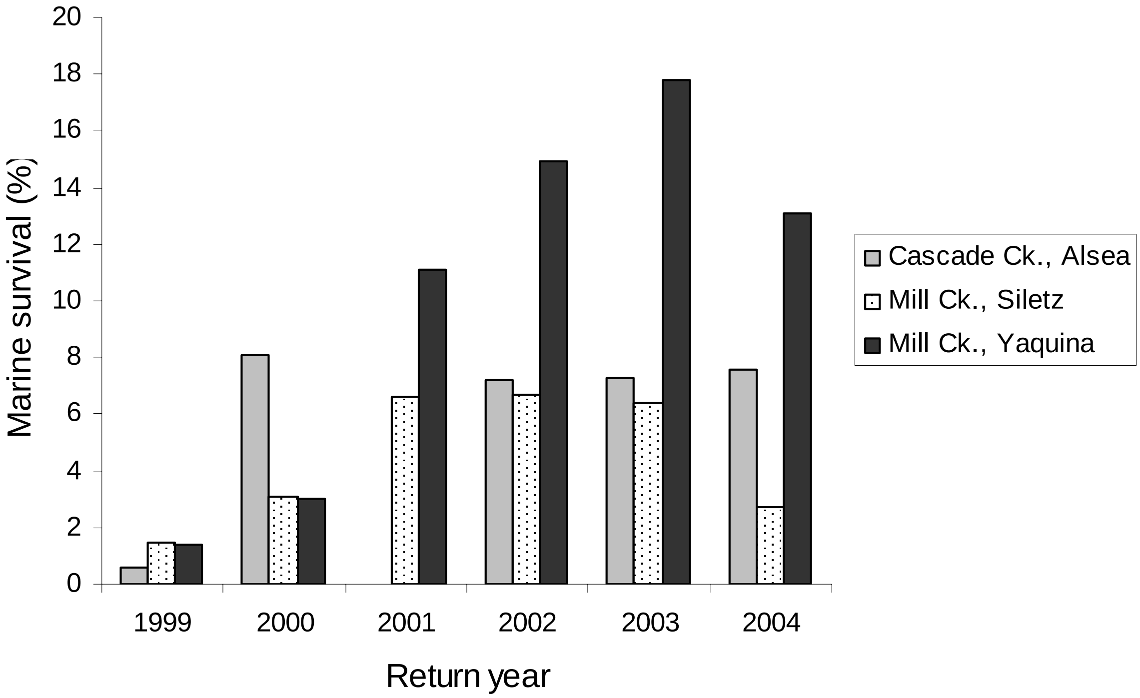


Figure 3: Estimates of marine survival of adult coho salmon at three mid-coast LCMP sites for the return years 1999-2004. Data for Cascade Creek is not presented for the 2001 return because of the low number of smolts migrating from that stream in the spring of 2000.

It appears that improvements in ocean conditions in recent years have led to significant increases in adult escapement to Mill Creek from 1997/98 to 2004/05 (Figure 4), with a subsequent increase in fry production. Prior to the spring of 2002, few fry were observed leaving Mill Creek Reservoir; however, from 2002 through 2005 large numbers of fry dispersed downstream out of the reservoir each spring (Figure 5). While some of these fry may take up rearing residence in the 4 km of stream between the reservoir and the main stem of Yaquina River, much of the pool habitat below the reservoir is already occupied by fry from adults that spawned below the reservoir.

Directly adjacent to the Mill Creek/Yaquina River confluence is an area of tidally influenced marsh habitat. In 2002 the marsh habitat was the focus of a Midcoast Watersheds Council restoration project during which holes were created in a series of dykes, allowing the main-stem Yaquina River to reconnect with its tidal flood plain. In the spring of 2003 and 2004, large numbers of coho salmon fry were observed in channels of this marsh (personal communication, Kim Jones, ODFW, and Stan Van de Wetering, Confederated Tribe of the Siletz Indians). It is likely that fry dispersing out of Mill Creek use this tidal marsh during a portion of their first year of rearing. Subsequent sampling established that fry observed in the marsh habitat exhibited rapid growth relative to fry rearing in surrounding tributaries and the Mill Creek Reservoir.

The LCMP calculates marine survival estimates from the numbers of coho salmon smolts (not fry) migrating out of the reservoir relative to the numbers of returning adults for any given brood year. Therefore the fate of these dispersing fry has important implications for the accuracy of both the freshwater and marine survival estimates for the coho salmon population at Mill Creek. Significant numbers of fry surviving in the marsh and contributing to the adult spawner population would cause an under-estimation of freshwater survival and an over-estimation of marine survival for the coho salmon population at Mill Creek.

The issue of marsh habitat utilization by juvenile coho salmon also raises important questions in the broader context of fisheries management and conservation. If marsh reared fry do contribute significantly to the adult population, it affects how restoration activities are prioritized, how adequate spawner escapement is defined, and how habitat factors limiting production are evaluated.

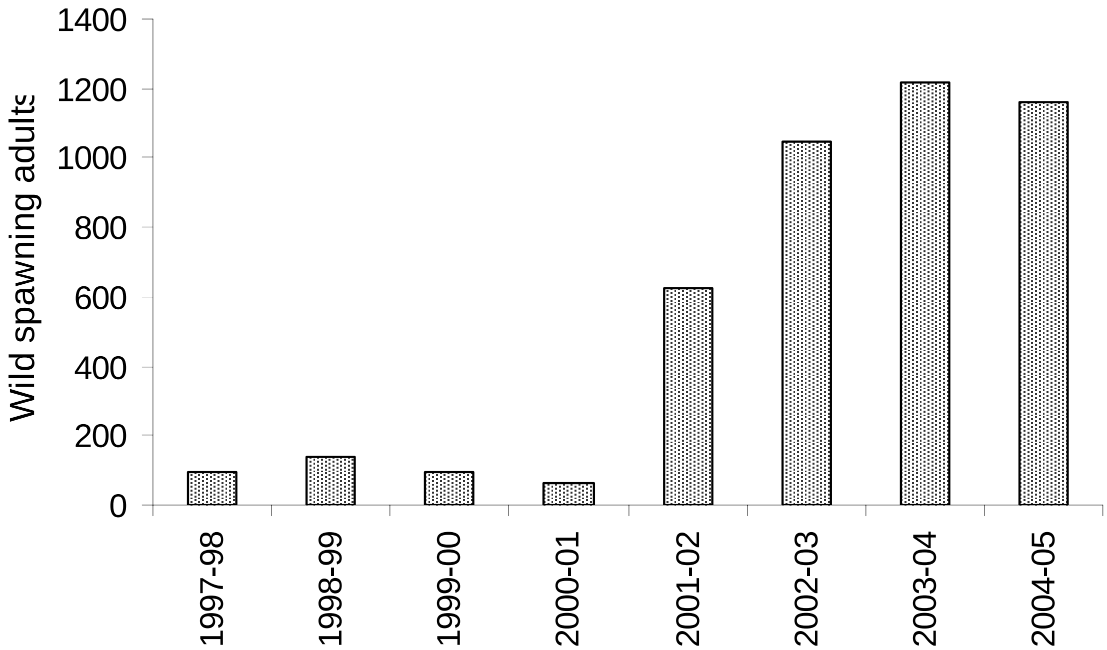


Figure 4: Abundance of wild spawning coho salmon adults at Mill Creek, Yaquina 1997/98-2004/05.

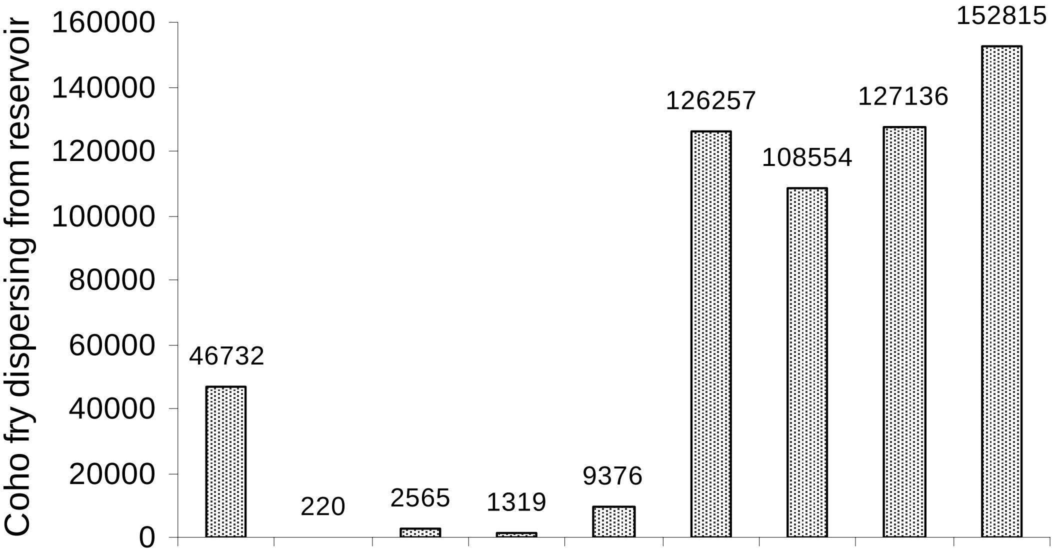


Figure 5: Estimated numbers of coho salmon fry dispersing from the Mill Creek Reservoir 1997-2005.

This paper has two main objectives; 1) Determine if coho salmon that reared as juveniles and emigrated as smolts from other tributaries in the Yaquina River basin are straying into Mill Creek when they return as adults, thereby inflating the marine survival estimate, and 2) Determine if any of the coho salmon fry dispersing from Mill Creek (or other tributaries) into the tidal marshes survive to contribute to the adult population returning to Mill Creek Reservoir, thereby inflating the marine survival estimate.

METHODS

ANALYSIS OF STRAYING

To determine if coho salmon that reared in other tributaries of the Yaquina basin are straying into Mill Creek as returning adults, we compared freshwater growth patterns on scales of migrating smolts and returning adults of the same brood years.

As stated above, juvenile coho salmon rearing in the Mill Creek Reservoir show accelerated freshwater growth compared with fish developing under 'normal' stream conditions. This growth is represented by greater mean fork length in the Mill Creek smolts, but also by thicker, more numerous and widely spaced circuli on the fishes' scales. Typically, the distance from the center of the scale to outside of the first freshwater annulus is greater in fish reared in the Mill Creek Reservoir than in stream-reared fish. To verify this, measurements from the center of the scale to the outside of the first annulus were compared between Mill Creek smolts and smolts from Bales Creek, another tributary of the Yaquina River, using scale samples taken from smolts in the spring of 2000 and 2001 (1998 and 199 brood years)(Figure 6). Bales Creek is a third order tributary of the Yaquina River and does not contain a reservoir or lake system. The Bales Creek drainage area is approximately 6.2^2 km with approximately 3.8km of habitat accessible for coho salmon. We used a *t* test to compare fish size and scale measurements between Mill Creek and Bales Creek.

Scales were observed under a microfiche at approximately 50X magnification, therefore measurements taken are of the magnified scale. All scale measurements were taken at 20^o from the central line of the scale on either the ventral or dorsal portion of the scale. (Figure 6). (A sub-sample of 20 scales from each stream indicted only minor (≤1mm) differences between the distance from scale origin to outer edge of the first freshwater annulus for ventral and dorsal portions of the scales.) Where possible for each sample, measurements of three scales were taken and the mean calculated. Scale samples were selected to be as representative of the smolt population length distribution frequency as possible.

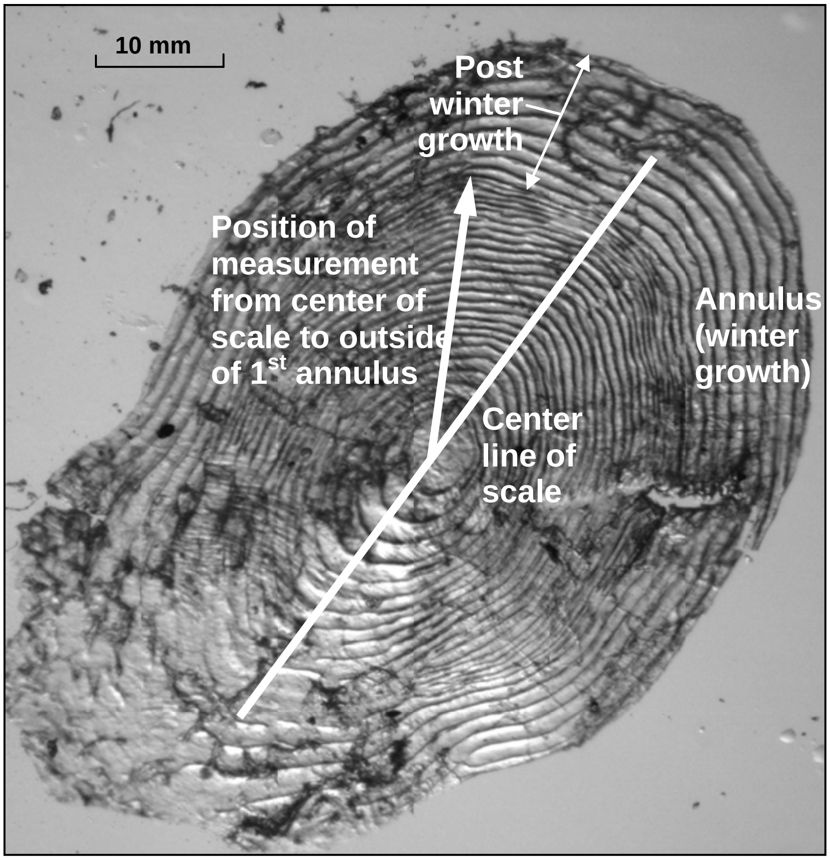


Figure 6: Scale of age-1+ coho salmon smolt from Mill Creek Reservoir. The large arrow indicates the position of the measurement between the center of the scale and the outside of freshwater annulus.

When the 1998 and 1999 broods returned to Mill Creek as adults in 2001 and 2002, scale samples were collected and similar measurements of freshwater growth patterns were made (Figure 7). We compared the smolt scale measurements and the adult scale measurements to determine if there were differences in the proportions of fish showing typical 'reservoir type' growth and fish showing typical 'stream type' growth. A larger proportion of fish showing stream type growth in the adult samples would suggest that fish from other tributaries are straying into Mill Creek.

ANALYSIS OF SALT MARSH REARING AND SURVIVAL

Sampling has shown that fry collected in the marsh had longer average fork lengths (75.6mm FL n=15, date = 5/21/04) than those emigrating from the reservoir (47.9mm FL n=28, 5/7/04-5/21/04 pooled), suggesting greater growth rate for marsh-reared fish. We hypothesize two potential early life histories that are distinct enough to be deposited as growth (annuli pattern) or chemical (Sr/Ca ratios) chronologies on scales and otoliths.

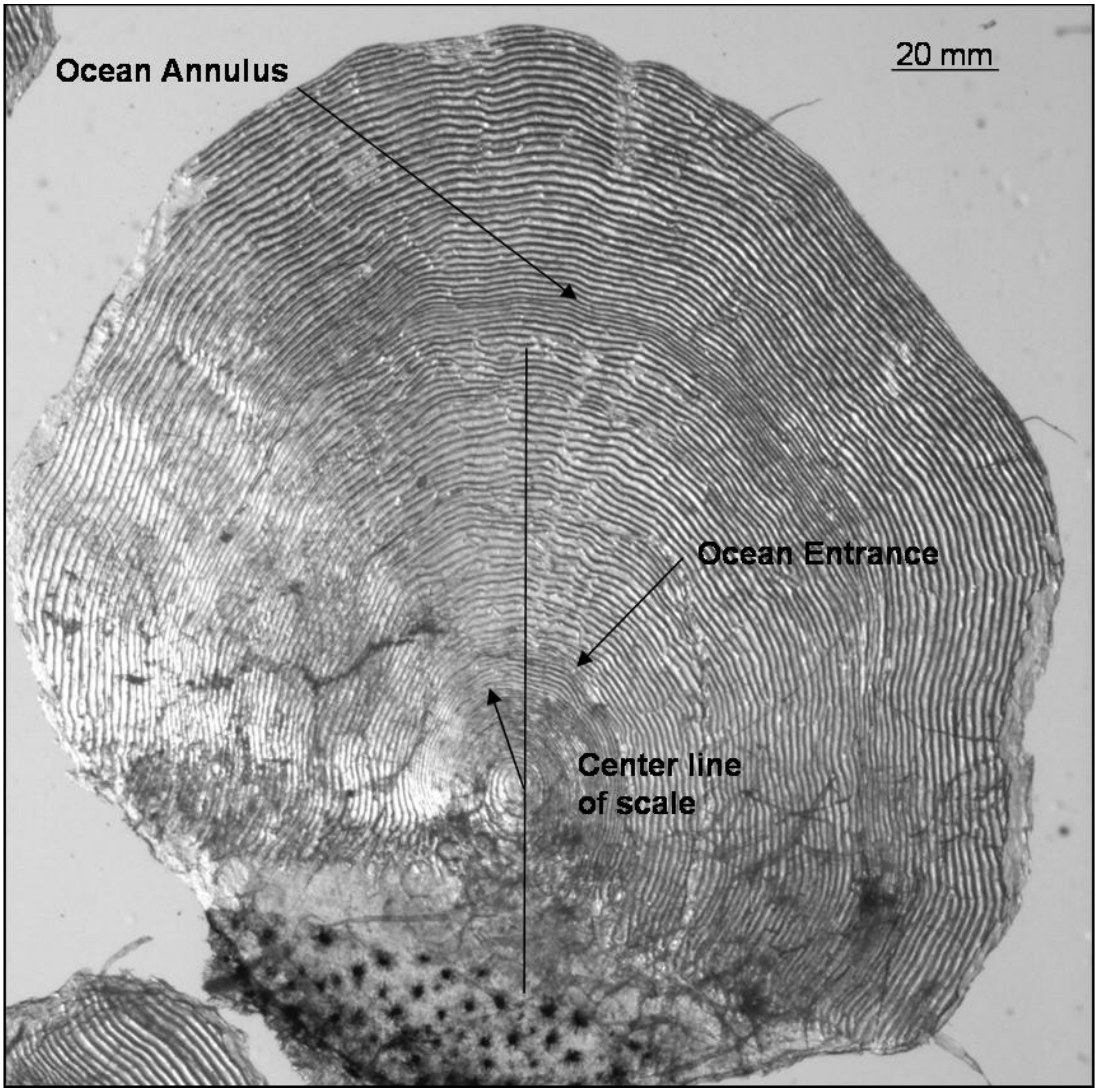


Figure 7: Scale of an adult coho salmon from Mill Creek. The position of the measurement between the center of the scale and the outside of freshwater annulus is shown. Ocean entrance and the ocean annulus are also marked.

LIFE HISTORY HYPOTHESIS 1:

High food productivity in the marsh habitat results in rapid fry growth, enabling them to smolt as age-0+ fish. Fish showing accelerated growth during their first summer of rearing and not showing a freshwater winter annulus on their scales would suggest the fish were in habitat that maximized growth during the spring after emergence. Although coho salmon fry grow well in the Mill Creek Reservoir, previous analysis has shown that fish typically smolt as age-1+ fish. Therefore, substantial numbers of returning adults that exhibit an age-0+ smolting scale pattern would suggest these fish may have reared in the marshes as fry. To determine if any fish from the marshes smolted as age-0+ fish and eventually returned to Mill Creek as adults, we examined over 100 adult scales each year from return years 2001-2005 for the absence of a freshwater winter annulus in the juvenile growth portion of the scale.

LIFE HISTORY HYPOTHESIS 2:

Fry utilize the marshes and grow rapidly but do not smolt as age-0+ fish. High water temperatures in the marsh exclude fish from the marsh by late June. These fish rear elsewhere for the remainder of the year and smolt ‘normally’ as age-1+ fish.

It was not possible to use scale analysis to determine whether coho salmon fry rearing in the marshes smolted as age-1+ fish and survived to return to Mill Creek. Although the marsh-reared fish show accelerated scale growth patterns as fry, high water temperatures force fish to leave the marsh by late June, thus there are no scale samples of these fish as smolts. In addition, because of their rapid growth, scale patterns on marsh-reared fish would likely be indistinguishable from the rapid growth pattern also exhibited by the reservoir-reared fish. Furthermore, scales from both groups of fish would show a freshwater winter annulus.

In an attempt to distinguish habitat associations of juvenile coho salmon with either the Mill Creek Reservoir or the salt marsh we analyzed the Strontium (Sr)/Calcium (Ca) ratios on otoliths. Although a variety of environmental and physiological factors may mediate the incorporation of strontium into fish otoliths, strontium levels in ambient water are pivotal (Bath et al., 2000). Sea water imparts a higher ratio of strontium to calcium onto otoliths relative to freshwaters (Secor, 1992; Fowler et al., 1995). Additionally, several experiments using strontium-enriched water show commensurate elevations of strontium in otoliths (Brown and Harris, 1995; Schroder et al., 1995). Juvenile coho salmon rearing in tidal marsh habitats likely experience higher salinities than fish rearing in freshwater habitats, and we would expect this difference to be reflected in otolith Sr/Ca ratios. This would potentially allow us to identify those fish that had reared in the marsh habitat. The initial sampling regime was adopted as a pilot study to determine if the analysis of otolith Sr/Ca ratios could identify the habitat transition of fry dispersing out of Mill Creek and taking up residence in the salt marsh. If successful, otoliths would be sampled from returning adult spawners and analyzed to determine what proportion, if any, of the adult spawner population had reared in the salt marshes.

Fish samples

Coho salmon fry (age-0+) were collected at two marsh sites and one freshwater site in May 2004. Marsh sites were the Mill Creek Marsh (directly adjacent to the mouth of Mill Creek) and the Airport Marsh (about 1 mile downstream from the mouth of Mill Creek). The freshwater site was the Mill Creek Reservoir. Additionally, smolt specimens (age-1+) were collected from the smolt trap below the Mill Creek Reservoir. These latter fish were sampled to give an indication of Sr/Ca abundance in the freshwater environment over a longer time period. To provide a sample group of fry with a known residence time in the marsh, a sample of fry were collected from Mill Creek Reservoir and transported to a live box stationed in Mill Creek Marsh. These fish were held in the live-box for two weeks before sacrifice. Table 1 summarizes collection locations for analyzed fish. Otoliths were extracted from all fish and sectioned for analysis according to standard WDF&W preparation procedures.

Water samples

Water samples were taken so that the different habitats from which the fish samples were taken could be characterized using their water chemistry. Water samples were collected from Mill Creek Reservoir, the Mill Creek Marsh where the live-box was located, the main channel of the Yaquina River near the Mill Creek Marsh, and the main channel near the airport marsh. Samples were filtered through 0.45 um membrane filters, then acidified to < pH 2 with quartz distilled nitric acid. Samples were diluted 1ml to 6ml with 1% quartz distilled nitric acid and analyzed with a Varian Liberty 150 ICP-OES. Concentrations were calculated from the emission intensities and the intensities of standard solutions. Accuracy of the method was verified by running a NIST fresh water certified reference material (nist 1643c).

Table 1: Summary of fish sample groups analyzed.

Location	N Analyzed	Mean Length (mm)
Airport Marsh Fry	7	62
Mill Ck. Marsh Fry	11	77
Mill Ck. Reservoir Fry	11	46
Mill Ck. Marsh Live Box Fry	9	49
Mill Ck. Reservoir Smolts	8	130

Otolith analyses

All sectioned otolith specimens were analyzed at the Keck Collaboratory for Plasma Mass Spectrometry at Oregon State University. The laser ablation system consists of a New Wave DUV 193 nm ArF laser coupled to a Thermal Elemental PQ Excell quadropole inductively coupled plasma mass spectrometer (ICP-MS). The sample chamber has a continuous flow of He gas that carries the ablated material through Tigon tubing to the mass spectrometer. Analytical transects were conducted from a point near the otolith core to a point beyond the margin of the otolith along a dorsal-posterior radius. There was some variation in the precise axis analyzed due to difficulties aligning the cross hairs with the laser or obvious cracks or pits in the otoliths. Each otolith analysis was paired with an analytical transect on a polished sample of NIST 610 glass standard, a sintered silica glass standard with about 500 ppm of some commonly analyzed trace elements.

Time resolved data were examined visually following each analysis and two regions were selected; one prior to the onset of ablation (background) and one after ablation began. Thermal Elemental Plasmalab software calculated integrated counts per second and standard deviations for all elements in both regions. These results and raw elemental count data for analyses were exported to spreadsheets, where all further data manipulation and analysis took place. Blank corrected count rates for each element were determined by subtracting their integrated background count rates from count rates at a particular location on the otolith transect. Element concentrations were calculated after Longerich et al. (1996) as outlined by Russo (2001) using the equation:

$$[x]_{sample} = (J_x)_{sample} * [x]_{Nist}/(J_x)_{Nist} * (J_{Ca})_{Nist}/[Ca]_{Nist} * [Ca]_{sample}/(J_{Ca})_{sample}$$

Where, J is the blank corrected count rate for each element (x). In this calculation, we used otolith calcium concentrations as an internal standard to correct for different ablation rates in aragonite and NIST glass. These values were determined independently by electron microprobe analyses of Salmon River Chinook salmon otoliths. These data were taken from microprobe analysis transects, from the core to the otolith edge, on 35 Salmon River Chinook otoliths, resulting in 568 individual analyses with a mean calcium concentration of 38.05% (s.d.=0.97).

Raw data for each measured element was plotted using macros written for Excel allowing us to approximately locate inflection points or peaks in elemental raw count data. For strontium, we focused on the core region, the peak strontium count rate position and the margin of the otolith. For core and margin values, a z-test was used on running averages of 10 count rate values in the region to determine when count rates were significantly increasing or decreasing. The position of peak values was determined visually. Quantitative Sr/Ca values at each location were determined using a mean of ten surrounding count rates.

Once the location of the strontium peak point of interest (POI) was recognized on raw count plots, we noted the time in the analytical transect where it occurred and determined its position on the otolith using the following equation:

$$\text{Distance from core} = ((\text{Time (POI)} - \text{Time Core})/1000)*5\text{um}$$

where, the distance from the otolith core (microns) equals the analysis time at the POI minus the time at the core, (dividing by 1000 converts msec to sec), multiplied by 5 um/sec, the speed of the laser ablating the transect.

RESULTS AND DISCUSSION

OBJECTIVE 1 – ANALYSIS OF STRAYING

The smolts from Mill Creek (the majority of which reared in Mill Creek Reservoir) had a significantly larger mean fork length and showed significantly greater mean freshwater growth (as represented by the distance from the center of the scale to the outside of the first annulus) than the smolts that reared under ‘normal’ stream conditions in Bales Creek (Table 2).

Table 2: The mean fork length and mean scale distance (center of scale to outside of first annulus) of coho salmon smolts from Mill Creek and Bales Creek in 2000 and 2001.

Parameter	Sample year	Mill Creek	Bales Creek	Significance level[a]
Mean length of smolts (mm)	2000	139	103	<0.001
Mean length of smolts (mm)	2001	125	98	<0.001
Distance to outside of 1st annulus	2000	24.2	18.4	<0.001
Distance to outside of 1st annulus	2001	20.6	16.5	<0.001

[a] t test

Figures 8 and 9 show the correlation between smolt fork length and distance to the outside of the first annulus for fish from Bales Creek and Mill Creek in 2000 and 2001. The correlation between smolt fork length and distance to the outside of the first annulus was stronger at Mill Creek (58% and 59%) than Bales Creek (38% and 26%) during both years (Figures 8 and 9). While there is obviously variation in this relationship, in both years many of the larger smolts migrating from the Mill Creek Reservoir had scales showing origin to outer annulus measurements ≥20mm, while scales from Bales Creek smolts rarely showed measurements exceeding 20mm.

In addition to greater size and growth rate for Mill Creek fish, they also exhibit a greater range in size and freshwater growth rate than smolts from Bales Creek (Figures 8 and 9). Some Mill Creek fish overlap in size and growth rate with Bales Creek smolts, a likely indication that samples from Mill Creek are a combination of fish that reared principally in the reservoir and another portion that reared mostly in the two tributaries flowing into the reservoir. These latter fish exhibit the typical 'stream type' growth patterns found in the Bales Creek samples.

Analysis of the freshwater growth patterns on Mill Creek adult scales from 2001/02 and 2002/03 (return years for smolts leaving in 2000 and 2001) indicated that there were no adult fish returning that had a scale measurement to the outside of the first annulus of less than ~ 19 mm (Figures 10 and 11). Smolts with a scale measurement less than 19mm corresponded with fish that were < 120 mm FL (Figures 8 and 9). That is, they exhibited 'stream type' growth in early life similar to Bales Creek fish. Considering that fish showing typical 'stream type' growth appear generally not to return to Mill Creek, it seems unlikely that strays from other Yaquina tributaries are in great enough abundance to influence the marine survival estimate.

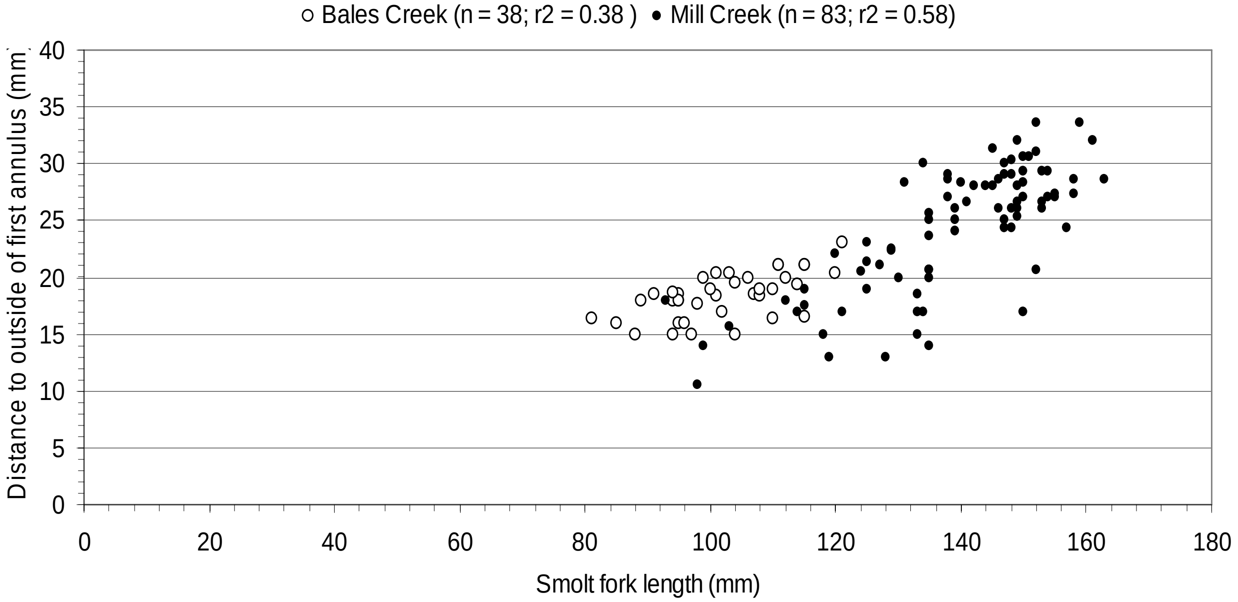


Figure 8: Smolt fork length against Distance to outside of first annulus for Bales Creek and Mill Creek 2000. Pearson correlation R^2 values are given.

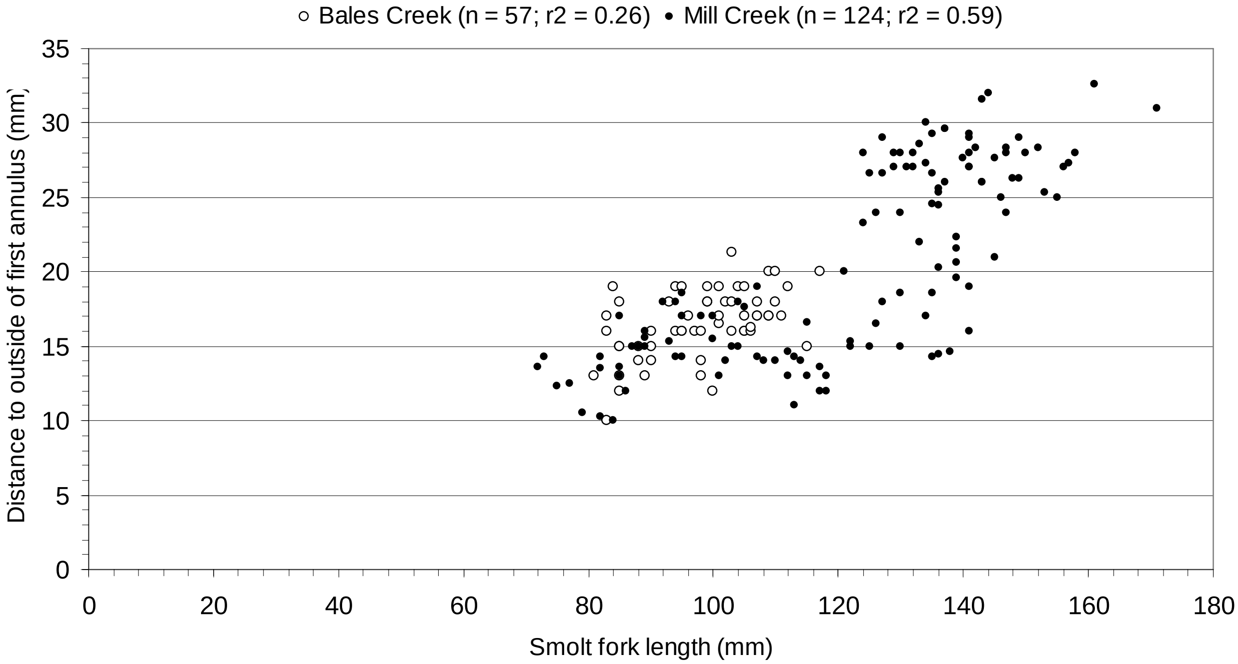


Figure 9: Smolt fork length against distance to outside of first annulus for Bales Creek and Mill Creek 2001. Pearson correlation R^2 values are given.

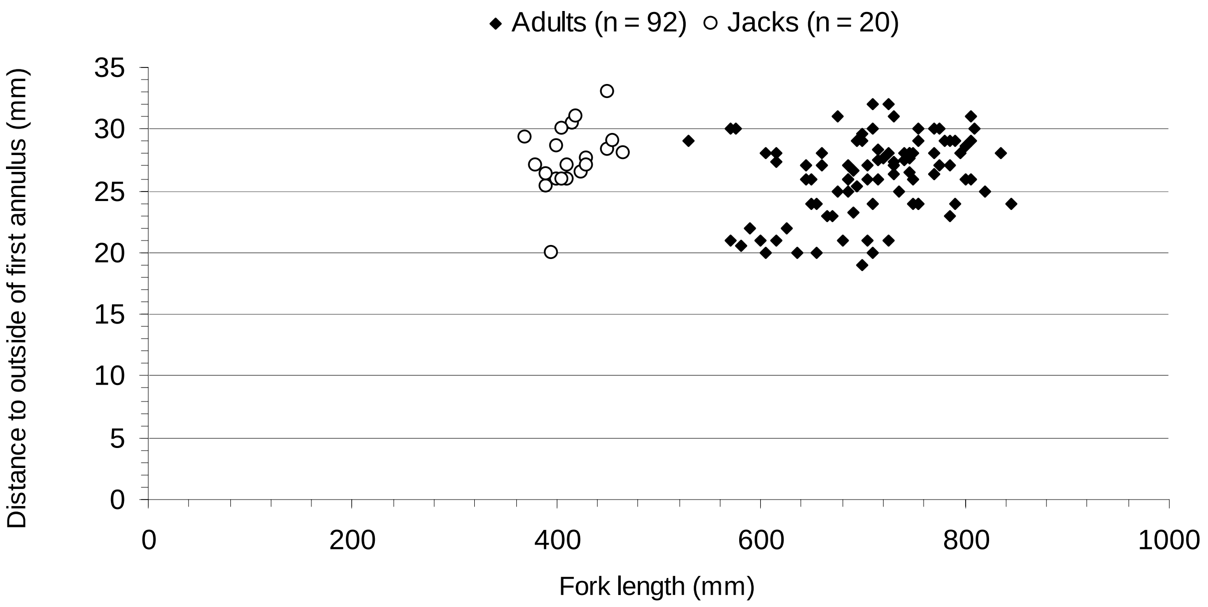


Figure 10: Distance to the outside of the first annulus against fork length of adult coho salmon in Mill Creek, 2001/02.

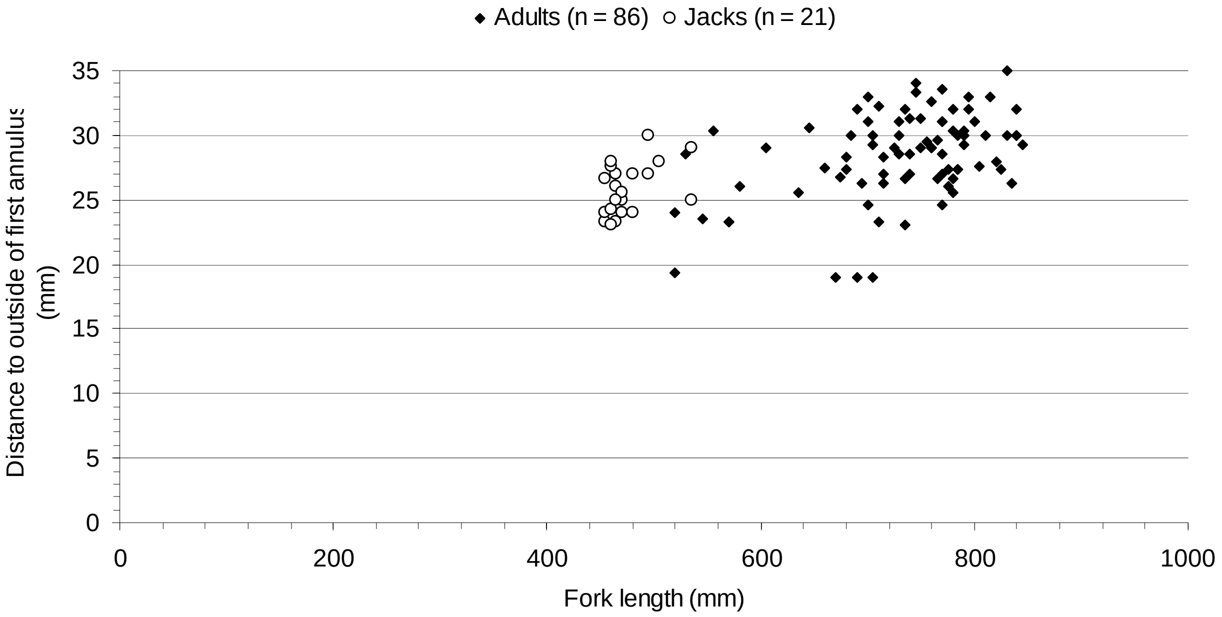


Figure 11: Distance to the outside of the first annulus against fork length of adult coho in Mill Creek, 2002/03.

OBJECTIVE 2 – ANALYSIS OF SALT MARSH REARING AND SURVIVAL

LIFE HISTORY HYPOTHESIS 1

None of the scales from over 500 adult coho that returned in the winters of 2001/02 through 2005/06 definitively showed an absence of a freshwater annulus. Scale patterns from less than 10 fish were considered questionable regarding the presence of a freshwater annulus. Therefore there was little evidence that returning adult fish had smolted as age-0+ fish. If we were to see age-0+ smolts they would most likely show up in the scales of the 2003/04, 2004/05 and 2005/06 adults, as these returning fish correspond with the years (2002, 2003 and 2004) that substantial numbers of fry were observed leaving the reservoir and presumably rearing in the marshes.

LIFE HISTORY HYPOTHESIS 2

The analysis to identify otolith chemical patterns corresponding with migration of juvenile coho salmon from Mill Creek Reservoir to marsh habitats is based upon the simple hypothesis that habitat salinity differences would be reflected in otolith strontium abundance of individual juvenile fish as they moved between habitats. Since freshwater habitats are typically characterized by relatively low strontium abundance, we expected fish rearing in the Mill Creek Reservoir to show strontium abundance decrease from the core of the otolith (a maternal baseline) and remain at a relatively low level throughout the rest of the freshwater segment of the otolith. We would expect a similar pattern for fry rearing in the marshes, but with an obvious increase in Sr/Ca near the otolith margins. Water samples from the marsh habitats showed salinities ranging between 2 - 4.5 ppt for the Mill Creek Marsh and between 11-16 ppt for the Airport Marsh.

A typical pattern of otolith strontium abundance for early life history of juvenile salmon shows relatively high Sr/Ca values in the otolith core region due to marine derived strontium being deposited in the egg yolk by the adult female (Figure 12), then ratios gradually declining to much lower levels characteristic of typically low strontium abundance in freshwater systems. Low Sr/Ca values generally persist in otolith transects until juveniles exit freshwater for higher salinity estuary habitats, when their otolith strontium abundance usually rises suddenly and dramatically, marking the end of freshwater rearing and the beginning of estuary/ocean residence.

Visual inspection of otolith strontium profiles for Mill Creek coho salmon showed a very consistent, but atypical pattern of strontium abundance in life history transects. Examples of these transects from each sample group are depicted in Figure 13(a-e). A striking feature of these profiles is that virtually without exception, regardless of collection location, high strontium count rates at the otolith core continued rising to reach much higher peak values during early freshwater life history. However, among all sample groups, mean otolith core Sr/Ca values ranged between 1.8 and 2.3 (Table 3), very similar to otolith core values obtained from other anadromous coho salmon populations (Volk et al., 2000).

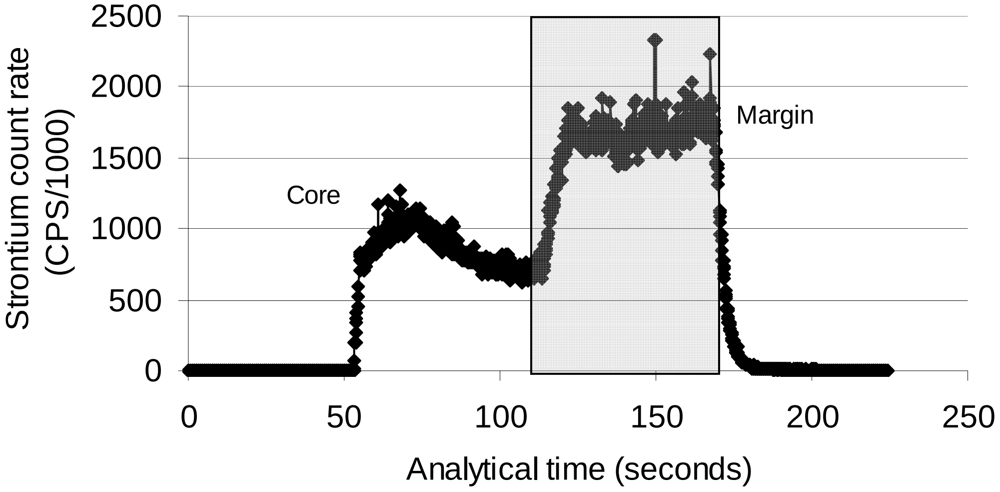


Figure 12: Otolith strontium profile for juvenile Chinook salmon from Salmon River, OR. Shaded area represents entrance and residence in estuarine habitat.

As expected, there was no significant difference in mean otolith core Sr/Ca values among all groups in the study (ANOVA, F=1.15, df=46, P>.05). Mean peak transect Sr/Ca values ranged between 3.1 and 4.2, and values among all groups were significantly different (ANOVA, F=5.50, df=46, P<.05), but not so if fish collected at the Airport Marsh were eliminated (ANOVA, F=1.51, df=39, P>.05). Using an otolith size to fish size relationship for these same Mill Creek coho, it was estimated that the position of these peaks corresponded to fish sizes less than 37mm. Thus, all fish seemed to deposit fairly high Sr/Ca on their otoliths while in fresh water, as newly emerged fry.

Our ability to discern early life history patterns from ototlith chemical profiles relied on distinct differences between ambient Sr/Ca ratios in freshwater and marine habitats, which would presumably be propogated as differences in otolith chemical composition. Typically, otoliths in salmonids rearing in freshwaters have low Sr/Ca ratios. Chinook salmon otolith Sr/Ca ratios from the Salmon River (just above head of tide) ranged between 0.68 and 0.92, and coho fry from a number of Puget Sound streams showed a mean freshwater otolith Sr/Ca value of 0.41 (Volk et al., 2000 and unpub. data). Our high otolith Sr/Ca values for coho salmon rearing in Mill Creek Reservoir were likely due to high ambient Sr/Ca values in Mill Creek Reservoir, where low calcium concentrations were 2-3 orders of magnitude lower than the marsh sites, leading to a Sr/Ca ratio that was 7 times higher than the marsh sites (Table 4).

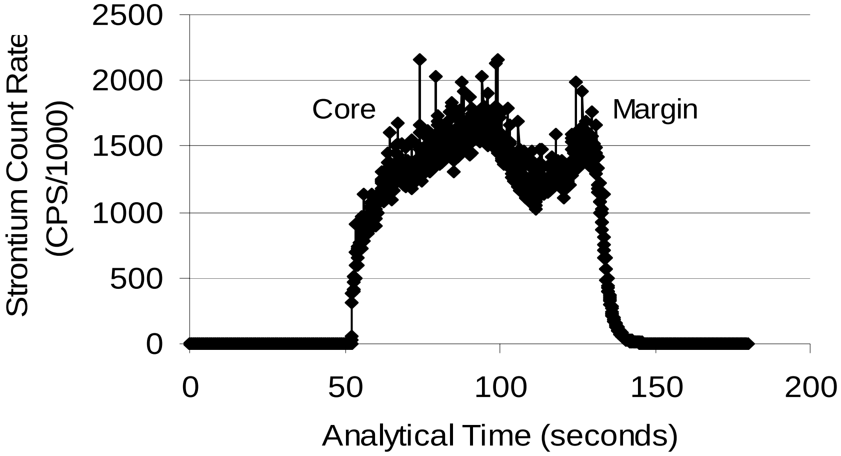


Figure 13a: Otolith strontium profile for fry held in Mill Creek Marsh live box.

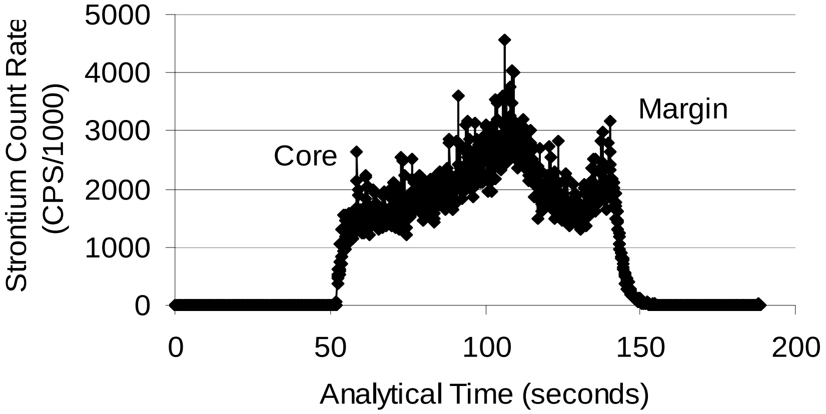


Figure 13b: Otolith strontium profile for fry sampled from Airport Marsh.

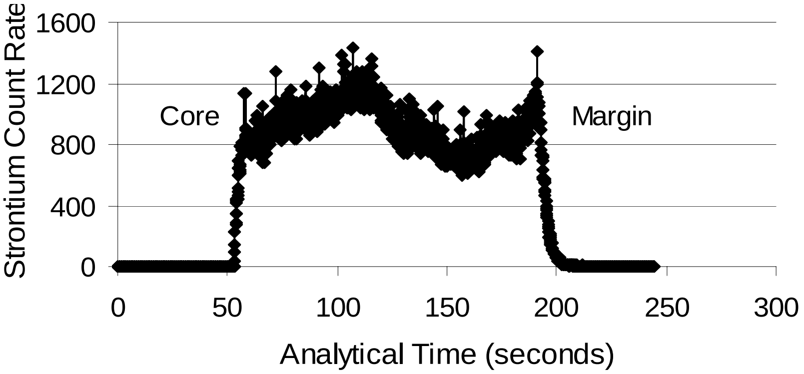


Figure 13c: Otolith strontium profile for fry sampled from Mill Creek Marsh.

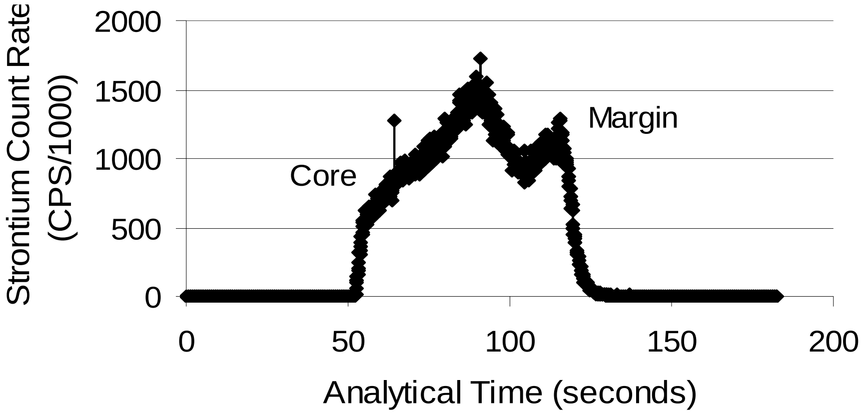


Figure 13d: Otolith strontium profile for fry sampled from Mill Creek Reservoir.

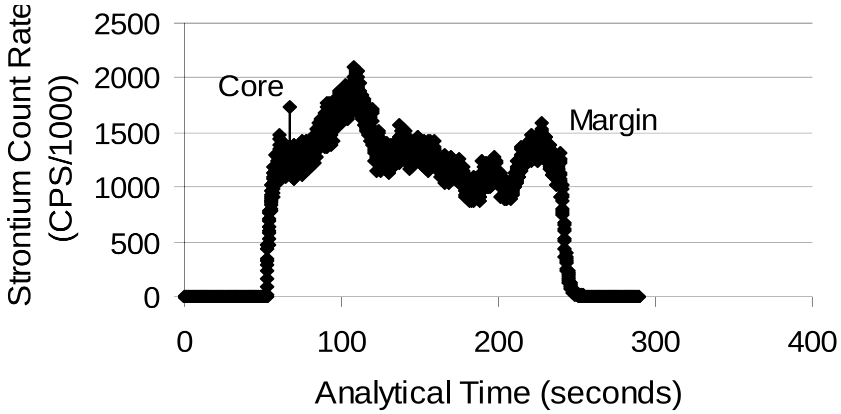


Figure 13e: Otolith strontium profile for smolts sampled from Mill Creek Reservoir.

Table 3: Mean strontium count values at three otolith positions.

Location	Mean strontium count at otolith core	Mean peak strontium count	Mean strontium count at otolith margin
Airport Marsh Fry	2.3	4.6	3.6
Mill Ck. Marsh Fry	2.2	3.5	2.9
Mill Ck. Reservoir Fry	1.9	3.3	2.3
Mill Ck. Marsh Live Box Fry	1.8	3.1	2.5
Mill Ck. Reservoir Smolts	2	3.2	2.6

Table 4: Summary of water chemistry analyses.

Date	Sample Location	Ca (ppm)	Sr (ppm)	Sr/Ca Molar Ratio
5/12/2004	Mill Ck. Marsh	23.92	0.45	8.53
5/19/2004	Mill Ck. Marsh	41.17	0.73	8.16
5/19/2004	Upper Mainstem Yaquin	35.08	0.64	8.41
5/25/2004	Mill Ck. Reservoir	0.34	0.04	56.79

Following the rise in strontium count rates to peak values, otolith strontium usually declined then rose again towards the margins of otoliths. Although we expected a marked rise in otolith margin strontium abundance from fish captured in estuary habitats (Figure 13a-c), it was apparent that fish sampled from strictly freshwater habitats in Mill Creek Reservoir showed a similar increasing trend in strontium count rates (Figure 13d-e). Otolith Sr/Ca values quantified at the margins of otoliths showed that there were significant differences between sample locations, with values ranging between 2.3 and 3.6 (Table 3) (ANOVA, F=11.80, df=41, P<.05). Fish collected from the two marsh habitats had significantly higher otolith margin Sr/Ca values compared to the other three groups (t-test, P<.05). (The fact that net pen sequestered fish in Mill Creek Marsh failed to show this elevated Sr/Ca value at the otolith margin is probably explained by their lack of growth while in the live box). We can only assume that for other groups, these values fairly reflect the habitats from which fish were taken, as we have no way of knowing how long fish may have resided in marsh habitats prior to capture. Water sample Sr/Ca values were very similar among all marsh sites (Table 4) and were typical of values accrued in otoliths at fairly high salinities. The higher salinity Airport Marsh site showed higher strontium concentrations, but lower calcium levels.

Our analysis is based on the prospect that the Mill Creek Reservoir water was characterized by fairly low Sr/Ca values and that similarly low otolith Sr/Ca values would rise significantly as fish migrated from freshwater habitats to the tidally influenced marshes, where we expected higher water strontium. Unfortunately, both water samples and otolith analyses from fry and smolts showed that Mill Creek Reservoir water was characterized by very high Sr/Ca values that diminished our ability to define habitat associations using this particular signal. Otolith Sr/Ca values during freshwater residence of Mill Creek Reservoir samples showed large fluctuations, but peaked more than four times higher than similar values recorded in salmonid otoliths from other freshwater systems. As a result, the large increase in strontium abundance that typifies migrations of juvenile salmon across salinity gradients was not very apparent. While it was true that otolith margin Sr/Ca values were significantly higher for marsh fish compared to the reservoir captured fish, indicating that relatively high water Sr/Ca values noted in Mill Creek may be characteristic of the lower Yaquina River in general, the utility of this small difference is likely to be limited. This result emphasizes the important point that although we often observe close relationships between salinity and Sr/Ca values in water, water strontium and calcium clearly fluctuate independently of salinity and factors such as underlying geology may be influential. In view of the atypically high and widely ranging Sr/Ca values in the Mill Creek Reservoir habitat and the variable salinity of the tidal marsh habitats we could not determine if coho salmon fry rearing in the salt marshes smolt as age-1+ fish then return to Mill Creek to contribute to the adult spawner population thereby inflating the marine survival estimate.

SUMMARY

Scale analysis indicated that it was unlikely that adults, which had reared in other tributaries of the Yaquina River were returning to Mill Creek and contributing to the adult spawner population. Smolts migrating out of the Mill Creek Reservoir typically showed much more growth (as a function of fork length and distance from the center of the scale to the outside of the first annulus) than smolts rearing in stream systems. The analysis showed that adults returning to Mill Creek all exhibited the 'reservoir type' accelerated growth pattern in the juvenile portion of their scales. Additionally it appeared that fish, which had not reached a threshold of growth (as represented by the distance from the center of the scale to the outside of the first annulus) by the time they migrated to the ocean, did not survive to return to Mill Creek. In view of the fact that coho salmon rearing in stream systems rather than the reservoir rarely reached the threshold of growth required to return to the reservoir, it seems unlikely that these fish stray into Mill Creek in great enough numbers to influence the marine survival estimate.

While coho salmon do not generally smolt at age-0+, examples of this life history pattern have occasionally been observed in wild populations of coho salmon in Oregon streams (personal communications, Lisa Borgerson, ODFW). Because of the rapid growth and large size of coho fry in the Mill Creek Marsh by late May, it seemed possible that many of these fish would shorten their freshwater residence and migrate to the ocean in June. However, through scale analysis we found no evidence that fry rearing in the marsh habitat were smolting as age-0+ fish and then returning to Mill Creek as spawning adults.

Due to high ambient Sr/Ca levels in Mill Creek we could not determine if coho salmon rearing in the salt marsh habitat as fry and smolting as age-1+ fish were returning to Mill Creek Reservoir as adults. Although age-1+ smolts are by far the most prevalent life history for coho salmon in Oregon streams, the possibility of marsh reared fry using this life history and contributing large numbers of adult spawners to Mill Creek, or the Yaquina basin in general, seems unlikely for several reasons. First, the coho salmon fry leave the Mill Creek Mash habitat by late June presumably due to high water temperatures, so these fish must find suitable rearing habitat for the remainder of the summer and following winter. Summer temperatures in the main-stem Yaquina River are also high and present limited rearing potential, thus mortality rates may be high on these fish. Second, the total population of marsh reared coho fry in the upper Yaquina basin is not believed to be large. While there appeared to be thousands of coho fry using the Mill Creek Marsh in spring 2004, the number of coho fry using the Airport Marsh was believed to be no more that a few hundred. Additional sampling of marsh habitat in mid-estuary where salinities were above 15 ppt showed few if any coho rearing (personal communications, Stan Van de Wetering, Confederated Tribe of the Siletz Indians). Given the continuing natural mortality on these fish during the remainder of their freshwater residence, the eventual smolt production from this life history may not be large enough to generate large numbers of returning adults.

The results of this paper indicate that neither straying of adult coho salmon from other tributaries of the Yaquina River or juvenile salmon rearing in salt marshes are contributing to the high marine survival estimate at Mill Creek. Therefore, it appears likely that the large smolt size and the associated 'fitness' of the reservoir reared Mill Creek fish plays a significant role in the high marine survival of these fish. Other lake systems on the central Oregon coast also show similar patterns. Siltcoos and Tahkenitch lakes have smolts that are relatively large at outmigration, and adult returns to tributaries of these lakes are typically higher than other streams on the central Oregon coast.

ACKNOWLEDGMENTS

We wish to thank Stan Van de Wetering and his coworkers of the Confederated Tribe of the Siletz Indians for their help in sampling the marsh habitat of the Yaquina River. We also would like to thank Lisa Borgerson and David Jepsen for the time they spent reviewing and improving the report with their comments.

REFERENCES

Bath, G.E., S.R.Thorrold, C.M.Jones, S.E.Campana, J.W. McLaren and J.W.H.Lam. 2000. Strontium and Barium Uptake in aragonitic otoliths of marine fish. Geochemica et Cosmochimica Acta, 64:1705-1714.

Brown, P.J. and J.H.Harris. 1995. Strontium batch marking of golden perch (Maquaria ambigua) and Trout cod (Maccullochella maquariensis). In: Recent Developments in Fish Otolith Research. D.Secor, J.M.Dean and S.E.Campana [eds].pp. 693-701.

Fowler, A.J., S.E. Campana, C.M.Jones and S.R.Thorrold. 1995. Experimental assessment of the effect of temperature and salinity on elemental composition of otoliths using solution-based ICPMS. Can. J. Fish. Aquat. Sci. 52:1421-1430.

Longerich, H.P., S.E. Jackson and D. Gunther. 1996. Laser ablation ICP mass spectrometric transient signal data acquisition and analyte concentration calculation. Journal of Analytical Atomic Spectrometry 11:899-904.

Russo, C.J. 2001. A trace element study of plagioclase and clinopyroxene phenocrysts in historical lavas from Mt. Etna, Sicily, by laser ablation ICP-MS. Masters Thesis. Oregon State University. 180 pp.

Schroder, S.L., C.M.Knudsen and E.C.Volk. 1995. Marking Salmon Fry with Strontium Chloride Solutions. Can. J. Fish. Aquat. Sci. 52:1141-1149.

Secor, D.H. 1992. Application of Otolith Microchemistry to Investigate Anadromy in Chesapeake Bay Striped Bass, Marone saxatilis. Fish. Bull. 90: 798-806.

Volk, E.C., A. Blakely, SD.L.Schroder and S.M.Kuehner. 2000. Otolith chemistry reflects migratory characteristics of Pacific salmonids: Using otolith core chemistry to distinguish maternal associations with sea and freshwaters. Fisheries Research 46:251-266.

3406 Cherry Avenue N.E.
Salem, Oregon 97303