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Follow the Fish

The WCVI Follow the Fish Program

One of British Columbia's most important natural resources:
Chinook salmon from the West Coast of Vancouver Island (WCVI)

Using fish otoliths to determine saltwater entry size
of juvenile salmonids and track habitat usage along WCVI.

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Canada

Natural-origin Chinook salmon along the West Coast of Vancouver Island (WCVI) are at critical levels, with low numbers of adults making it back to spawning grounds, reduced genetic diversity of wild populations as a result of interbreeding with hatchery fish, and declines in size-at-age and age-at-maturity which means that fewer and smaller female Chinook return now as compared to the past.

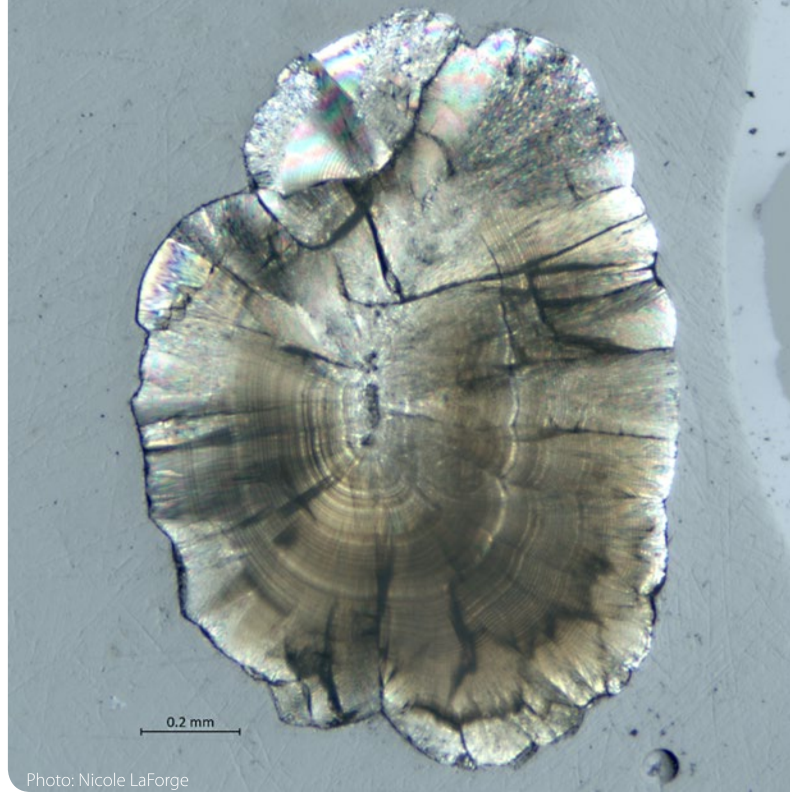


Photo: Nicole LaForge

Otolith sample captured by the LA-ICP-MS technique.

It is generally believed that risks occurring during the freshwater rearing stages, including increased mortality of incubating eggs and insufficient rearing habitat, lead to 'carry-over' effects such that the affected juveniles, possibly smaller and less robust, are at increased risk during the early marine phase. WCVI juvenile Chinook rear in nearshore waters for several months, so they are exposed to many risks during their early marine phase, such as pathogens, parasites, disease, poor water quality, lack of food, and predation.

As part of the WCVI Follow the Fish Program, DFO initiated a study to assess the size and habitat usage of WCVI juvenile Chinook making the transition from freshwater into marine waters. This information was to be related to subsequent adult returns, to determine the extent of carry-over effects along WCVI and to better understand the factors that result in successful rearing and return.

Otolith microchemistry is one of the methods that is being used to better understand the life history of WCVI Chinook salmon. Using otoliths, it is possible to retroactively determine the size of a smolt at freshwater entry from the adult otoliths using a method known as 'laser ablation-inductively coupled plasma-mass spectrometry', or LA-ICP-MS. This technique can measure the changes in strontium concentration recorded in the otolith, indicating when this fish moved from freshwater (where strontium is low) into marine environments (where strontium is high). The approach can also provide information on historical habitat use by examining otoliths for other elements.

First, we describe what otoliths are, what kinds of information they can be used to provide, and then we describe the Follow the Fish otolith microchemistry project.


Photo: Mitch Miller

Cover Photo: Eiko Jones

What is an otolith?

The word 'otolith' provides us with some clues as it is derived from the Greek work "oto" which means ear, and the word 'lith' which means stone. Otoliths are small, mineralized structures within the inner ear made of calcium carbonate that form throughout a fish's life, helping with orientation, acceleration, balance, and hearing. There are three types of otoliths which occur in pairs, and researchers usually examine the largest pair, called sagittae, to understand the fish's life history (**Figure 1**). People also have otoliths, though they are referred to as otoconia, which when disordered can cause vertigo!

Otoliths function somewhat like a diary-daily deposits create rings which start forming during the late stages of embryonic development. As they grow day by day, small amounts of other elements present in the fish's environment get passively added into the calcium crystal. These elements are derived from the water being absorbed by the fish or from its food, preserving a record of what was in the water and what it ate at the time that layer was formed. They provide a permanent record of the environment that the fish lived in- because once the elements are incorporated, they do not come back out (unlike other tissues such as scales and bones that minerals get resorbed from if the fish doesn't have enough to eat!).

In addition, different river systems may contain different compositions of these chemical elements, so microchemistry techniques also can be used to discriminate among stocks or even determine the lake or river of origin.

Otoliths are like a diary written in crystal!

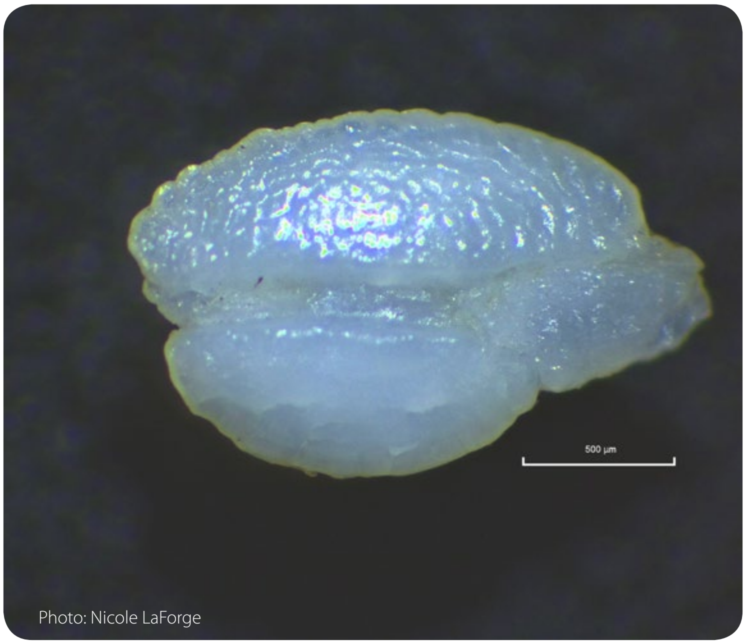


Figure 1. Images show both sides of an otolith from a juvenile Chinook salmon (5 months old). This otolith is close to 2 mm long.

Why is this important?

Otoliths allow us to look back in time to see what challenges threatened fish populations faced, possibly allowing us to determine how to help those populations or species recover.

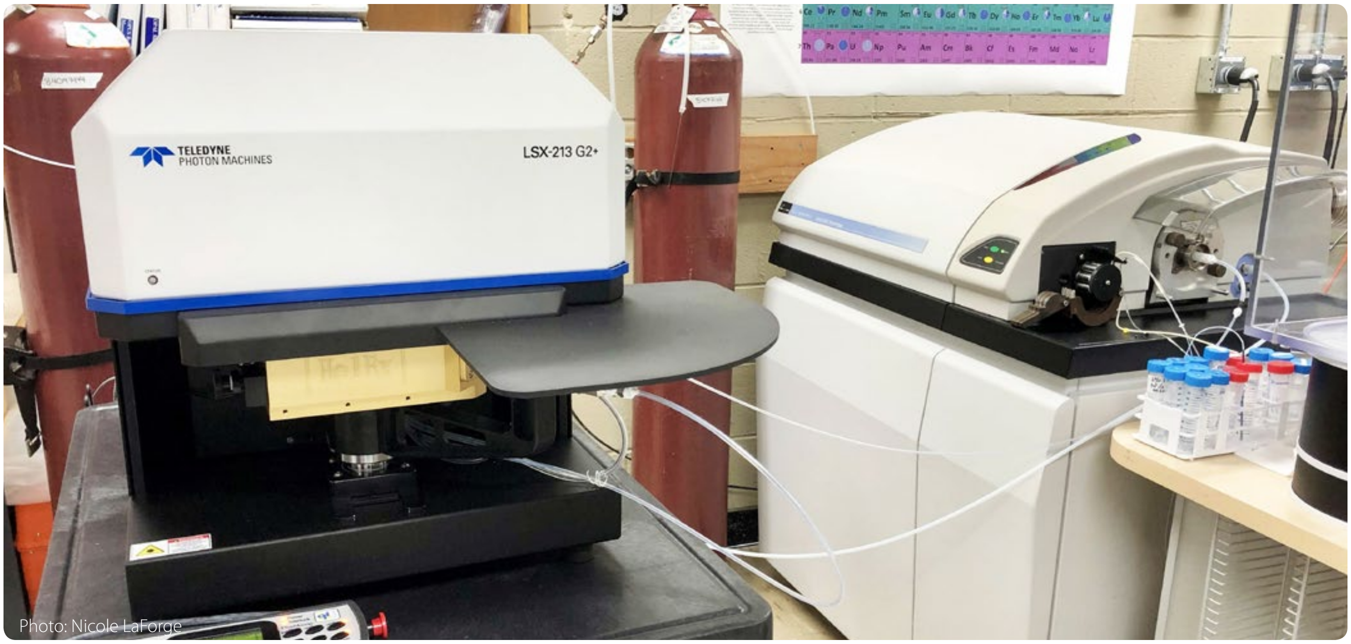


Figure 2. The LA-ICP-MS system is an important component of the otolith microchemistry lab equipment at the Institute of Ocean Sciences, Sidney, BC. Polished otolith samples go into the laser instrument on the left and the tiny amounts of sample vapourized by the laser get transported through the tubing into the mass spectrometer on the right, where the types of elements and their amounts are measured.

What can we use otoliths for?

Otolith chemistry can provide a researcher with information on:

- Changes in salinity experienced by the salmon ie. when they moved from freshwater to estuary to marine waters. This is achieved by using the chemical element strontium as an indicator.
- The age of the salmon. This is achieved by counting the rings in an otolith or looking at changes in concentrations of elements such as zinc and phosphorus.
- The size of the salmon. The radius of an otolith correlates to the size of the fish, so measuring otoliths can give an indication of the length and weight of fish.
- Levels of exposure to heavy metal pollutants.
- Salmon diet: elements from the food eaten by the fish also enter the otoliths.
- Salmon species: each species of fish have otoliths with a slightly different shape!

Methodology

Otoliths are removed from fish caught by fishers or collected in the river when they either leave or return to spawn. Scientists use polishing and microscopy to prepare them for microchemical analysis using a laser and a mass spectrometer, called LA-ICP-MS, or 'Laser Ablation Inductively Coupled Plasma Mass Spectrometry' (**Figure 2**). Results of this analysis show how concentrations of elements change in a fish during its entire life.

The types of graphs that can be produced include:

- Graphs of strontium concentrations (indicating salinity), showing when a young salmon moves from freshwater to saltwater (**Figure 3**).
- Graphs of the changes in concentrations of other elements such as magnesium or manganese. These are indicators of high metabolic rates, and therefore periods of fast growth of a young salmon (**Figure 4**).
- Otolith size can also be used to determine fish size. Scientists have been able to develop relationships between otolith size and fish size by measuring many fish and their otoliths and plotting these as shown in **Figure 5**. In this figure, based on measurements of many Sarita River Chinook smolts entering the Sarita River estuary, the regression equation can tell us that an otolith radius of 320 um corresponds to a fork length of 41 mm for this fish when it was a smolt entering the estuary.
- Looking back at Figure 5, using information on the actual size of the otolith, and relating this to the elemental composition, scientists are therefore able to state what size the fish was when it went to sea (**Figure 6**).

The Mass Spectrometry Lab at the Institute of Ocean Sciences is currently the only DFO facility that has the instruments needed for otolith microchemistry research.

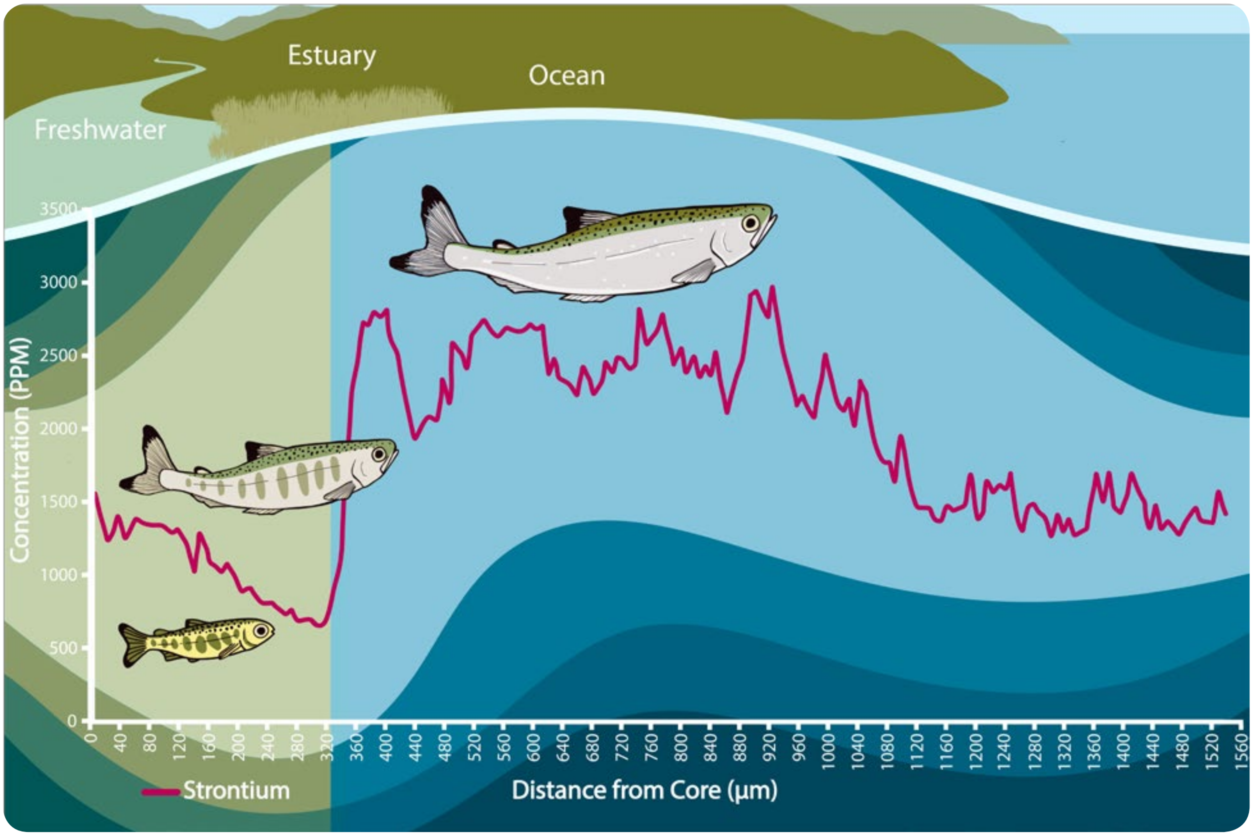


Figure 3. Changes in strontium concentrations show the movements of a Sarita River Chinook salmon during its entire lifetime. The lowest strontium occurs when the fish was a fry and had used up its yolk and started feeding in freshwater. The steep increase in strontium shows that this fish spent a very short time in the estuary before it transitioned to living fully in the marine environment.

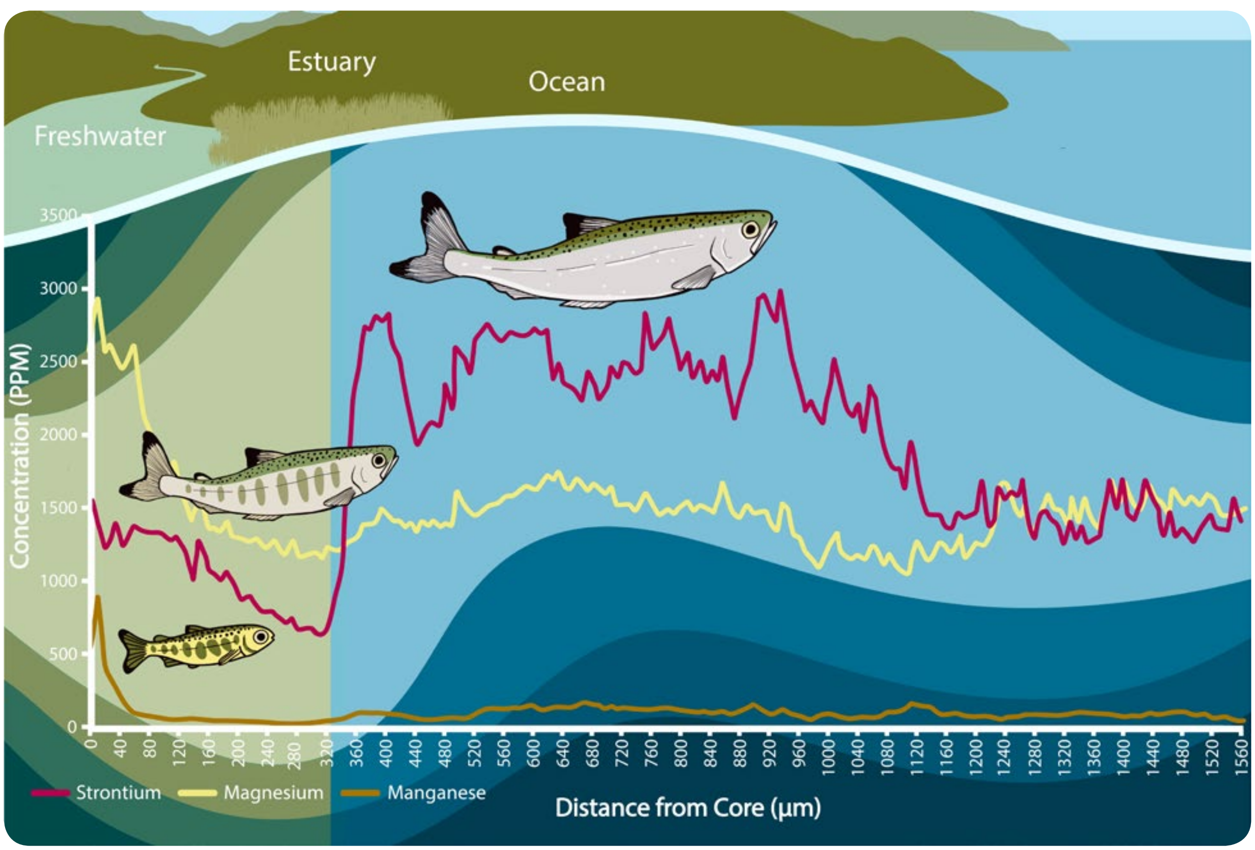


Figure 4. Strontium (red), magnesium (yellow), and manganese (brown) concentrations in a returning adult Sarita River Chinook salmon otolith from the core (left) to the edge (right).

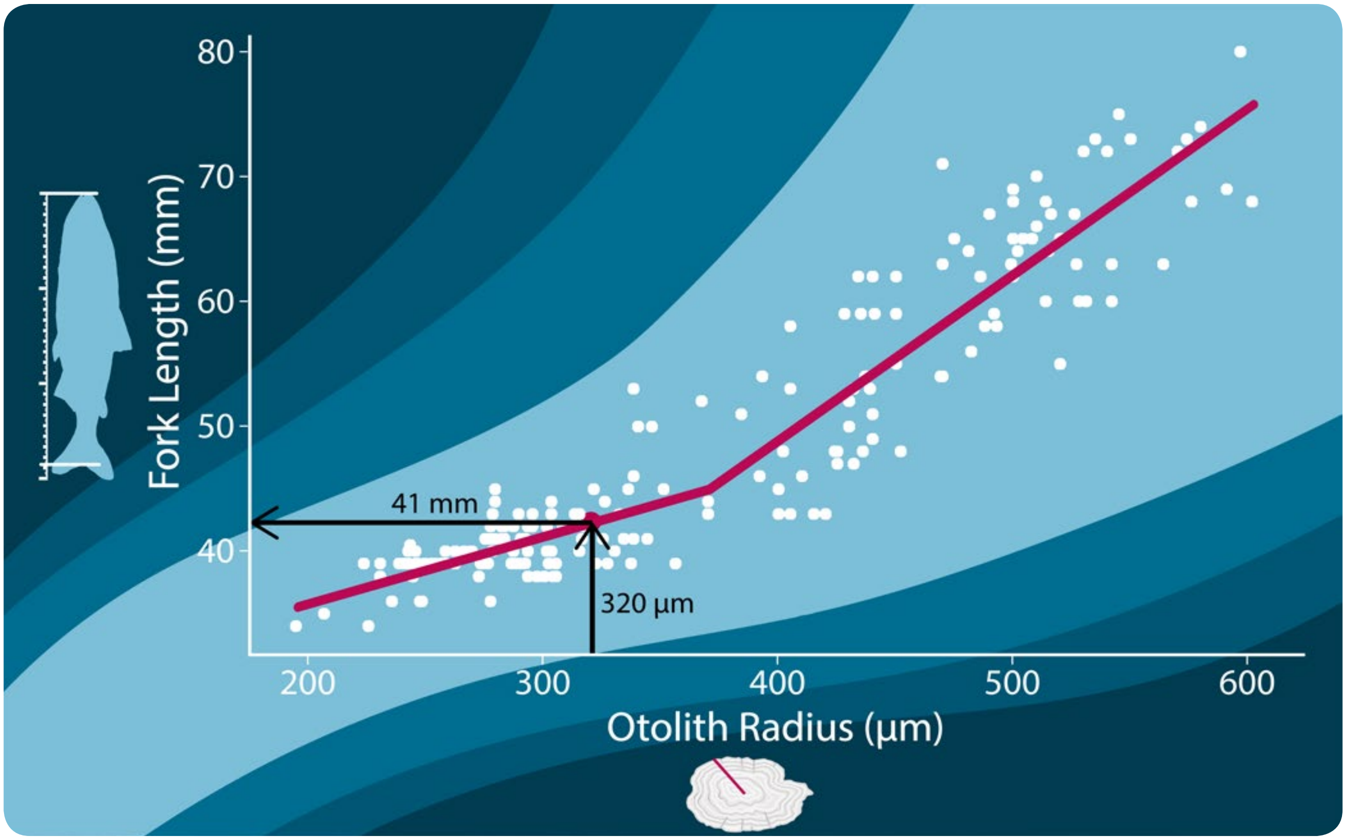


Figure 5. The fork length to otolith radius relationship for Sarita River Chinook salmon. There is a shift in growth when Chinook switch from the fry to the parr stage which occurs around 45mm fork length.

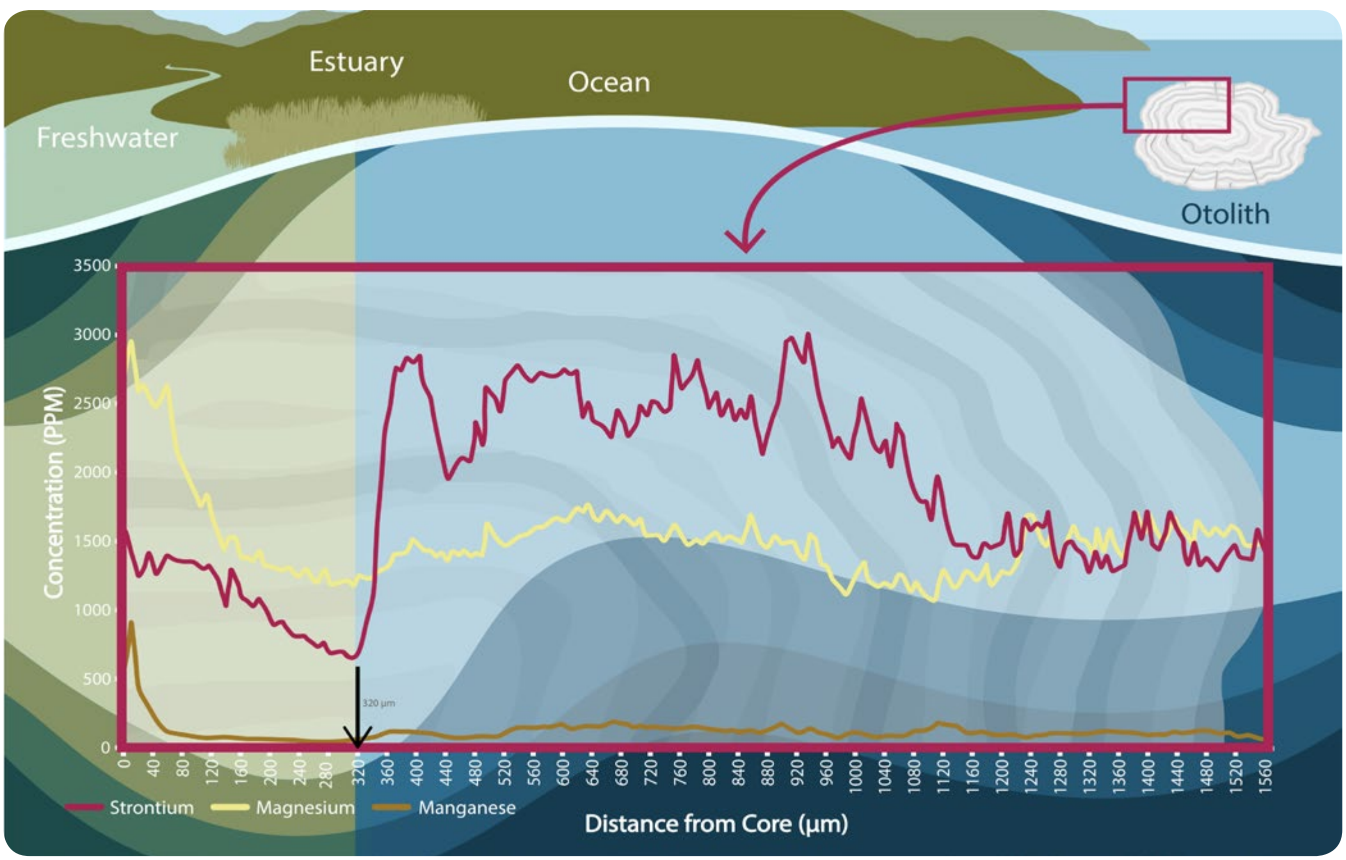


Figure 6. This Chinook salmon is predicted to have entered the estuary where the otolith radius would be 320µm, which corresponds to a fish that was around 41mm long (see Figure 5).

Chinook salmon in the Sarita River either leave as tiny fry between February to April, or as larger parr in May and June. By identifying the life history type of returning Chinook salmon, we can identify what strategy contributes more to the overall river population and gives us a glimpse as to how we can eliminate stressors during their early marine period.

This kind of information allows fisheries managers to make informed decisions to protect and restore fish populations and enables them to make sustainable harvesting plans.

In Summary:

- Otoliths are structures formed of calcium crystals in the inner ears of all bony fish that preserve a permanent record of their environment, diet, growth and metal pollutant exposure.
- They can provide information on salinity, location, size and age.
- Scientists use polishing and microscopy to prepare them for microchemical analysis using a laser and mass spectrometer, called LA-ICP-MS.
- Results of this analysis show how concentrations of elements change in a fish during its entire life.
- Otoliths provide a lot of very valuable information that can assist in making conservation and sustainable fishery decisions.

Purse Seining in Barkley Sound.

What work is DFO doing using otoliths along WCVI as part of the Follow the Fish program?

Survival rates of WCVI Chinook in the marine environment are poorly understood, but believed to be influenced by when the juvenile fish transition into the ocean from their natal freshwater systems.

The goal of this specific Follow the Fish Program project is to establish the size of Chinook salmon at saltwater entry by examining otoliths of Barkley and Clayoquot Sound-produced newly smolted individuals through their first year, as well as looking back in time by examining the otoliths of returning adults to determine their size at saltwater entry when they were smolts. The project is focussed on addressing data gaps identified during the WCVI Marine Risk Assessment process (Irvine et al. 2024[1]), related to life history diversity, habitat usage and how these variables impact survival to return. In particular, the project aimed to assess ***how size at saltwater entry may be related to successful adult return***.

Barkley and Clayoquot Sounds are the key locations for this work, with some additional collections from San Juan and Nitinat Rivers. Juvenile WCVI Chinook on these systems are collected from freshwater primarily through RSTs (rotary screw traps) and beach seining. Otoliths are also obtained from juveniles collected during purse seine activities (in Barkley Sound) in the summer, and from microtrolling in the fall and winter (for all the Sounds). Adults are collected as they return to the WCVI rivers, from those selected to spawn at the hatchery, carcasses sampled in river, and from fisheries targeting hatchery-origin salmon in the river. This work provides the framework for how studies on other at-risk systems can be approached, with summer Puntledge and various Fraser River Chinook salmon already collected and analyzed.

In total, close to 2000 otoliths are being examined for this project!

1. Irvine, J.R., Luedke, W., Pearsall, I., Sastri, A., Carson, C., Menendez, C., Hutchinson, J., Miller-Saunders, K.M., and Hawkins, T. 2024. Marine Risk Assessment for Natural- Origin West Coast Vancouver Island Chinook Salmon (*Oncorhynchus tschawytscha*). Canadian Technical Report of Fisheries and Aquatic Sciences. 3603: ix + 308 p.

Results to Date

Sarita River

Here we provide some results for work done on Chinook entering Barkley Sound from the Sarita River. This system has provided some interesting contrasts as there are four different populations of Chinook on this system, including:

- Two hatchery release types:
  - > Small enriched
  - > Large traditional
- Two types of natural-origin Chinook:
  - > Early Small (30-49 mm; entering the ocean February – April; termed 'fry')
  - > Late Large (>50 mm; entering the ocean May – June; termed 'parr')

As can be seen in **Figure 7**, most of the natural-origin outmigrants from the Sarita system are the "Early Small" type. However, when the otoliths of adults returning to this system are examined, it is apparent that a much greater proportion of the successful return was made up of the "Late Large" type (**Figure 8**).

The DFO team has used these data to examine the smolt to adult return survival rates for the different groups of fish, finding that survival rates of the fish leaving rivers when they were over 50 mm in size are much higher than for the fish leaving when they were smaller than 50 mm (**Figure 9**).[2]

A rotary screw trap (RST) on the Sarita river is used to trap juvenile Chinook.

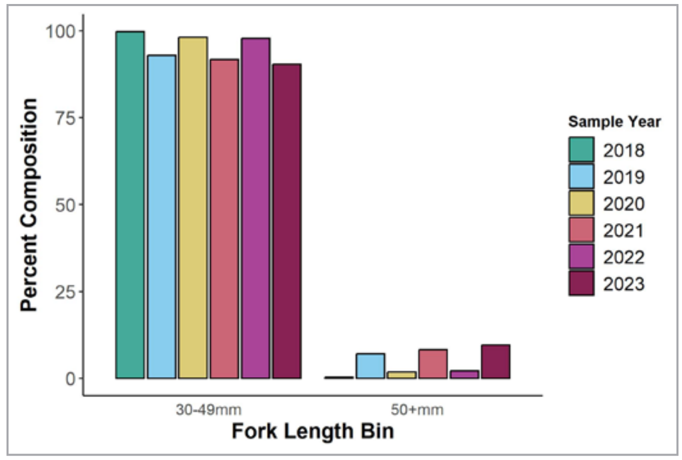


Figure 7. LGL Limited smolt outmigrant data binned by the two types of Chinook natural-origin outmigrants on the Sarita River (n = 4397).

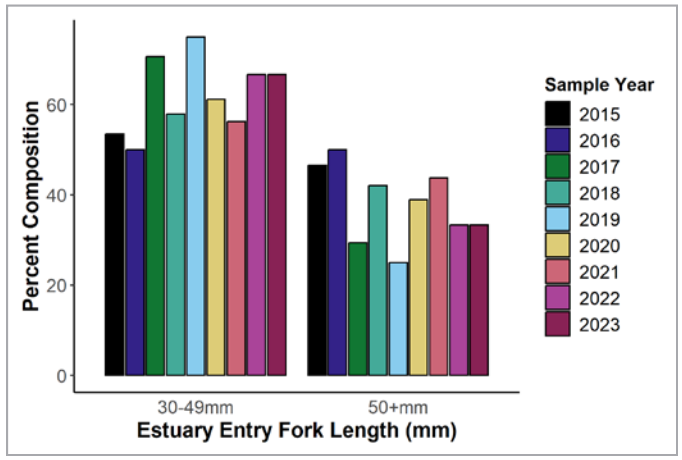


Figure 8. Sarita River natural-origin smolt outmigrants types as observed in the adult returns through otolith chemistry (n = 219).

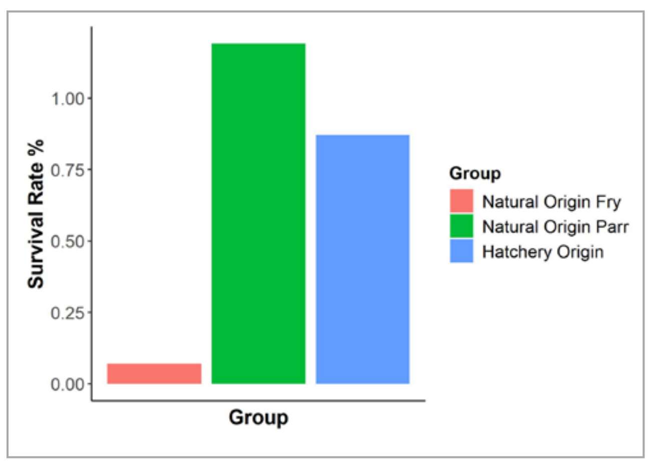


Figure 9. Average survival rates of Sarita Chinook inferred by taking averages of smolt outmigrant numbers and adult returns for the calendar years 2019-2023 (NOT from brood years).

2. LaForge et al. (In Press). Using Otolith Microchemistry to Identify Life History Specific Survival Rates of Sarita River Chinook Salmon. Trans. Am. Fish. Soc.

However, if we focus on a single brood year, we get a different estimate (**Figure 10**). Here we find that natural-origin parr (>50 mm) survive at fairly high rates, and the gap between hatchery-origin (all types) and natural-origin fry closes. The proportion of natural-origin Chinook salmon in the Sarita River has been high for the last two years as well, which is due to this increasing survival rate amongst natural-origin Chinook salmon.

Size at marine entry also appears to affect the age at return and the time spent rearing in the estuary. **Figure 11** shows that typically, the smaller fish return older, spending more time growing at sea. 84% of the oldest fish returning were the smallest fish at estuary entry. This means that outmigrant strategy will have impacts on fecundity, because larger females typically lay more eggs at spawning. However, the older age at return might expose the Early Small type fish to higher fishing pressure.

Results from otolith microchemistry analyses have shown that about 18.7% of the Sarita River natural-origin population use the estuary for extended periods of time (≥3 weeks), while other individuals appear to leave and then return to the estuary (though it is unclear if it is the same estuary). It should be noted that the incorporation time of strontium in the otolith can be on the scale of a couple of weeks, so estuary transition times may be faster on average than what the team has calculated (Vignon et al. 2023).[3] However, most of the fish suspected of using the estuary for long periods of time showed prolonged periods of intermediate barium and strontium values before a final transition into a fully marine signal. **Figure 12** shows although neither the Early Small or Late Large outmigrant type natural-origin fish spent much time in the estuary, the larger sized fish typically spent more time rearing in the estuary. This may be beneficial for those fish, allowing them longer periods of time for acclimation to salt water, less exposure to predators if they can rear in eelgrass or kelp habitats, and more time in the rich feeding nursery habitats typically found in these estuary habitats.

In Summary:

- There are 4 types of smolts leaving the Sarita River (2 hatchery, 2 natural).
- We can identify the type of natural-origin Chinook by looking at the adult otoliths using otolith chemistry.
- Early Small smolts make up the majority of the outmigrants, but Large Late smolts survive far better.
- Depending on the time period, natural-origin smolts may do better or worse.
- Early Small natural-origin smolts make up 92% of the natural-origin 5-year-olds.
- Some outmigrants may use the estuary for a limited period in April.

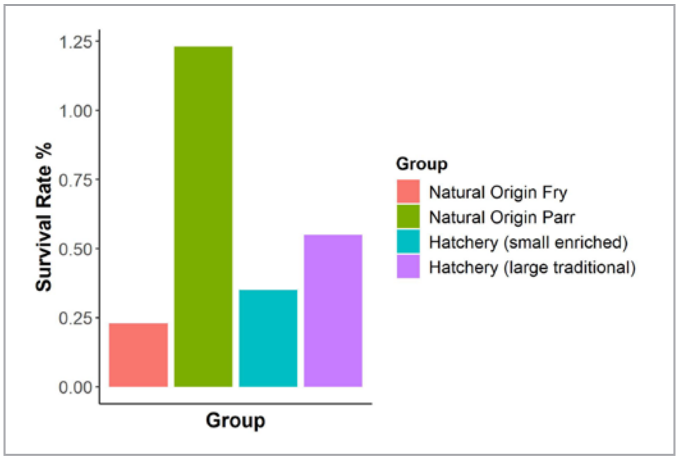


Figure 10. Survival rates for the 2018 Sarita River brood year between two natural-origin outmigrant life history types and two hatchery release types. (Hatchery data from thermal marks, natural-origin data from otolith chemistry).

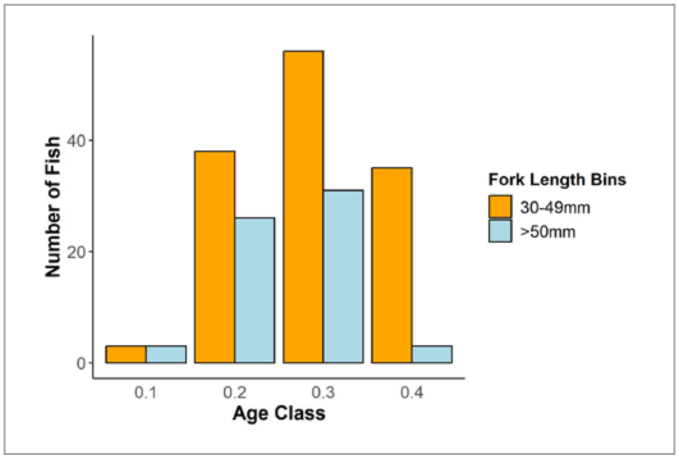


Figure 11. Age at Return barplot showing the number of Sarita Chinook salmon from each of four age classes from the 30-49 mm and 50+ mm estuary entry bins. Ages are represented by the number of freshwater annuli followed by the number of marine annuli on the scale. n = 225.

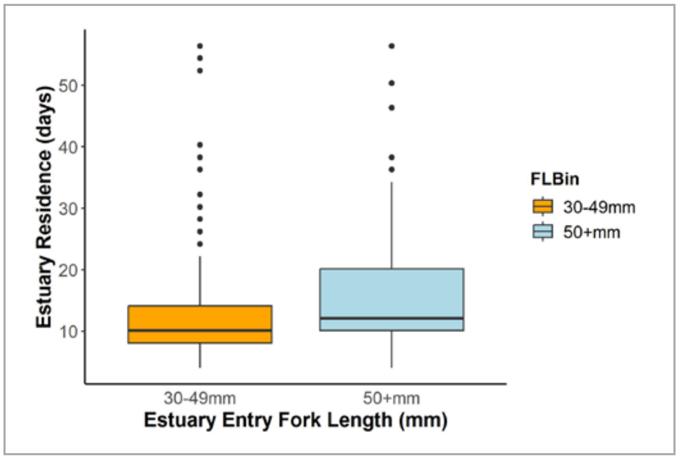


Figure 12. Boxplot showing the size at estuary entry vs the residence time for Sarita River adult Chinook returns between 30-49 mm and >50 mm estuary entry FL (fork length) size bins. n = 225.

3. Vignon, M., Tabouret, H., Aymes, J-C., Pecheyran, C., Rives, J., Coste-Heinrich, P., Huchet, E., and Bareille, G. 2023. Effect of metabolic rate on time-lag changes in otolith microchemistry: an experimental approach using Salmo trutta. J. Exp. Biol. Vol 226 (Issue 13): jeb245265.

Photo: Eiko Jones

Other results

The DFO team have found several additional preliminary and interesting results. They have observed that juvenile Chinook caught through microtrolling along WCVI do not tend to be the smaller early-entry fish. However, as seen in the Sarita example on the previous page, they do find that early-entry fish are present in adult returns. They suggest that early-entry fish either move further away from the WCVI Sounds and so they are not caught by microtrolling, or they are remaining close to shore rearing in the eelgrass where they are not accessible to microtrolling methods. This corresponds with earlier studies that noted that older WCVI Chinook salmon are far more likely to be captured further north.

30-49 mm natural-origin fry make up 84% of the oldest natural-origin Chinook salmon found within the Sarita River, therefore they are most likely leaving the local marine environment and undertaking lengthy marine migrations. These migrations can result in lower overall survival rates due to predation along these routes. This would also suggest that some proportion of the natural population from the Sarita River are not impacted as greatly by local WCVI environmental conditions; rather they are more exposed and impacted by the environmental conditions of northern BC as well as SE Alaska. Further analyses of Sarita River Chinook salmon captured in different fisheries could further illuminate how the two different natural-origin life histories move throughout the marine environment.

How might these findings be used to ameliorate WCVI Chinook survival/returns?

In general, very few natural-origin Chinook salmon are tagged with coded-wire tags[4], which makes it difficult to identify patterns of survival outside of a very coarse assessment. With otolith microchemistry, however, it is possible to identify different life history types within a population, their relative contribution to the total population, the potential threats they are exposed to in the early marine environment, and how they use habitat through time. This allows for identification of the most successful strategies during different periods of environmental conditions, an understanding of relative pressures impacting the different life histories, and potential for improved management.

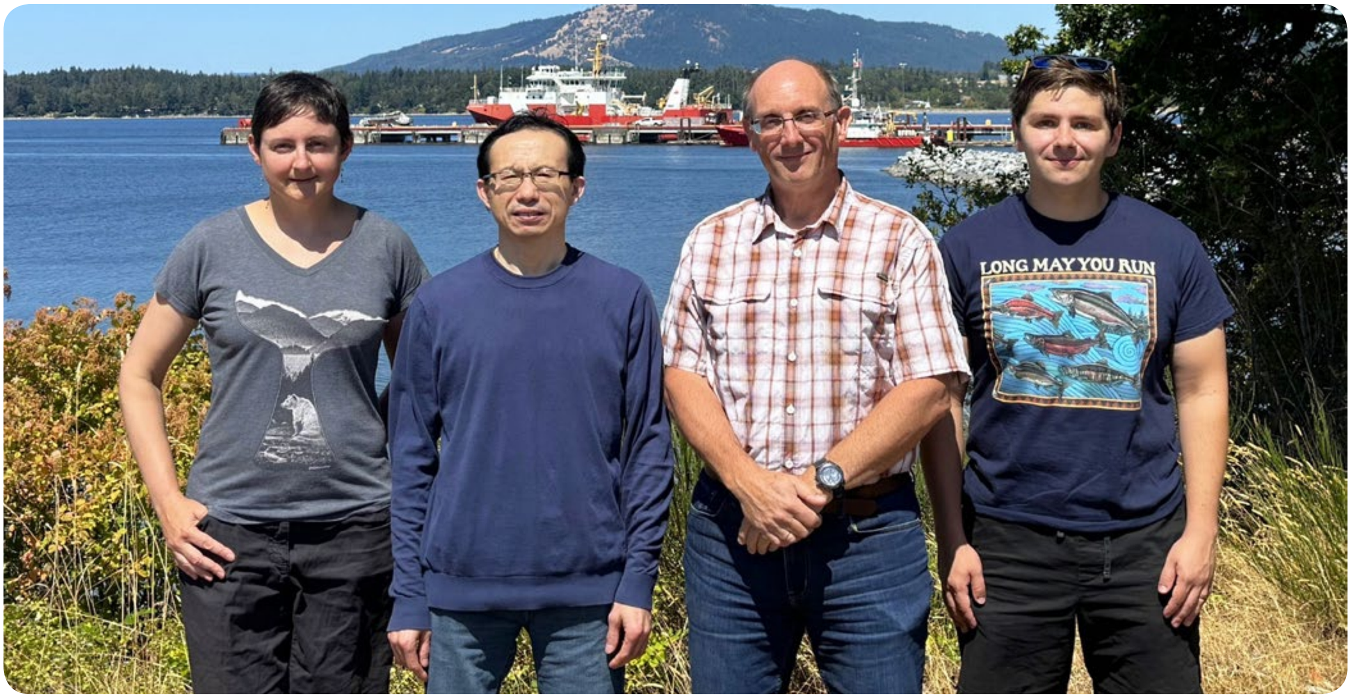
For example, improved returns could possibly be achieved by ameliorating conditions for natural-origin parr. These fish leave the Sarita River later and at a larger size than smaller fry, and have a much improved survival rate to adult return. Work to reduce in-river stressors and improvements to rearing habitat may be beneficial. Work is ongoing to determine whether similar strategies and survival rates are apparent for other WCVI populations.

Finally, this study highlights the importance of phenotypic diversity within a population. The high survival rates of the Late Larges, and the higher ages at return of the Early Small natural-origin fish highlight the trade-offs associated with these different strategies.

The level of phenotypic diversity exhibited by natural-origin Sarita Chinook likely would not be possible to replicate with hatchery production alone. This natural diversity provides a buffer against population extinction events, and further emphasizes the value of protecting our BC wild salmon population.

Photo: Eiko Jones

4. Coded wire tags or CWTs are tiny pieces of magnetized wires used to identify and track fish, particularly salmon and steelhead. These tags are injected into the snout of juvenile fish before release from hatcheries or other facilities. The tags contain a unique code that allows researchers and fisheries managers to track individual or groups of fish, providing valuable data for stock assessment, fisheries management, and research.



The Otolith Microchemistry team at IOS. From left to right: Nicole LaForge, Xiangjun Liao, Andrew Ross, and Micah Quindazzi.

Nicole LaForge

Nicole LaForge is a scientist who studies the microchemistry of biological tissues such as fish otoliths and whale teeth at the Institute of Ocean Sciences (IOS) for the Department of Fisheries and Oceans (DFO) in Sidney, BC. She has an MSc from the University of Victoria in Developmental Biology and Embryology. Nicole has extensive experience in the preparation and analysis of samples by Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) and joined DFO in 2023 to develop the use of this powerful analytical technique in-house for the Pacific Salmon Strategy Initiative and beyond. The mass spectrometry laboratory at IOS has the only instrumentation capable of generating this type of high-resolution time-resolved biological data within DFO.

Xiangjun Liao

Dr. Xiangjun Liao is an analytical chemist at the DFO Institute of Ocean Sciences in Sidney, B.C. He obtained his PhD from McGill University and MSc from Nankai University. He has developed various methods and applied them to analyze up to 500 compounds and metals in different matrices. Xiangjun rejoined Fisheries and Oceans Canada in May 2019 to support work under DFO's Whale Initiatives by developing and validating methods to detect and quantify hormones, PPCPs, targeted metabolites in samples from ringed seals (blubber, liver, plasma), beluga whales (blubber, liver, plasma), killer whales (feces, breath condensate, plasma, urine), chinook salmon (whole fish, liver and blood) and Pacific Salmon Strategy Initiative (PSSI) regarding otolith chemistry and 6-PPD quinone.

Andrew Ross

Dr. Andrew Ross is a Research Scientist at the DFO Institute of Ocean Sciences in Sidney, B.C. Born and raised in England, Andrew first became fascinated by the ocean during summer holidays on the south coast and learned to SCUBA dive while studying for a B.Sc. in Chemistry at the University of Surrey. He earned his Ph.D. in Analytical and Marine Chemistry from the University of British Columbia, then led research in plant proteomics at NRC before joining DFO where he established the Marine Biotoxin Monitoring Program in 2020. Andrew is lead scientist on the PSSI project to investigate the levels and potential health impacts of exposure to biotoxins produced by harmful algae in Pacific salmon on the west coast of Vancouver Island.

Micah Quindazzi

Micah Quindazzi is a PhD Candidate who uses microchemistry to study the migrations of Chinook and Coho salmon at IOS in Sidney, BC. Micah has comprehensive experience in the study of all topics related to the otoliths of salmonids. He has been involved in PSSI since 2021 to study the estuary entry size and marine migrations of WCVI Chinook salmon. He has worked with Nicole to develop techniques for the study of salmonid otoliths using LA-ICP-MS. He is also working on ECVI and Fraser River systems using similar techniques.

Photo: Eiko Jones

Next steps

The team intends to continue to use otolith microchemistry to identify the life history strategies and habitat use patterns of Chinook poulations from other WCVI river systems and also to compare those to ECVI (East Coast Vancouver Island) and lower mainland river system populations to ultimately improve understanding of all of the salmon populations in BC. This information will greatly improve DFO's ability to sustainably manage and rebuild our critically important salmon populations.

With special thanks to:

Huu-ay-aht First Nation, LGL Limited, the Follow the Fish sample collection and dissection teams (Jessy Bokvist, Kaleb Mantha-Rensi, Kayla Zielke, Brian Hendriks and John Fulton), Mackenzie Mueller and Nathan Matthews from the Biotoxins dissection team, Aidan Goodall at DFO Stock Assessment and Nitinat Hatchery staff.

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For more information,

Pacific Salmon Strategy Initiative:
www.dfo-mpo.gc.ca/campaign-campagne/pss-ssp/index-eng.html

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Fisheries and Oceans Canada. 2025. Using fish otoliths to determine saltwater entry size of juvenile salmonids and track habitat usage along WCVI.
New research and monitoring for Pacific salmon and their ecosystems.
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