PACIFIC SALMON FOUNDATION

OTOLITH STUDIES

Marine Science Program Newsletter

Photo by Nicole Christiansen

Otoliths are small mineralized ear bones that form throughout a fish's life. As an otolith is formed it creates a record of information that researchers can study to learn about that fish. The Pacific Salmon Foundation is supporting student researchers in the Juanes Lab at the University of Victoria who are developing novel techniques using otoliths to understand migration patterns of Chinook and Coho and one of their important prey, Pacific herring. In this newsletter we share the latest results from these projects along with some background information about otoliths.

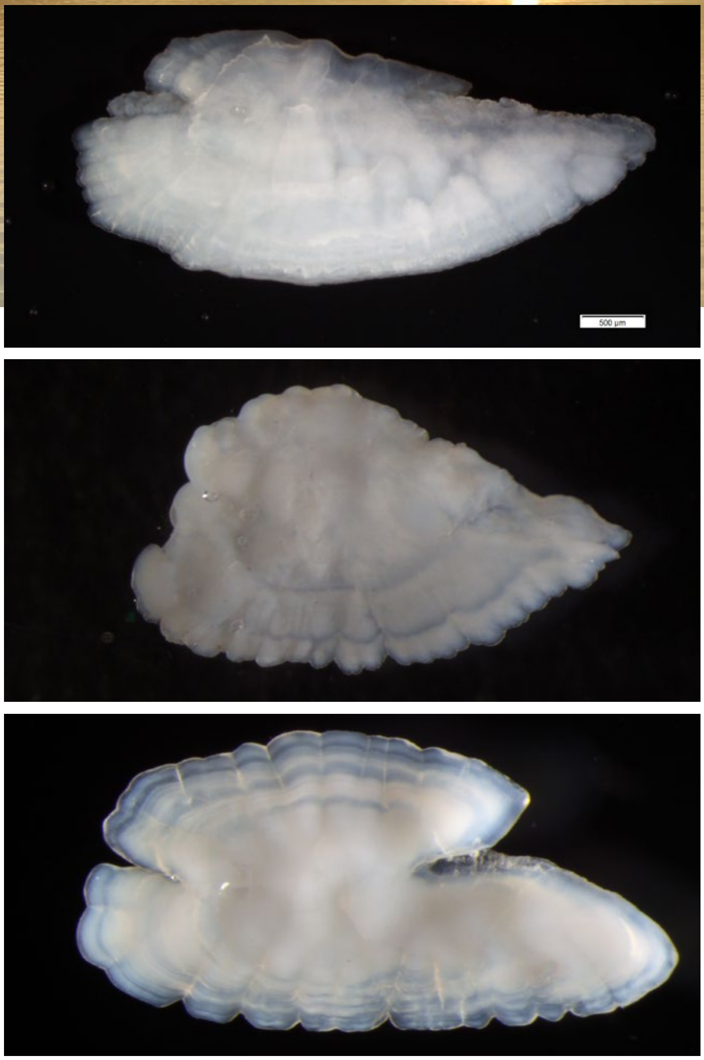

Figure 1. Otoliths from an adult Chinook (top), Coho (middle) and herring (bottom). Photos by Micah Quindazzi and Jessica Qualley

WHAT CAN OTOLITHS BE USED FOR?

Otolith Growth Rings: Annual Growth and Age

Otoliths are a very reliable tool for determining the age of a fish. In Pacific salmon annual growth shows up as two distinct bands: a wide ring of dark material (spring and summer growth) and a narrow ring of relatively clear material (fall and winter growth). The latter is often referred to as the annulus. Freshwater annuli tend to be closer together relative to marine annuli as a result of the greater growth of Pacific salmon when they are at sea. Biologists can estimate the age of the salmon by counting the annuli similar to the way one can count rings on a tree to determine its age. Additionally, individual based growth rates can be determined, since otolith size is related to fish size.

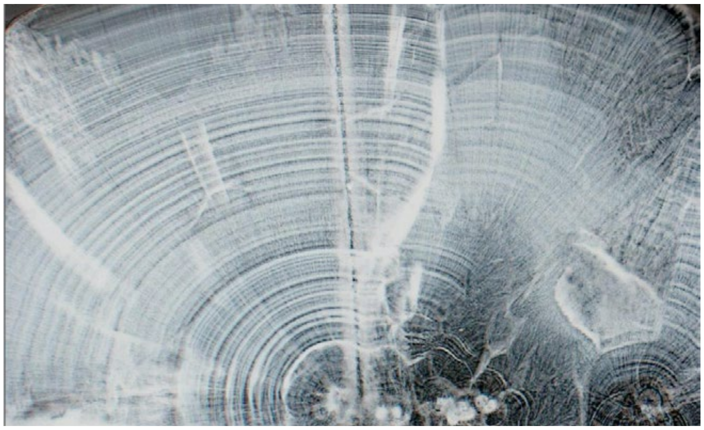

Figure 2. An adult Chinook otolith, showing the annuli
Photo by Lance Campbell, WDFW

Cover photos: Top, Eiko Jones; Left, Jessica Qualley; Middle, Micah Quindazzi; Right, Mitch Miller

Otolith Shape and Size: Fish Identification and Predation Studies

Otoliths have a distinct shape which is often characteristic of the species of fish. Therefore, biologists can look at the shape and size of undigested otoliths from stomach contents or droppings to reconstruct the species of fish eaten by avian, fish or mammalian predators. Additionally, the size of the otolith can be used to determine the size of the fish eaten.

Thermal Marking Studies at Hatcheries

The Salmon Enhancement Program (SEP) utilizes thermal otolith marks to mass mark juvenile salmon in hatcheries. This is achieved by creating abrupt changes in water temperatures during incubation which result in a pattern of dark rings in the microstructure of the otoliths. Hatcheries use specific sequences of temperature changes to result in unique patterns for marking the otoliths of their fish. Thermal marking is useful for situations when hatchery salmon juveniles are too small for coded wire tag (CWT) applications or if a release group is particularly large and it is not practical to mark all of them. The hatchery-specific marking patterns can be used to identify the hatchery origin of adults recovered, ultimately providing information on estimates of hatchery contributions in a fishery or fish returning to the rivers, as well as on high seas distribution and migratory characteristics of Pacific salmon.

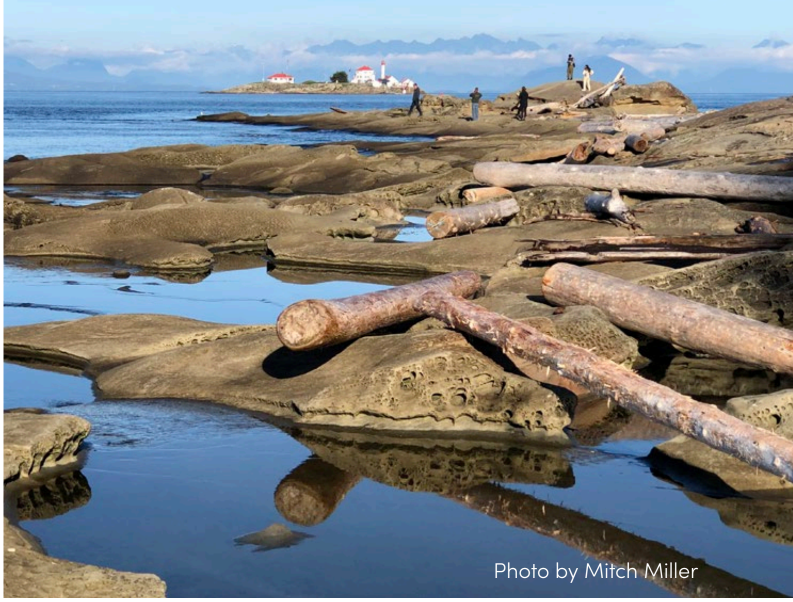

Photo by Mitch Miller

Otolith Microchemistry: Where did the fish live?

The chemical composition of each layer of an otolith depends on what was in the water around the fish at the time the calcium carbonate was laid down. Quantities of elements such as strontium and calcium can be measured from core to edge of the otolith, and the results correspond to the migration history of the fish. This means that the different parts of the otolith have a unique chemical signature that researchers can use to determine where salmon have been living over their lifetime. Also, because different river systems may contain different compositions of these chemical elements, microchemistry techniques also can be used to discriminate among stocks or even determine lake or river of origin.

CURRENT OTOLITH RESEARCH

Microchemical techniques to evaluate priority contaminant sources along the migration routes of Chinook (*Oncorhynchus tshawytscha*) and Coho Salmon (*Oncorhynchus kisutch*)

Coho and Chinook salmon of the Salish Sea have distinct migration types for their marine phase. The salmon either stay 'resident' within the Salish Sea or out-migrate to the open ocean—the continental shelf around Washington and Vancouver Island or as far as the Gulf of Alaska. The exact mechanisms and factors, whether genetic or environmental, that go into determining the migration path the salmon end up taking are unknown but this 'decision' of sorts has profound implications. Where Coho and Chinook grow out and mature influences their size, reproductive capacity as well as the contaminant burden they take on.

Ph.D. candidate, Micah Quindazzi, is seeking to better understand the implications and the factors that go into determining the migration type of a given salmon.

Photo by Eiko Jones

However, traditional methods for tracking ocean migrations are constrained by costs, methods of retrieval, and the need to individually tag the salmon. Wild salmon, particularly those of critically endangered stocks, e.g., Upper Fraser Chinook, are the most difficult to track with current methods. To overcome these problems, he is developing methods to decipher migration life history using the 'intrinsic tags' of otoliths. Specifically, Micah is looking at the elemental and isotope makeup of otoliths to determine where the salmon has been.

The first objective of his Ph.D. is to optimize and refine the microchemical otolith technique using salmon with a known migration history (Fig. 3). Previously, applying otolith analysis technology for marine migrations was challenging due to the commonly used tracer elements being too homogeneous in marine environments. Now, however, the technology's precision has improved and other elements have been identified as potential tracers by tracking differences in oceanographic processes and differences in physiological conditions experienced across regions. Baseline salmon are used as indicators of what otoliths should contain in terms of trace elements. Stable isotope values can be predicted as they follow continuous trends based on the conditions of the water column.

His results thus far using Coho show consistent trends between salmon caught in the Strait of Georgia and those caught off the West Coast of Vancouver Island (Fig. 4). By using random forest classification models, there is an 85% classification success rate between baseline salmon from these two regions. This model was then used to examine the migratory history of Coho collected from the Big Qualicum, Chilliwack, and Quinsam river systems in Southern British Columbia. Micah is now conducting a broader analysis involving Coho and Chinook salmon across the Northeast Pacific in conjunction with many governmental and international entities, such as the International Year of the Salmon.

While tracking the migrations of salmon is quite the endeavour in its own right, Micah also seeks to determine what causes the variety of marine migrations found at a population level. Specifically, he is looking at intrinsic factors, such as estuary entry time, estuary residence, and early marine growth, as well as extrinsic factors, such as broader oceanographic conditions. Micah is also investigating the contaminant burdens of Chinook returning from these various marine regions. This information will help inform the relative health risks for Southern Resident Killer Whales and humans.

Figure 3. Otoliths of 24 Coho salmon loaded into the sample tray of an LSX-213 G2+ laser ablation system for analysis of trace elements. The signature of elements in the otolith provides insights into the migration history of the Coho to help identify whether that fish stayed resident in the Strait of Georgia, or migrated to the west coast. Photo by Micah Quindazzi

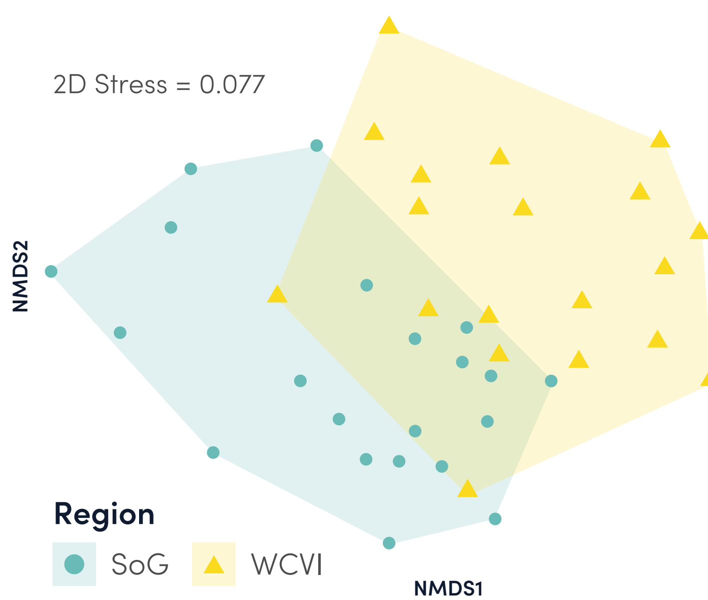

Figure 4. A cluster plot (nMDS) showing the relative difference in trace elements between baseline Coho salmon from the Strait of Georgia (blue) and the West Coast of Vancouver Island (yellow). Although there is some overlap, the classification model had an 85% classification success rate.

OTOLITH MICROCHEMISTRY-BASED IDENTIFICATION OF MIGRATION LIFE HISTORY VARIATION IN PACIFIC HERRING (*CLUPEA PALLASII*) IN THE SALISH SEA

Figure 5. Masters student Jessica Qualley fishing for non-migratory summer herring in the northern Strait of Georgia.

Pacific herring are a vital part of the food chain in the Salish Sea. In the last four decades, there have been ecosystem level changes within the Strait of Georgia that include shifts in Pacific herring spawn timing and distribution. Questions have arisen as to whether these changes could be contributing to declines in Chinook and Coho populations.

The population structure of herring in the Strait of Georgia is not well understood. Most herring in the Strait are known to migrate to the continental shelf to feed throughout the summer. However, non-migratory herring have been reported in the literature. We have also seen in recent years that adult herring make up a large proportion of Chinook salmon diets in the northern Strait of Georgia during the summer (UVic Adult Salmon Diet Program). Variation in summer herring abundance from year to year in the Strait of Georgia likely has consequences throughout the food chain — including for salmon, seabirds, and marine mammals that rely on herring as a food source. The variation in migratory behaviours and underlying causes are poorly understood. All of these uncertainties make it difficult to determine whether shifts in Pacific herring subpopulations and behaviours might be related to salmon declines, and hampers the ability to make effective evidence-based decisions for managing the Pacific herring fishery in a way that supports salmon populations.

Master's student Jessica Qualley is hoping to address these uncertainties through a cost-effective otolith analysis that she is developing. The aim is to detect and differentiate migration life history types in Pacific herring populations by measuring the elemental composition of their otoliths. Unique otolith element markers for different migration types can be used to assess the relative importance of migratory and non-migratory herring in salmon diets, their vulnerability to fisheries, and to understand why different migration strategies occur in the population.

First, by applying laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to herring otoliths she will characterize variation in migratory life history types within the population. Then, taking the paired otoliths from fish with their migration histories already determined, she will work to develop a solution-based mass spectrometry (SO-ICP-MS) method to identify "elemental tags" for alternative migration life history types. If effective, SO-ICP-MS should provide a more efficient, cost-effective indication of migration life history type for application in fishery management and enable research on factors regulating migration life history.

Jessica and her team have developed effective jigging methods for capturing non-migratory summer herring in the northern Strait of Georgia (Fig 5). Migratory herring have also been obtained through the DFO Roe Herring Test Fishery, DFO Hake Survey, and the Integrated Pelagic Ecosystem Survey. Otoliths are extracted and preserved for otolith microchemistry analysis which is currently ongoing. The next steps are to prepare otoliths for two different mass spectrometry techniques that will identify unique otolith element markers. A fine-scale approach will use laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) to quantify trace element ratios relative to calcium along transects on the otolith surface that target specific life stages. A coarse-scale approach will quantify stable isotope ratios of $^{13}C/^{12}C$ and $^{18}O/^{16}O$ of whole otoliths. Comparing the two approaches can inform future sampling protocols, analytical costs, and the capacity of otolith microchemistry techniques to answer important ecological questions.

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