**Temporal Patterns in Chinook Salmon Migration Across Western Alaska Watersheds**

**Introduction:**

Chinook salmon populations are experiencing unprecedented declines across much of their range. This trend is especially severe in Western Alaska watersheds, which contain some of the world's last pristine Chinook habitat but have seen steep declines in returning Chinook and Chum salmon in recent years. Salmon from this region support lucrative commercial fisheries, contribute billions of dollars to regional and global economies, and have historically supported subsistence harvests for dozens of communities in the region. As runs have collapsed, however, many upstream communities have voluntarily reduced or ceased subsistence fishing altogether, triggering a region-wide crisis of food insecurity, cultural loss, and the potential disappearance of a critical economic resource. As a result, resource managers face the difficult task of designing management strategies which balancing ongoing harvest opportunities with the urgent need to rebuild salmon populations and strengthen their resilience to future perturbations.

There is growing recognition of the critical role that intrapopulation variability plays in fostering resilience at the ecosystem scale in both terrestrial and aquatic ecosystems. In salmon populations, substantial variation in both return timing and spatial distribution of habitat use produces significant complexity in life history strategies within and among populations. Overall population performance in salmon ecosystems is shaped by the statistical averaging of multiple distinct, semi-independent sub-units distributed across space and time. Weak or negative covariance among these stocks helps buffer the broader population against the poor performance of any individual subunit, whose success may fluctuate in response to a dynamic mosaic of multi-dimensional environmental conditions. This “portfolio effect” dampens ecosystem variability by distributing risk across its components, much in the same way that financial diversification of a portfolio spreads investment risk across sectors to reduce overall volatility. Ecosystems composed of numerous negatively or weakly correlated “assets” are therefore better equipped to withstand both localized and system-wide disturbances, as such events may favor some components while disadvantaging others. In many salmon populations, particularly those at lower latitudes, this natural complexity has been eroded due to poor management and anthropogenic impacts on salmon ecosystems (Griffiths et al., \_). As a result, many systems now exhibit increased synchrony across subunits, leading to greater covariance in performance and generating “boom-or-bust” cycles in ecosystem productivity. This homogenization increases ecosystem vulnerability, even if aggregate return numbers appear stable or even more productive than more diversified ecosystems in the short term. Consequently, long-term resilience is better assessed by the health and viability of contributing subunits rather than by total run size alone.

Efforts to rebuild and conserve the long-term resilience of Western Alaska Chinook salmon must therefore account for this spatiotemporal complexity and design management strategies which maintain it in the long term. These include designing harvest methods which consider both overall exploitation rate as well as the timing of harvest throughout the season. Strategies that concentrate harvest in periods of peak abundance (e.g., highest CPUE per day), for example, may fail to account for whether this peak consists of a mix of vulnerable, weak stocks or a single, more robust stock that can sustain higher exploitation. Instead, management strategy should aim to allow harvest opportunities on healthy stocks while minimizing the risk of overexploitation for co-migrating weak stocks. In practice, however, implementing such stock-specific management approaches requires detailed data on the spatiotemporal ecology of salmon populations; information that has historically been limited at sufficiently fine spatial and temporal scales.

In the absence of fine-scale data on stock-specific spatial ecology in Western Alaska, management strategies have been implemented at relatively coarse spatial scales across large river basins. In the Yukon River Basin, for example, decisions are based on broad stock aggregates defined by the resolution of available genetic baselines. As a result, large portions of the watershed (e.g. Canadian-origin salmon) are managed as a single aggregate stock. This approach obscures the presence of multiple contributing sub-stocks, each of which may exhibit substantial variation in life history traits both within and across seasons (Connors et al., 2023). In contrast, the Kuskokwim River Basin employs front-end closure strategies aimed at allowing an estimated number of early-returning fish to escape before harvest begins. While this strategy supports basin-wide escapement goals, it does not account for the relative stock composition of fish protected by the closure versus those exposed to harvest afterward. Moreover, assessments of basin health are typically conducted on annual timescales and focus primarily on total returns over time. This overlooks the relative health of individual sub-stocks and shifts in their spatiotemporal distribution or contribution to the broader metapopulation portfolio. In both cases, managing based on aggregate spatial or temporal patterns risks obscuring underlying trends which may very independently from the aggregate and respond differently to environmental pressures or management actions. Here, we apply otolith-based methods to reconstruct spatiotemporal patterns of Chinook salmon natal origin distribution in the Kuskokwim River basins to: (1) identify the spatiotemporal structure of returning populations in Alaska’s most productive salmon-bearing watersheds; (2) assess how this structure varies with overall run dynamics; and (3) evaluate the potential impacts of harvest strategies, including front-end closures, on stocks across these systems.

**Methods:**

**Otolith Sample set**

Otoliths were collected over multiple years from both the Yukon and Kuskokwim River basins. Sampling was conducted continuously at the Lower Yukon Test Fishery (LYTF) near Emmonak, Alaska, and at the Bethel Test Fishery (BTF) near Bethel, Alaska. Both fisheries are designed to monitor the stock composition of returning salmon throughout the run. Otolith collections were intended to represent both the timing and abundance of fish returning across the season. Approximately 500 otoliths were collected from the Kuskokwim River between 2017 and 2021, and from the Yukon River in 2015, 2016, and 2021. From these collections, about 250 otoliths were selected for analysis to ensure coverage across the full sampling period and to provide proportional representation relative to catch per unit effort (CPUE) throughout the run

**Sample Prep and LA-ICPMS**

Otoliths were sectioned along the transverse plane, mounted on microscope slides, and polished to expose internal growth structures. Prepared samples were then sent to the University of Utah Strontium Isotope Laboratory for analysis using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Ablations were performed along a transect from the core of each otolith to just beyond the onset of marine growth, which was identified based on the presence of dark annuli. The analysis captured both strontium isotope ratios (⁸⁷Sr/⁸⁶Sr) and elemental concentrations (⁸⁸Sr), producing a continuous geochemical time series spanning early freshwater development through marine entry.

To isolate the region of the otolith corresponding to freshwater natal origin, we applied a manual selection protocol that considered several features. First, we identified a decline in ⁸⁸Sr concentrations associated with movement away from the embryonic core. Next, we used empirically derived estimates of the distance from the core to the expected natal origin region. Finally, we examined otolith morphology along the transect to identify transitions between early life stages. The resulting data were used to infer natal origin by comparing the measured ⁸⁷Sr/⁸⁶Sr values within this region to spatially explicit strontium isotope isoscapes developed for the Yukon and Kuskokwim river basins.

**Isoscapes**

**Assignment framework and priors**

**Management units and timeseries construction**

**Dynamic Factor Analysis**

**Theory**

**Model Selection**

**Spatial distribution of loading and extracted Qaurtile and loading specific timeseries**

**Results:**

**Discussion:**