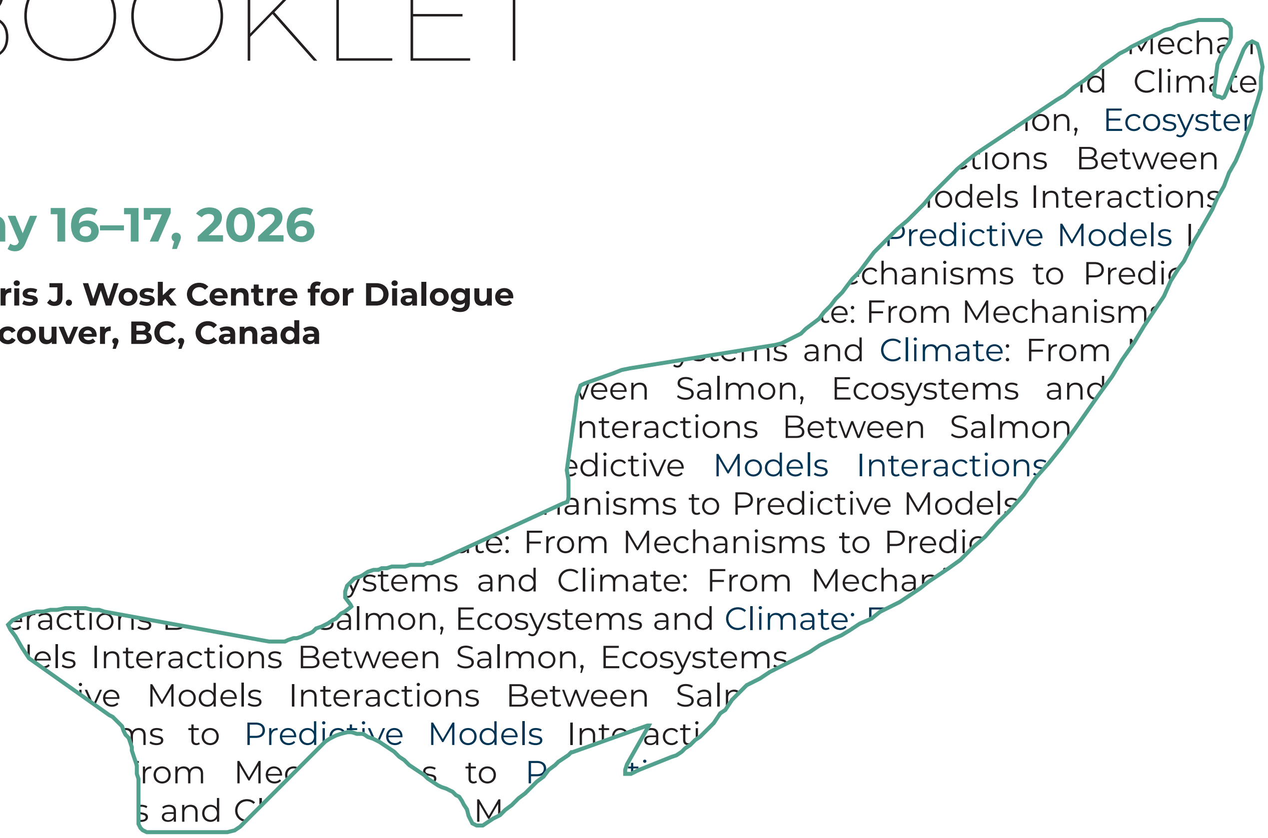
The North Pacific Anadromous Fish Commission
Hybrid Workshop:

INTERACTIONS BETWEEN SALMON, ECOSYSTEMS AND CLIMATE:

From Mechanisms to Predictive Models

PROGRAM AND ABSTRACTS BOOKLET



May 16–17, 2026

Morris J. Wosk Centre for Dialogue
Vancouver, BC, Canada

Co-sponsored by the North Pacific Marine Science Organization

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The NPAFC Workshop on

Interactions Between Salmon, Ecosystems, and Climate: From Mechanisms to Predictive Models

May 16–17, 2026

Morris J. Wosk Centre for Dialogue, Vancouver, BC, Canada

The North Pacific Anadromous Fish Commission (NPAFC) is pleased to invite you to a 2-day hybrid workshop from May 16–17, 2026, on *Interactions Between Salmon, Ecosystems, and Climate: From Mechanisms to Predictive Models*. The workshop will be held at the Morris J. Wosk Centre for Dialogue, 580 W Hastings St, Vancouver, BC, Canada, and will bring together scientists, managers, and other stakeholders to consider the current status and future of salmon and their habitats for the conservation of anadromous populations in a changing world.

Background

The North Pacific Anadromous Fish Commission (NPAFC) developed and approved the next Science Plan during the 2023 annual meeting. The 2023–2027 Science Plan builds on previous international collaborative research efforts, including work for the International Year of the Salmon. The main goal of the 2023–2027 science plan is to "Establish a research framework to develop a mechanistic understanding of the effects of a changing climate on salmon abundance and distribution trends in the North Pacific Ocean." The research objectives are as follows:

1. Improve knowledge of the relative biomass, distribution, migration, and fitness of Pacific salmon in the ocean (Present Knowledge); and
2. Understand causes and anticipate changes in the production of Pacific salmon and the marine ecosystems producing them (Forward Action).

In addition to the 2023–2027 science plan, the Basin-scale Events to Coastal Impacts (BECI) project is currently under active development (https://beci.info/about-us/), which also builds in part on achievements during the International Year of the Salmon project and has been shaped with NPAFC's interest in climate impacts on Pacific salmon. The BECI project aims to establish a North Pacific Ocean Knowledge Network that works toward integrating climate, oceanographic, ecological, biological, socioeconomic, and traditional knowledge across national and disciplinary boundaries. BECI plans to focus initially on Pacific salmon as an exemplar species, then expand to other commercially and ecologically important transboundary species. The knowledge network seeks to:

1. Connect diverse data sources on ocean conditions and climate impacts throughout the North Pacific basin;
2. Transform fragmented information into synthesized, actionable knowledge; and
3. Deliver timely, accessible insights to support climate-informed decision making.

The research priorities outlined in the NPAFC 2023–2027 Science Plan and the BECI project underscore the need for a Second NPAFC Science Workshop to synthesize findings, address mechanistic knowledge

NPAFC gaps, and optimize collaborative frameworks. Such a workshop would enable critical evaluation of progress on key objectives—including salmon biomass dynamics, climate-driven distribution shifts, and ecosystem productivity—while fostering integration across oceanographic, ecological, and fisheries datasets. By consolidating basin-scale research efforts and advancing methodological standardization, the workshop would directly enhance the North Pacific Ocean Knowledge Network, ensuring robust, interdisciplinary science to predict and mitigate climate impacts on Pacific salmon. Given the accelerating pace of environmental change, this workshop represents a necessary step toward refining hypotheses, aligning international research agendas, and strengthening the empirical foundation for sustainable management.

Workshop Objectives

- Advance mechanistic understanding of climate-driven changes in Pacific salmon abundance and distribution.
- Improve synthesis and interoperability of multidisciplinary data for the North Pacific Ocean Knowledge Network.
- Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios.

Topic Sessions

Topic 1. Linking climate-ocean variability to salmon population dynamics
Moderator: TBA

Outcome: The relative contributions of natural environmental variability and anthropogenic factors on Pacific salmon distribution and abundance are quantified and integrated into predictive models for future habitat and productivity shifts.

There are multiple and complex reactions of Pacific salmon populations across the North Pacific to environmental changes: shifts in marine carrying capacity and thermal habitats, seasonal redistribution (including potential Arctic expansion), and increasingly extreme interannual fluctuations in run strength. These changes reflect both direct climate impacts (e.g., ocean warming, altered prey fields) and cumulative anthropogenic stressors. Recent events—including record-high and record-low returns of key stocks occurring in adjacent years—highlight the urgent need to: (1) identify threshold mechanisms driving high-amplitude variability; (2) disentangle climate signals from intrinsic population dynamics, (3) develop models that can project both gradual trends and extreme fluctuations. Understanding these dynamics will improve forecasts of economic and ecological risks, particularly for fisheries facing increasingly unpredictable interannual variability.

1-1. Mechanisms Behind Shifting Salmon Distributions
1-2. Decoding Extreme Population Fluctuations
1-3. Next-Generation Modeling Approaches
1-4. Summary and discussion

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)
Moderator: TBA

Outcome: Agreement on core metadata standards and interoperability protocols for sharing oceanographic, ecological, and fisheries datasets is achieved.

Pacific salmon research and management depend on diverse datasets, including oceanographic conditions, ecosystem indicators, and fisheries-dependent/independent data. However, these datasets often exist in disparate formats, with inconsistent metadata, spatial/temporal resolutions, and access protocols. This fragmentation hinders the ability to (a) conduct comprehensive, basin-scale analyses of climate-salmon interactions, (b) validate mechanistic models linking environmental change to salmon productivity, and (c) support timely, science-based decision-making under climate uncertainty. Developing robust techniques to collate historical datasets, standardize modern data collection methods, and demonstrate successful multi-dataset integration through case studies is essential to overcome fragmentation, maximize the value of existing data, and build a unified knowledge base for addressing climate-driven challenges in Pacific salmon conservation and management.

2-1. Overcoming Data Fragmentation: Standardization Needs
- Critical gaps in metadata
- Case studies of successful harmonization
- Prioritizing FAIR (Findable, Accessible, Interoperable, Reusable) principles for NPAFC datasets

2-2. Emerging Tools for Unified Data Synthesis
- Standardizing genetic baselines
- Platforms for real-time data sharing

2-3. Summary and discussion

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios
Moderator: TBA

Outcome: A prioritized list of critical knowledge gaps and practical solutions to address them, including thresholds for salmon resilience, key uncertainties in forecasting models, recommended strategies.

Despite decades of extensive research by NPAFC countries, critical uncertainties persist regarding Pacific salmon dynamics, including whether winter constitutes a survival bottleneck, the drivers behind declining age-at-maturity and body size (environmental stress vs. evolutionary adaptation), and the extent of inter/intraspecific competition in changing ecosystems. These unresolved questions stem from contradictory hypotheses, monitoring gaps (particularly in winter), and inconsistent evidence across studies, hampering science-based management decisions. This workshop will prioritize these knowledge gaps and develop targeted research strategies—including experimental studies, synthetic data analyses, and emerging technologies—to transform speculation into evidence-based thresholds for conservation and fisheries management, ensuring NPAFC's science can address these pressing challenges in a rapidly changing North Pacific.

Oral Presenters

Please have your presentation saved on a USB memory stick and give it to the Secretariat when you arrive to register at the workshop. Please see the following schedule so the Secretariat can have your presentation saved on the presentation computer well in advance of the session.

If you have not submitted your presentation when you pick up your registration materials at the registration desk at the workshop, **the latest time to submit your oral presentation to the Secretariat is the following:**

If your presentation time is	Bring your presentation to the Secretariat by
May 16 (Saturday) a.m. (morning)	May 16 (Saturday) **between** 9:30–10:30
May 16 (Saturday) p.m. (afternoon)	May 16 (Saturday) **by** 13:40
May 17 (Sunday) a.m. (morning)	May 17 (Sunday) **by** 10:30
May 17 (Sunday) p.m. (afternoon)	May 17 (Sunday) **by** 13:40

Virtual Presenters

Please submit your presentation to the NPAFC Secretariat by 16:30, May 13, 2026 (Vancouver time). During the workshop the NPAFC Secretariat will be actively communicating with you prior to your presentation.

Poster Presenters

Posters should be delivered to the registration desk on Saturday, May 16, between 09:30–10:30. Posters should be removed on Sunday, May 17, by 18:00. Posters not removed by 18:00 may be discarded.

Tentative Program

(*Subject to change without notice*)

**Presenter*

May 16 (Saturday) Oral Presentations

May 17 (Sunday) Oral Presentations

Topic 2. Data Integration Frameworks: Harmonizing Oceanographic, Ecological, and Fisheries Datasets (Tools, Standards, and Case Studies for Cross-disciplinary Synthesis)
(Moderator: Jackie King)

POSTER SESSION

(*Subject to change without notice*)

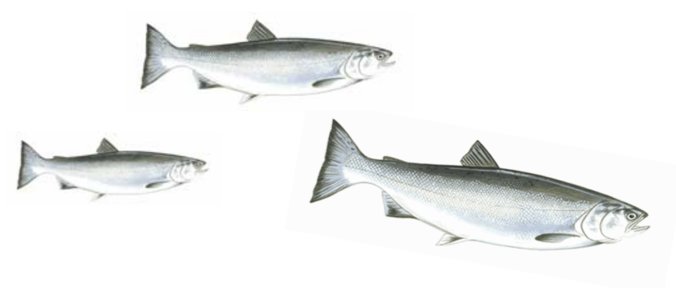
**Presenter*

Topic 1. Linking Climate-Ocean Variability to Salmon Population Dynamics

Topic 2. Data Integration Frameworks: Harmonizing Oceanographic, Ecological, and Fisheries Datasets (Tools, Standards, and Case Studies for Cross-disciplinary Synthesis)

<u>Topic 3. Identify Critical Knowledge Gaps and Prioritize Research to Forecast Salmon Responses Under Future Climate Scenarios</u>

Oral Presentations



Oral Presentation-1

Topic 1. Linking climate-ocean variability to salmon population dynamics

Cumulative Stressors and Climate-driven Variability and Shape Upper Fraser River Chinook Salmon Dynamics

Eric Hertz[1], Rachel Chudow[2], Todd Hatfield[2], Jane Healey[1], Jason Hwang[1], Jane Pendray[1], Gord Sterritt[3], Linda Stevens[3], and Eric Vogt[2]*

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[2]*Ecofish Research, 250 Dogwood, Suite 202, Campbell River, British Columbia V9W 2X9*
[3]*Upper Fraser Fisheries Conservation Alliance, 298A Mission Road Williams Lake, BC V2G 5K9*

Pacific salmon populations across the North Pacific have experienced pronounced declines, heightened interannual variability, and increasingly asynchronous responses to climate forcing, particularly among interior, stream-type Chinook Salmon. Middle and Upper Fraser River Spring 5-2 Chinook Salmon (Designatable Units 9 and 11) exemplify these dynamics. These populations undertake long freshwater migrations, rear extensively in freshwater, and migrate early into marine environments, exposing them to multiple climate-sensitive bottlenecks across their life cycle. Here, we present a basin-informed, life cycle–based assessment that integrates population trends, environmental change, and cumulative anthropogenic stressors to identify mechanistic drivers of decline and extreme population fluctuations.

Using a structured recovery-planning framework, we synthesized population status data, life-history characteristics, and freshwater, estuarine, and marine environmental settings, alongside a comprehensive inventory of threats spanning natal watersheds, the Fraser River mainstem, the estuary, and offshore marine environments. A two-step risk assessment evaluated threats across life stages and environments and then integrated results at the Designatable Unit level to identify stressors most closely aligned with observed long-term declines and high-amplitude variability in adult returns. This approach explicitly links mechanisms of impact—such as altered thermal regimes, changes in prey availability and competition, predation pressure, disease dynamics, and fisheries interactions—to life-stage-specific sensitivity.

Results indicate that declines in Upper Fraser Spring 5-2 Chinook Salmon are not driven by isolated freshwater impacts or single stressors, but instead reflect cumulative effects interacting with climate-driven changes in marine survival. Stream-type life histories appear particularly vulnerable to climate-mediated shifts in marine productivity and phenology, which amplify survival bottlenecks established earlier in freshwater. These interactions likely contribute to increasingly extreme year-to-year fluctuations in returns, consistent with coastwide patterns of reduced portfolio effects, declining age diversity, and heightened sensitivity to environmental variability.

By transforming fragmented biological and environmental information into an integrated, mechanistic understanding of population dynamics, this work directly supports NPAFC objectives to synthesize basin-scale knowledge, identify critical drivers of salmon abundance and variability, and inform climate-responsive management. The framework is transferable to other

salmon populations and provides a practical pathway for linking climate-ecosystem interactions to population-level outcomes under accelerating environmental change.

Oral Presentation-2

Topic Session 1. Linking climate-ocean variability to salmon population dynamics

A Hierarchical Lifecycle Model Quantifies the Effects of Environmental Variables on Sockeye Salmon Productivity

Jan F. Finke, Travis Tai, Cameron Freshwater, Brendan Connors, Amber M. Holdsworth, Greig Oldford, Howard Stiff, Dan Selbie and Patrick L. Thompson*

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Many Sockeye Salmon (*Oncorhynchus nerka*) populations in British Columbia have declined over recent decades. Climate change driven increases in temperatures and associated changes in marine mixing regimes, freshwater hydrology, and related ecosystem impacts are main factors of these declines. Although the impacts of climate change are widespread, the response to the associated environmental changes are likely to vary among regions and populations. Therefore, a population specific and quantitative understanding of climate change driven impacts is needed for adaptive management strategies.

To address this need we build a model of multiple sockeye salmon populations from diverse regions, and corresponding environmental variables. The model was build in a hierarchical lifecycle framework using smolt, return and spawner abundances, and freshwater and marine variables. This model structure enabled us to quantify population and variable specific functional responses. The coefficients for each variable and population pairing highlighted individual effects, and were combined to project the productivity of each population under future climate change scenarios.

All populations are strongly affected at some stage in their lifecycle, but the key variables and their effect size vary across populations and regions, often displaying a south to north gradient. Key environmental variables are freshwater and marine temperatures, coastal mixed layer depth and river discharge. Increases in temperatures and mixed layer depth generally have negative effects while increases in river discharge tend to have positive effects on populations' productivities. The combined effects of variables under future climate change scenarios result in substantial declines of all populations. This work produced population specific quantitative effects of environmental variables and projected productivities of individual populations under future climate change scenarios, informing adaptive management strategies.

Oral Presentation-3

Topic Session 1. Linking climate-ocean variability to salmon population dynamics

Quantifying Environmental and Climate Drivers of Fry-to-adult Survival in Okanagan Sockeye Salmon Using a Causal-inference Framework

Patrick L. Thompson, Howard Stiff, and Athena Ogden*

*Pacific Science Enterprise Centre, Fisheries and Oceans Canada, 4160 Marine Dr. West Vancouver, V7V 1H2, Canada (*Email: patrick.thompson@dfo-mpo.gc.ca)*

The recovery of Okanagan sockeye salmon since the late 1990s represents a notable success story at a time when salmon populations are threatened by ongoing climate change. Although improvements in survival are attributed to management actions targeting freshwater life stages and to favourable marine conditions, these causal links have not been formally quantified.

Here, we present an age structured model of fry to adult survival (to the mouth of the Columbia River) to evaluate the influence of environmental conditions encountered during downstream migration through the Columbia River and in both early and later marine life stages. The model uses a Bayesian joint-likelihood causal-inference framework, in which we explicitly model the causal relationships among environmental drivers that are themselves influenced by shared regional climate conditions. This structure allows us to estimate the direct and indirect pathways through which individual environmental factors affect survival. Our model indicates that the strongest drivers of survival are 1) the abundance of northern copepods during the early marine period, 2) temperatures experienced during this same period, and 3) fry length prior to outmigration.

We estimate that warm early-marine conditions reduce survival both directly and indirectly by suppressing northern copepod availability, highlighting a pathway linking climate-driven warming, shifts in prey availability, and the resulting changes in survival. Together, these results suggest that the early marine phase is particularly sensitive to climate-driven warming, and could represent a key bottleneck for Okanagan sockeye under future conditions. This analytical framework also supports forecasting of marine survival and return abundance under varying environmental conditions, providing a basis for incorporating environmental and ecological processes in management planning.

Oral Presentation-4

Topic 1. Linking climate-ocean variability to salmon population dynamics

Weakening of the Cold Oyashio Current Intrusion Causes Low Early Growth Rate and Poor Adult Return of Chum Salmon Along the Northeastern Coast of Honshu, Japan

*Miwa Yatsuya**

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The abundance of chum salmon in the Honshu area has sharply declined, especially over the past 15 years. In this study, I examined the impact of the coastal environment on the growth and adult return of chum salmon in the Honshu area by analyzing scale circulus distance, an index of growth rate previously used in studies of salmon. Scale samples were collected from age-4 female chum salmon caught with a weir in the Sakari River in Iwate Prefecture on the northeastern coast of Honshu, Japan, from 2003 to 2023. I measured the spacing of each circulus on the scales and calculated the distances from the focus to the fifth circulus and between the 5th and 10th circuli (5–10CW). I also calculated the distances between the 10th and 15th and the 15th and 20th circuli, as well as the distance from the focus to the first annulus. I analyzed the correlations between coastal environmental factors, such as sea surface temperature and the southernmost latitude of the cold Oyashio intrusion in spring, and circulus width and the number of age-4 adult chum salmon that returned to the Sakari River.

The results revealed a significant negative correlation between the southernmost latitude of the spring Oyashio water intrusion and the 5–10CW circulus distance for the corresponding year class inhabiting the coastal environment. Furthermore, the 5–10CW distance and the number of returning age-4 adults of the corresponding year class in the Sakari River showed a positive correlation. These findings suggest that a weak Oyashio southward intrusion leads to low early growth rate of chum salmon and fewer adult returns of the corresponding year class.

The biomass of cold-water zooplankton, which are nutrient-rich and suitable prey for salmon, has been reported to decline when the Oyashio intrusion is weak. Additionally, it is known that the metabolic energy consumption of chum salmon increases when ambient water temperature is high. Previous studies have also shown that chum salmon juveniles with low early growth rates experience high mortality during their northward coastal migration. Thus, I hypothesize that the weakened cold Oyashio intrusion in spring in this study caused high water temperatures and low early growth rates in chum salmon, likely due to low food availability and high energy consumption. I consider this to have led to high mortality in the coastal area and poor adult return of the year class.

Oral Presentation-5

Topic 1. Linking climate-ocean variability to salmon population dynamics

The Vertical Distribution of Juvenile and Subadult Chinook Salmon in Coastal British Columbia

Wesley Greentree[1,2], Will Duguid[2], Nick Bohlender[3], Cameron Freshwater[4], Katie Innes[2], Bridget Maher[1], Jamieson Atkinson[5], Samantha James[2], and Francis Juanes[1]*

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[2]*Pacific Salmon Foundation, 1385 W 8th Ave #320, Vancouver, BC, V6H 3V9, Canada*
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The vertical distribution of Pacific salmon reflects complex trade-offs between growth, predation risk, and physiological constraints. Additionally, environmental gradients experienced by salmon at sea tend to be stronger vertically than horizontally. Therefore, understanding the vertical distribution of salmon in the ocean can provide insights into behaviour, ecological interactions, and environmental conditions. In the northern Strait of Georgia, we tagged 28 first ocean winter Chinook salmon (*Oncorhynchus tshawytscha*) with depth-sensing acoustic transmitters. Genetic analysis indicated that most individuals were hatchery-origin and from the Qualicum-Puntledge fall population on the east coast of Vancouver Island. Between October 2023 and January 2026, tagged salmon were detected more than 60,000 times by acoustic receiver arrays, which were concentrated in the northern Strait of Georgia and Discovery Islands. Chinook salmon were consistently found between the surface and 75 metres deep during the first ocean winter. In the second ocean spring, likely coincident with high turbidity caused by phytoplankton blooms, Chinook salmon were often closer to the surface. In the second ocean winter, Chinook salmon were detected up to 225 metres deep in the offshore region of the northern Strait of Georgia, where they aggregate with Pacific hake (*Merluccius productus*). As in the second ocean spring, Chinook salmon returned closer to the surface in the third ocean spring. We compared high-resolution data from this small number of tagged individuals to depth-specific catch-per-unit-effort of Chinook salmon in microtrolling surveys in the northern Strait of Georgia, Discovery Islands, and southern Gulf Islands. Seasonal shifts in vertical distributions influence Chinook salmon catchability in scientific surveys and bycatch rates in fisheries, meaning that further study is warranted.

Oral Presentation-6

Topic 1. Linking climate-ocean variability to salmon population dynamics

A Paradigm Lost? The PDO, Growth and Survival of Juvenile Salmon in the NCC

Brian Beckman[1], Cheryl Morgan[1] and Brian Burke[2]*

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[2] *NWFSC, National Marine Fisheries Service, Seattle, WA (*email: beckmabr@oregonstate.edu)*

The Pacific Decadal Oscillation (PDO) represents an index of sea surface temperature variation across the North Pacific Ocean. Variation in the PDO has been found to correlate with variation in the survival of a wide variety of salmon populations across the NE Pacific, including fish originating from the Columbia River in the northwestern US. A primary paradigm for the regulation of salmon survival is that variation in the PDO is related to variation in salmon food, feeding and growth and that salmon growth is directly related to juvenile salmon survival during early marine residence. Thus, the correlation between the PDO and salmon survival has generated the mechanistic hypothesis that variation in growth causes variation in survival. We have assessed growth of juvenile coho and interior Columbia River spring (ICRS) Chinook salmon in the Northern California Current since 2000 to test this hypothesis. Mean insulin-like growth factor 1 (IGF1) levels (an indicator of growth) differed significantly over succeeding decadal intervals (2000–2009 vs. 2011–2022) for both stocks of salmon. IGF1 levels post-2010 were consistently higher than found pre-2010. There are no regional nor basin-scale oceanographic processes that relate to this increase in growth. Across the time series, IGF1 levels were correlated with an index of zooplankton abundance, suggesting that juvenile salmon growth is related to lower trophic level processes. However, across this same time series there is little to no correlation of IGF1 levels to either coho or ICRS Chinook salmon survival (SARs). In addition, the highest IGF1 levels measured in the time series were during the 2016 El Nino, a year where PDO levels would suggest low growth would have occurred. These results directly challenge the growth and survival hypothesis. Nevertheless, over this same time period, the significant correlation between the PDO and salmon survival was maintained. So, while we found no support for the proposed mechanism (growth), the under-lying correlation between the PDO and marine survival remains. We will re-assess and compare previous studies of growth and survival in the NE Pacific to our results to ascertain whether our results are spurious or whether our results reflect a general break-down in previously established correlations.

Oral Presentation-7

Topic 1. Linking climate-ocean variability to salmon population dynamics

Does Anadromy Increase the Vulnerability of Salmonids to Extreme Events?

Wesley Greentree[1,2] and Jake Dingwall[1,2]*

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Migratory animals move between distinct environments to optimize different parts of their life cycle. Over many generations, migratory animals can follow shifting environmental conditions, supporting population persistence. However, the dependence of migratory animals on multiple habitats may increase their vulnerability to unpredictable events, such as extreme weather events or human alteration of ecosystems. Migratory diversity among and within species of the family Salmonidae (salmon, trout, char, and whitefish) provides a unique opportunity to develop and test competing hypotheses of how long-distance migrations influence population-level vulnerability to extreme events within generations. Across more than a dozen species, we compiled adult abundance time series (minimum 20 years) of more than 1000 salmonid populations that are anadromous or freshwater-resident. With this novel dataset spanning 1930 to 2025, we identified extreme changes in annual adult abundance, defined as an increase or decrease in abundance greater than five times the previous year. We tested if anadromy increases (additive risk hypothesis) or decreases (spatial buffering hypothesis) the vulnerability of salmonid populations to extreme changes in abundance. Preliminary analysis indicated that extreme changes in abundance were more common in anadromous populations and in recent decades. Case studies of extreme fluctuations in the abundance of North Pacific anadromous salmonids were examined and qualitatively compared to both freshwater and marine conditions.

Oral Presentation-8

Topic 1. Linking climate-ocean variability to salmon population dynamics

Thermal Conditions Control Size of East Kamchatka Pink Salmon Stock

Andrei S. Krovnin, Albina Kanzeparova, Aleksandra Sumkina, and Georgii Muryi*

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East Kamchatka (EK) pink salmon form one of the largest Pacific salmon stocks with a predominance of odd-year generations. Over the last 55 years, their catches have showed considerable variations both in odd and even years, from 18,830 tons in 1971 to 227,232 tons in 2019 and from 1,970 tons in 1972 to 111,261 tons in 2018, respectively. This is obviously associated with variability of climatic and, first of all, thermal conditions at various stages of the marine period of pink salmon life. To identify the connections between the thermal state of surface water and catches of pink salmon as characteristics of the stock state, the first three EOFs of sea surface temperature anomaly (SSTA) field in the North Pacific region from 45° to 65°N were calculated for each month of year. They explain about 71 % of total variance. It was obtained that the catch time series in odd and even years correlate best (positively) with the first principal component (PC1) that characterizes the thermal background in the surface layer of the whole region under consideration. The results of the pair correlations between PC1 and catches in each of the months from May of year of downstream migration to August of spawning (catch) year indicated that thermal conditions during the downstream migration of fish and their early feeding period in the sea had a rather large effect on the state of the pink salmon stock (catch) ($r = 0.56 \div 0.62$). The maximum correlation coefficient, equal to 0.65, was noted in October of year of downstream migration, when pink salmon migrated from the sea to the ocean. Thus, it can be assumed that SST was one of the critical factors for survival of pink salmon on their way from the Bering Sea to the North Pacific. During the wintering period, the first mode of SSTA variability had much smaller impact on the EK pink salmon stock, especially in odd years. By the beginning of the summer season of catch year, the relationship between the PC1 and catch anomalies increased again up to 0.60, indicating the influence of the Bering Sea surface temperature on the success of spawning migrations and rate of pink salmon approaches to the coast of Northeast Kamchatka. Possible causes of large differences between expected and actual catches of EK pink salmon in odd 2013 and 2017 and even 2014, 2018 and 2020 were considered. It was shown that the differences observed may be associated with formation of short-term marine heat/cold waves on the spawning migration routes of pink salmon.

Oral Presentation-9

Topic 1. Linking climate-ocean variability to salmon population dynamics

Shifting Stage-specific Constraints on Productivity Shape Recovery Potential for Yukon River Chinook Salmon

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Identifying key life history periods in which population productivity is constrained represents a persistent challenge in conservation and natural resource management. For species with complex life cycles, such as Pacific salmon (Oncorhynchus spp.), population dynamics may be shaped by interactions between natural and anthropogenic impacts occurring across multiple habitats and life history stages. In such cases, a stage-structured modeling approach is useful for identifying key life history periods and processes therein acting to drive realized abundance trends. Here, we develop an integrated life cycle model to explore stage-specific constraints on population productivity and recovery potential for Yukon River Chinook salmon. The Yukon River has historically supported one of the largest stock complexes of Chinook salmon in the world, forming the basis of important fisheries that are vital to the wellbeing of communities in this region. However, returns of Chinook salmon to the Yukon River have declined substantially, prompting conservation concerns and limitations on harvest opportunities. Our results point to periods of low juvenile recruitment as likely contributors to declining abundance levels over the past two decades, supporting previous studies implicating factors operating in the early (i.e., spawner-to-juvenile) life history stages. However, we find that elevated post-juvenile natural mortality following a protracted marine heatwave period has increasingly limited population productivity and recovery potential in recent years. Collectively, our results emphasize how shifting conditions can induce novel stage-specific survival bottlenecks in species with complex life cycles, with important implications for conservation and management outcomes.

Oral Presentation-10

Topic 1. Linking climate-ocean variability to salmon population dynamics

Pink Salmon Adaptation to the Warming Climate: Smaller but Stronger?

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Pink salmon continue to predominate in Pacific salmon run reaching 79.6% from total salmon numbers in the commercial catches in 2023. In the North Pacific pelagic fish community, pink salmon is considered as a successful competitor that is well adapted to the climate warming and resilient to heat waves. Pink salmon follow a general trend towards decrease of mature fish size that is observed for other salmon species. Hypothesized explanations include selectivity of fishery towards bigger fish, hatchery propagation effects, food competition, and higher energy spending to respiration compared to growth in the warmer ambient environment.

We have analyzed the size-decrease trend by regional groupings and odd- and even-year broodlines. Despite the odd-year broodline demonstrates well-expressed positive trend in abundance and the even-year broodline shows a stable level of stocks, the size-decrease trend is rather evident in both data sets. Slope of size decrease is 1.3 times steeper in the odd-year broodline. The most expressed size-decrease trend is observed in British Columbia before 2013, when it was changed to increase in small catches.

Average fish size also grows in even-year broodline in Russia in even years after 2018 (year of the record catch) while it continues to decrease in the odd-year broodline. Pink salmon juveniles' survival rates have a moderate positive correlation with the SST anomalies in areas of oceanward migrations. Pink salmon wintering and feeding grounds in Pacific Ocean do not shift northwards. Pink salmon does not form highly productive stocks in the Arctic despite it migrated there since the current century beginning. Some southern pink salmon stocks shows relatively good pink salmon returns like in the Primorie region in Russia in 2023. It could be concluded that pink salmon adaptations are mostly directed to providing better survival in the current range than to its expansion.

Oral Presentation-11

Topic 1. Linking climate-ocean variability to salmon population dynamics

The Century-long Dynamics of Stocks and Average Body Weight of Pacific Salmon in the Russian Far East through the Prism of Climate Cycles and Trends

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The complex pattern of variations in the thermal characteristics of the environment surrounding Pacific salmon, including the linear positive trend and periodic changes for a 80-year cycle, has been elucidated. A positive relationship was found between the dynamics of pink, chum, and sockeye salmon harvest and the general vector of variations in the temperature background. The full cycle periods in the population dynamics of pink, chum, sockeye, coho, and Chinook salmon are expected to also last about 80 years, while the cycles of pink, chum, and sockeye salmon are synchronized with temperature extrema. The dynamics of Chinook salmon catches occur in antiphase to those of pink, chum, and sockeye salmon. The extrema for coho salmon abundance are shifted 20–25 years ahead of the extrema for pink, chum, and sockeye salmon and are approximately 15 years ahead of the extrema for Chinook salmon. It is assumed that the maximum of average catches of the common Pacific salmon species (pink, chum, and sockeye salmon) in the current cycle already passed by the early 2020s.The reduction in average catches of Russian Pacific salmon may last until the 2050s, will be higher than the previous minimum, and will reach the level of average annual catches of approximately 250000 t. During the 70–100-year warming period, as confirmed by ichthyological studies, Chinook salmon has “lost” up to 60% of the average body weight of individuals, while chum, sockeye, and coho salmon have lost up to 25–30%. The average body weight of pink salmon depends on the abundance of individuals feeding together, especially in years when extra-strong year-classes are formed, rather than on variations in ambient temperature.

Oral Presentation-12

Topic 1. Linking climate-ocean variability to salmon population dynamics

Juvenile Salmon Surveys Provide Insight into Early Marine Ecology and Valuable Tools for Forecasting Adult Returns

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In Alaska, multiple marine research surveys have been established to sample salmon during their juvenile life stage (first summer at sea) to learn about their abundance, distribution, and early marine ecology. The juvenile life stage is a critical time in a salmon's life history: juvenile salmon need to grow quickly to avoid predation and store enough energy for their first winter at sea. Two long-running (>20 years) juvenile salmon surveys in Alaska occur in the northeastern Bering Sea (NBS) and in southeastern Alaska (SECM). These surveys use surface trawl gear to sample juvenile salmon, oceanographic equipment to measure the temperature and salinity of the water column, and bongo nets to sample zooplankton. The NBS survey primarily focuses on Chinook salmon from the Yukon River while SECM targets pink salmon from southeast Alaska. The long-term operation of these surveys has given us the ability to quantify the strong, positive relationship between juvenile abundance and future adult returns, and to develop adult run size forecasting tools These forecasts help fishery managers and stakeholders anticipate and plan for future run sizes in their region. Biological samples (e.g., genetics, stomach contents, muscle samples for energy density) are collected during surveys and provide an understanding of salmon health and how temperature affects condition. From the NBS survey, we have learned that temperature affects the diet and energy density of juvenile salmon, but the magnitude is species-specific. In the SECM survey, we have found temperature, prey quality, species density, and species-specific habitat use shape early marine survival. Based on the success of these two long-standing surveys, two new juvenile salmon surveys have been established in Alaska: in the western Gulf of Alaska and southeastern Bering Sea. These new surveys are in their second year of operation. Goals for the suite of marine juvenile salmon surveys in Alaska are to 1) build an understanding of the early marine ecology of salmon species across our multiple large marine ecosystems, 2) develop forecasting tools to aid in fisheries management, and 3) contribute to a whole life cycle understanding of the factors driving salmon population dynamics and how those may be changing.Oral Presentation-12

Oral Presentation-13

Topic 1. Linking climate-ocean variability to salmon population dynamics

Integrating Salmonid Thermal Niches into Subarctic Pacific Ecosystem Models Improves Hindcast Simulation Performance

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The pelagic phase of Pacific salmonids (Oncorhynchus spp.) life cycles, which is spent in open subarctic waters, is crucial to the growth and survival of these species. In the past two decades, both long-term warming and shorter-term marine heatwaves have occurred in the open subarctic Pacific. These could adversely impact salmonids both directly (i.e. through physiological stress due to temperatures exceeding thermal optima) and indirectly (i.e. via altered composition and/or reduced biomass of prey zooplankton and micronekton). Understanding these impacts of climate change and variability on salmon is of crucial importance to NPAFC member states. This paper integrates salmonid thermal niches and sea surface temperature (SST) time series into hindcast simulations of pelagic ecosystem dynamics. These were conducted in mass-balanced models of the open eastern and western subarctic Pacific ecosystems constructed in Ecopath with Ecosim. Thermal preference curves for anadromous Pacific salmonid groups (i.e. sockeye, even– and odd-year pink, chum, coho, and Chinook salmon plus steelhead trout), based on data from the International Pacific Salmon Data Legacy Database, were introduced into the ecosystem models to provide scaling coefficients reducing fish foraging efficiency as SSTs departed from thermal optima. SST time series (1990–2021), obtained from the U.S. NASA HadISST program for the eastern and western subarctic Pacific, were employed to drive the scaling of salmonid foraging efficiencies in dynamic ecosystem simulations according to the specified thermal preferences. These simulations revealed the importance of temperature, combined with top-down and bottom-up trophic impacts, in driving salmon population and ecosystem dynamics in the open subarctic Pacific. Scaling of salmonid foraging efficiency to thermal preferences using the SST time series improved fits to salmonid biomass and catch time series in hindcast simulations, with greater improvement observed in the eastern subarctic ecosystem model than in its western counterpart. Trends in climatic indices (e.g. PDO and NPGO) and/or physical oceanographic variables (north-south current speed), all correlated with SST, were associated with primary production anomaly patterns reconstructed in the hindcast simulations. These findings reveal the value of integrated simulations of climatic and trophic impacts on the pelagic phase of Pacific salmonid life cycles. They also highlight the potential for projection of such impacts under future climate scenarios.

Oral Presentation-14

Topic Session 1. Linking climate-ocean variability to salmon population dynamics

SalmonMSE: A Decision-support Tool for Pacific Salmon Accounting for Climate-ocean Variability

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Risk-based decision support tools are needed for Pacific salmon to inform sustainable management. In Canada, management is expected to account for the biology of the fish and environmental conditions affecting the stock. salmonMSE is a stochastic, closed-loop simulation tool based on ‘management strategy evaluation’ (MSE) using a life-cycle based model that can incorporate oceanographic drivers and biological realism of salmon populations impacted by harvest, hatchery and habitat management levers. salmonMSE is adaptable to different salmon species, with varying biological characteristics, data availabilities and management contexts. Here, we present two case studies that provide risk-based advice on the impacts of harvest, hatchery, and habitat management strategies given hypotheses about underlying environmental drivers: Upper Straight of Georgia Chinook and Westcoast Vancouver (WCVI) Island Chinook. Upper Strait of Georgia Chinook are exposed to mixed-stock fisheries and are subject to hatchery enhancement and habitat restoration. Productivity of this stock is impacted by ocean conditions especially during a bottle neck in survival during the fist year of marine life. The model was fit to available spawner time-series, hatchery releases, (coded wire) tagging data, and sea-surface temperatures as a proxy for nearshore ocean conditions. Projections are expanded to include hypotheses about future ocean conditions, and scenarios for harvest and hatchery production. Our case study on WCVI Chinook further accounts for life-history diversity within the populations (early and late maturing fish with different marine survival rates), and environmental drivers of freshwater survival. Based on these case studies, we demonstrate how management scenarios can be evaluated under various assumptions about the biology of the fish and ecosystem drivers of stock dynamics, to inform assessment advice accounting for ocean-climate variability.

Oral Presentation-15 (Virtual)

Topic 1. Linking climate-ocean variability to salmon population dynamics

Ocean Age-2 Temperature Influences Cumulative Maturation Schedules: A Comparison of Beta GLMM and Bayesian Hierarchical Approaches

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Age-at-maturation schedules integrate early marine growth conditions and are a key determinant of run size and age composition in Chinook salmon. However, maturation proportions are bounded (0–1), frequently clustered near extremes, and structured by brood year, violating assumptions of Gaussian linear models. We modeled cumulative maturation proportions at Ages 4–6 for Canadian-origin brood years 1984–2015 using a beta generalized linear mixed model (GLMM) with logit link and random brood-year intercept. Satellite-derived sea surface temperature (OISST) during ocean age-2 was included to test sensitivity during a critical marine period.

The GLMM demonstrated strong age structure (Age.L = 4.06 ± 0.10 SE; Age.Q = 0.36 ± 0.06 SE; $p < 0.001$) and a positive, highly significant association between SST and cumulative maturation ($\beta = 0.415 \pm 0.062$ SE; $z = 6.68$; $p < 0.001$). Brood-level random intercept variance (0.072; SD = 0.27) captured residual cohort variability. Simulation-based residual diagnostics detected no significant dispersion, uniformity, or zero-inflation issues, supporting the beta error structure.

A parallel Bayesian hierarchical beta model produced nearly identical parameter estimates ($\beta\_SST = 0.41$; 95% credible interval: 0.28–0.55), well-mixed chains (Rhat = 1.00), and minimal sensitivity to prior scaling. Posterior predictive checks closely matched observed maturation patterns. The concordance between inference frameworks indicates that results are driven by data structure rather than modeling philosophy.

Forward projections for brood years 2016–2020 using observed SST conditions show elevated maturation probabilities in warmer years, particularly at younger maturation ages, consistent with temperature-mediated shifts in growth trajectories. By explicitly modeling bounded proportions, cohort structure, and climate covariates within a hierarchical framework, this approach provides an uncertainty-aware tool for forecasting age composition under continued North Pacific warming. Integrating juvenile abundance, survival, and temperature-informed maturation probabilities strengthens run-size projections and climate attribution for Canadian-origin stocks.

Oral Presentation-16

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

Capabilities Required from a Digital Twin of a Salmon's Life

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Introduction

Digital twins for watersheds and oceans are increasingly used to improve understanding, forecasting, and management of aquatic systems. These systems typically combine (a) models driven by historical data to explore counterfactual "what-if" scenarios and inform strategic planning, and (b) near-real-time data streams to track system states and support tactical decision-making during emergent events. A recent extension of this approach is the integration of artificial intelligence, enabling digital twins to learn from heterogeneous data sources and model outputs.

Problem

We examine the potential development and application of digital twins for threatened and priority salmon populations, linking novel biological and environmental models with multiple catchment-scale digital networks to enhance management and scenario-testing capacity. Deferring discussion about the required computational infrastructure, here we explore the motivations, conceptual foundations, and challenges associated with building salmon digital twins that represent the life cycle from a "salmon's-eye view."

Solution

We consider who would use such systems, how they might be applied, and what factors could constrain their adoption and long-term evolution. Emphasizing an end-user perspective, we present conceptual use cases to stimulate discussion about the complex decisions that salmon digital twins could support. The presentation invites participants to reflect on the following questions:

- What essential elements are required for a salmon digital twin to be useful?
- How would you personally use such a system?
- Which management or conservation problems should be prioritized?
- What benefits would a salmon digital twin provide, and to whom?
- Would these benefits justify the investment required to develop integrated salmon and habitat digital twins?

Conclusion (pending workshop)

During this workshop, salmon ecologists described what a salmon digital twin must deliver to be useful (and widely used) for research and management. The results highlighted key capabilities that they will needed from a digital twins *platform*, such as:

- translating environmental data into indicators that reflect how salmon experience habitat conditions;
- maintaining up-to-date knowledge of status and emerging threats to salmon by life stage and to their habitats;
- automatically integrating and analysing data from multiple sources: drones, satellite images, field reports;
- enabling easy exports from integrated data and model outputs to external tools used by managers and researchers; and
- scaling to many salmon populations and the diverse habitats they inhabit.

Oral Presentation-17

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

Developing A Refined View of High Seas Pacific Salmon Distributions Through Machine Learning

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The oceanic habitat conditions that Pacific salmon encounter during the pelagic life stage have a substantial effect on their distribution, growth, and survival. For this reason, many research efforts have worked to characterize the oceanic ranges of each species and how they relate to factors like sea surface temperature. Many of these characterizations, however, present a coarse view of salmon distributions generated through summarizing or smoothing catch data over large spatial scales. In order to address contemporary challenges to salmon management, such as evaluating where and when high seas competition among species may take place or enhancing the effectiveness of enforcement activities against Illegal, Unreported, and Unregulated (IUU) fishing, new approaches are needed to maximize the spatiotemporal information gained from composite historical datasets. In this work, we apply eXtreme Gradient Boosting (XGBoost), a machine learning model, to historical high seas salmon catch records assembled in the International Pacific Salmon Data Legacy Database. Specifically, a delta approach is employed to develop year-round distribution models of both the presence/absence and abundance patterns of six Pacific salmon species and evaluate seasonal movement patterns. The estimated salmon distribution patterns are compared to each other and to the NPAFC convention area to investigate the locations and times where species may compete or interact with high seas fishing activities. Furthermore, these updated views of salmon distributions are synthesized to identify outstanding research needs and opportunities for future efforts to further increase knowledge of salmon ocean ecology in a changing North Pacific.

Oral Presentation-18

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

Salmon Domains: A New Perspective on Oceanic Distributions of Pacific Salmon

Skip McKinnell

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During the past 75 years, scientific expeditions to the high seas to catch salmon have shown that species, and populations within species, are widely distributed in the salmosphere. More often than not, distributions are defined by observed ranges using something akin to a minimum convex hull (connect the outermost dots). This approach tends to exaggerate/bias distribution maps because extreme values are overly influential in defining the hull. Furthermore, the perspective of the range tends to leave an impression that abundance is uniformly distributed within it. The concept of species domains arose from an examination of how abundance is distributed within ranges, and finding that most species have contagious distributions that differ markedly in their geographic location and extent. The domain concept may help to explain how the evolution of different migratory behaviours has limited the interactions among species in the ocean. The distributions of pink salmon and sockeye salmon in the Gulf of Alaska are a good example. The utility of the domain concept for other purposes is introduced.

Oral Presentation-19 (virtual)

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

Spatiotemporal Analyses of Trawl Survey Data to Inform Preseason Forecasts and Understanding of Early Marine Survival for Bristol Bay Sockeye Salmon

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Surveys indexing juvenile salmon in the marine environment following ocean entry provide benefits for both advancing ecological understanding and direct application for fisheries management. The National Oceanic and Atmospheric Administration in collaboration with the Alaska Department of Fish and Game conduct surface trawl surveys in the southeastern and northern Bering Sea regions that index sockeye salmon (*Oncorhynchus nerka*) originating from the Bristol Bay Alaska, among other species. These surface trawl surveys capture juvenile salmon during summer and fall of the ocean entry year, after a portion of early marine survival, and provide an opportunity to inform preseason forecasts of future adult returns and quantify the role of regional marine processes in regulating survival. While current preseason abundance forecast methods for Bristol Bay sockeye salmon primarily rely on the abundance of adult sockeye that experienced similar survival conditions at marine entry but returned in prior years, this marine index of juvenile abundance has proven to be a reliable predictor of future adult returns up to two years in advance. Here we describe the implementation of spatiotemporal models to control for changes in spatial sample design among years for this surface trawl survey, and the development of spatiotemporal juvenile index for predicting future adult returns to Bristol Bay. Further, using this survey abundance index we describe the influence of nearshore sea surface temperature and phytoplankton bloom phenology on the marine survival of Bristol Bay sockeye salmon.

Oral Presentation-20

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)
(2-1. Overcoming Data Fragmentation)

A Practical Semantic Framework for Integrating Salmon Data Across Programs and Jurisdictions

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Pacific salmon science and management rely on combining observations from many jurisdictions, programs, and decades—yet integration remains slow and error-prone because datasets arrive with inconsistent column names, undocumented codes, and ad hoc formats. Too often, integration is pairwise and temporary: two projects harmonize fields just long enough to answer one question, then repeat the same translation work for the next partner dataset. This presentation describes a practical alternative—a "standardize your data once, reuse everywhere" workflow in which each program maps its data to shared salmon definitions once, making future collaborations far more routine. We present a semantic data system with four interoperable components. (1) The Salmon Data Package (SDP) specification defines a simple, portable folder structure—data files plus a column dictionary, code lists, and machine-readable metadata—that travels with the data and opens in common analysis environments. (2) The DFO Salmon Ontology and controlled vocabularies provide stable definitions for salmon-relevant concepts (e.g., species, conservation units, enumeration methods), so dictionary entries can link to shared meaning rather than local interpretation. (3) The metasalmon R package automates the mechanics: inferring starter dictionaries from raw data, suggesting semantic matches between dataset terms and standard terms from controlled vocabularies and ontologies, and validating package structure and completeness. (4) A custom Salmon Data GPT assistant configured to reference the SDP specification and salmon vocabularies helps draft column descriptions, propose vocabulary links, and surface code lists from a small uploaded data sample—critically—as human-reviewed drafts that are then checked by validation tools. This work was developed during the Pacific Salmon Strategy Initiative within Fisheries and Oceans Canada's Data Stewardship Unit, builds on the International Year of the Salmon Data Mobilization, and aims to improve data stewardship across the salmon science community. The long-term direction is a practical "workbench" for practitioners to standardize datasets with minimal friction—packaging data with machine-readable dictionaries, code lists, and validated semantic links—so they can be reused immediately by collaborators and analysis workflows. As more programs publish semantically described packages, these links become the backbone of a salmon data knowledge graph that enables discovery, querying, and meta-analysis across regions and programs. To scale this approach beyond one organization, we are advancing it through the Research Data Alliance Salmon Ontology Development Working Group to ensure a shared interoperability layer that supports consistent mapping while allowing program- and dataset-specific extensions.

Oral Presentation-21

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Genomic Tools for Forecasting and Adaptive Management of Pink Salmon (*Oncorhynchus gorbuscha*) in the Sea of Okhotsk Basin

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Pink salmon (*Oncorhynchus gorbuscha*) dominates salmon catches in Russia, and fluctuations in its abundance largely determine the overall outcome of the fishing season. However, pronounced interannual variability in both total returns and regional stock contributions makes reliable forecasting particularly challenging, especially in the Sea of Okhotsk basin. Traditionally, forecasts of spawning runs were based primarily on ichthyological observations. In recent years, genetic approaches have become an essential component of assessment. We apply genetic stock identification to estimate the contribution of regional stocks to mixed marine aggregations of juveniles and, in combination with total abundance estimates, to predict region-specific spawning returns and expected catch volumes. Using genomic resources developed in the laboratory of Jim Seeb at the University of Washington, we designed two compact SNP panels for Russian pink salmon: one for even-year and one for odd-year spawning lineages, comprising 8 and 10 markers, respectively. This operational tool has been applied for several years and has consistently demonstrated higher forecast accuracy compared with predictions based solely on traditional ichthyological methods. To further enhance resolution and address remaining limitations in regional assignment, we conducted a large-scale ddRAD sequencing project encompassing major Asian spawning regions. The resulting dataset substantially refined the marker panels and strengthened the genetic baseline supporting fisheries management in the Sea of Okhotsk basin. Despite these advances, the abundance of returning stocks remains strongly influenced by climatic events and environmental processes acting throughout the life cycle. Some drivers can be directly observed and incorporated into predictive models; however, others operate during the oceanic phase, when monitoring is limited and their effects become apparent only indirectly. In such cases, additional analyses are required to clarify forecast deviations and to identify persistent patterns in spawning migrations. Our results demonstrate that integrating genetic, biological, and climatological information not only improves forecast accuracy, but also strengthens the scientific basis for adaptive, precautionary, and internationally coordinated management of pink salmon resources across the North Pacific under accelerating environmental change.

Oral Presentation-22

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Reconstructing Juvenile Life-history Using Otolith Regressions and Microchemistry in Adult Salmon

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Estuary entry and residency impact the survival and growth of juvenile Pacific salmon, making the reconstruction of these events in adults critical to understanding the dynamics surrounding this part of their early marine phase. In this study, I quantified relationships between otolith radius and fork length for Chinook salmon across their entire early life cycle. Breakpoint regressions between otolith radius and fork length were used as there is a distinct shift in growth at the fry-parr transition. Estuary entry patterns varied greatly by system and by origin. Systems like the Cowichan River had a unimodal outmigration pattern amongst the natural origin Chinook, while the Sarita River had a bimodal outmigration pattern. Hatchery Chinook in five of the six systems monitored were released at a far larger average smolt size than the average estuary entry size successfully returning adults left at, indicating a size-based threshold for either survival, or likelihood of conducting a jack life-history strategy. Additionally, the discrimination of estuarine and nearshore habitats was achieved using Ba/Sr ratios, which were particularly effective in British Columbia systems where nearshore reference samples were available. Natural origin Chinook, particularly around the Fraser and Puntledge systems, used their estuaries for a considerable amount of time on average, while Cowichan and Sarita Chinook used their estuary for just over two weeks on average. Overall, integrating otolith regressions with microchemical analyses allowed for the identification of key juvenile life-history events, which then highlighted later life-history specific survival patterns.

Oral Presentation-23

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Statistical Evidence for Climate-driven Migration Route Shifts in Northwest Pacific Chum Salmon: Knowledge Gaps and Validation Priorities

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Since the early 2000s, chum salmon return patterns in the Northwest Pacific have diverged among populations. Returns from the Korean (KR) population sharply declined and then gradually recovered, whereas those from the Japanese (JP) population continuously decreased and those from the Russian (RS) population increased rapidly. These contrasting trends have traditionally been explained by differences in early life-stage survival, growth conditions, and interpopulation competition. However, this explanatory framework does not adequately account for why East/Japan Sea populations experienced relatively limited declines or partial recovery despite rapid warming than adjacent waters.

This study addresses this explanatory gap by focusing on environmental changes in offshore staging areas where population-specific migration routes diverge during spawning return migration, particularly the Sea of Okhotsk. We hypothesize that warming in the Sea of Okhotsk—through which Korean, Japanese, and Russian populations commonly migrate—altered return route selection for a subset of populations entering the East/Japan Sea, thereby contributing to divergent return patterns among populations.

To test this hypothesis, we applied structural equation modeling (SEM) using datasets of return abundance, release numbers, regional catch, and sea surface temperature the 1980s to the present. Analyses were conducted separately for periods before and after 2000 to compare shifts in the relative importance of explanatory factors and changes in causal pathway structure influencing return abundance.

Results indicate that after 2000, oceanic environmental conditions associated with the Sea of Okhotsk and return migration pathways contributed strongly to explaining return variability than release metrics. The influence of traditional return routes weakened, while the relative importance of alternative pathways increased. These findings provide statistical evidence supporting climate-driven shifts in salmon return migration routes. However, the lack of individual-level data capable of directly confirming route selection—such as otolith marking, genetic stock identification, and satellite-based tagging—limits mechanistic understanding of route-switching processes and the identification of environmental thresholds.

We identify this limitation as a critical knowledge gap and propose the following research priorities under an NPAFC-led multinational framework: (1) harmonization and sharing of existing microsatellite and otolith datasets across member countries; (2) joint design and deployment of coordinated tagging and genetic tracing programs in the Soya Strait–Tatar Strait

(SY–TTR) transition zone; and (3) co-development of predictive tools and adaptive management strategies responsive to verified changes in return dynamics. These efforts will establish a shared knowledge and data infrastructure that enhances early detection, stock attribution, and ecosystem-based decision-making under warming scenarios.

Oral Presentation-24 (virtual)

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Knowledge Sharing About Pink Salmon Across Ocean Basins Facilitates Management Actions

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Range-expanding and invading pink salmon, from natal Pacific origins and an introduced non-native population in northwestern Russia, have nearly achieved a circumpolar distribution. Their occasional harvest across the Canadian Arctic has caused concern among harvesters and their rapid proliferation across the Atlantic Ocean has required immediate management action by several countries. Here, we encourage knowledge sharing across ocean basins and highlight information gaps and planning needed to assess potential impacts and guide management decisions for range-expanding and invasive species in non-natal areas outside the Pacific Ocean. Such knowledge sharing can also provide important lessons learned from these non-natal areas to inform management in the native range. We categorize key gaps to those that provide a better understanding of (i) the invasion potential of pink salmon, (ii) interactions among pink salmon and other key species, and (iii) current mitigation efforts. We also identify actions that can be taken immediately to support understandings regarding the current and future pink salmon distributions. Recognizing that pink salmon now span multiple ocean basins and jurisdictions, acquiring and archiving information is best achieved through a coordinated multinational approach.

Oral Presentation-25

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

The Forgotten Pink Salmon in the Laurentian Great Lakes: An Unexpected Invasion with Insights for Three Oceans

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Introductions of species outside of their native range can serve as unplanned experiments that provide new insights into ecological plasticity and adaptation. An example of such an introduction, pink salmon in the Laurentian Great Lakes are exposed to varying food web conditions and latitudinal and seasonal environmental gradients representative of the extremes of their native Pacific range. We synthesize seven decades of information on the understudied Great Lakes pink salmon invasion, use knowledge from marine systems to help fill gaps in understanding, and highlight how this case can inform research and management of pink salmon amidst changing and novel habitat conditions in the Pacific, Arctic, and North Atlantic Oceans. Following their introduction to Lake Superior, pink salmon quickly spread to all five Great Lakes, displaying unexpected life history changes and behaviors. Their invasion history demonstrates a remarkable ability to establish from a small founder population, adapt to a variety of environmental conditions, produce explosive year classes to rapidly increase in abundance, and complete a full life cycle entirely in freshwater. One of the most striking changes is a shift from the rigid two-year life cycle exhibited in their native range to a variable maturation age ranging from one to four years, likely influenced by prey availability as well as temperature and other environmental factors. We discuss these observations and their implications for management elsewhere, as well as outline high-priority research themes necessary for understanding pink salmon dynamics in the Great Lakes with broader relevance for the native and non-native ranges. Developing a better understanding of factors that influence establishment potential and rapid changes in abundance, how novel abiotic conditions and habitat features regulate distribution and productivity, and how variability in maturation age arose and altered population dynamics would provide invaluable insights for managing pink salmon everywhere it occurs.

Oral Presentation-26

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Freshwater Landlocked Chinook Salmon Behaviour and Use of Habitat Diverge from Source Populations in the Pacific Region—Cross-system Science for a Changing Native Range

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Chinook salmon (*Oncorhynchus tshawytscha*) support multi-billion-dollar fisheries and are ecologically and culturally important in both their native Pacific range and in the Laurentian Great Lakes, where they were introduced in the late 1960s. Management decisions in both regions are driven by a balance of the ecological role of the species, the demands of stakeholders, and the health of the stocks. Thus, an improved understanding of their spatial and behavioural ecology developed through comparisons among native and introduced habitats would provide insights regarding their plasticity and adaptive capacity under novel or changing environmental conditions. Chinook salmon populations are facing numerous challenges in their native region that have analogs in the Great Lakes. However, despite a founder effect, the Great Lakes populations are thriving, and natural reproduction is steadily increasing alongside annual stocking programs. These differences in population status between the two regions prompt questions about potential differences in their spatial ecology. Here, we synthesized acoustic telemetry data from the northeast Pacific Ocean and Lake Ontario to understand Chinook salmon habitat use by quantifying synonymous and divergent behaviours associated with the two populations. Our preliminary results show significant differences in realized Chinook salmon thermal niches and utilization of the water column in relation to the thermocline and bathymetric depth, particularly for the winter period. These results provide evidence for divergent behaviour in the spatial ecology of Chinook salmon in Lake Ontario compared to populations in the Pacific, perhaps resulting from a seasonal temperature cycle spanning or exceeding the conditions at the source population's range limits along with other factors. More generally, these insights demonstrate behavioural plasticity in Chinook salmon that promote adaptation and advantage in novel environments, attesting to the species' resilience to changing and challenging environmental conditions. Further these preliminary results validate the value of conducting cross-system comparisons between the Great Lakes and native Pacific populations to generate useful insights for informing and supporting management as both systems are increasingly impacted by climate change.

Oral Presentation-27

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Acoustically Derived Distribution and Abundance Estimates of Salmon and their Prey in the North Pacific Ocean in Winter as Observed by the 2022 IYS Pan-Pacific Expedition

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Winter has been hypothesized as a “survival bottleneck” for the oceanic phase of Pacific salmon species due to presumed low prey availability. During February/March of 2022 the International Year of the Salmon (IYS) Pan-Pacific Expedition, Canadian, American, and Russian science vessels collected multifrequency echosounder backscatter intensity data along their survey tracks. Combining these datasets using advanced backscattering partitioning models, we quantified the distribution of salmon and the major mesopelagic and micronektonic taxa in the North Pacific Ocean at a higher spatial resolution than previously achieved. Here we present the spatial distributions and estimated abundances of salmon and their prey derived from the 2022 IYS survey. We also discuss the potential capabilities and limitations of shipboard echosounders to fill the open-ocean knowledge gap and the complementary data streams that would be vital for improving acoustic estimates of salmon and salmon prey abundance.

Oral Presentation-28 (virtual)

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Assessing Global Pink Salmon Introductions to Identify Potential Barriers to Freshwater Establishment

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Pink salmon (*Oncorhynchus gorbuscha*) have been repeatedly introduced within and outside their native Pacific range since the early 1900s. Given the current concerns about the potential impacts of pink salmon on ecosystems in their expanding Arctic and invaded Atlantic ranges, assessing these introduction attempts to better understand freshwater survival could provide insights into the potential for pink salmon to establish in rivers outside their native distribution. Here, we completed a systematic literature review to summarize global pink salmon introductions both within and outside their native range and then extracted characteristics for each introduction attempt, including source and recipient locations, life-stage introduced, lineage (even- or odd-year) introduced, and the reported outcome measured by the presence and number of generations of returning adults. Introductions of pink salmon have been attempted 190 times across four continents, spanning 93 years. Perhaps surprisingly, only 62 attempts resulted in observations of adult returns the following year and five of those naturally produced multiple generations of pink salmon in recipient systems. Only two introductions have maintained self-sustaining populations to date, resulting in invasions throughout all five Laurentian Great Lakes and in drainages across the Atlantic Ocean. Ongoing synthesis will evaluate whether differences in key metrics (latitude, ocean basin, phenology, temperature, development rate, odd- or even-year populations) between source and recipient systems and populations can act as barriers to pink salmon reproduction and establishment in freshwater. To address the growing global concerns regarding the rapid expansion and increased production of pink salmon in warming native and non-native ecosystems, a greater understanding of the potential for freshwater survival of pink salmon in introduced or newly accessible habitats will help to inform adaptive management strategies throughout the expanding native and invaded ranges.

Oral Presentation-29

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Investigating Sources of *Ichthyophonus* Infections in Yukon River Chinook Salmon

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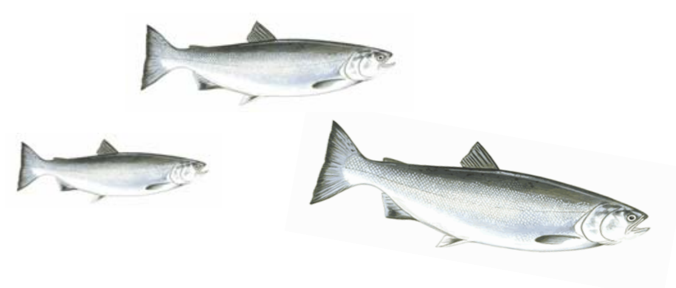
Run sizes of Yukon River Chinook salmon have declined since 1998, resulting in reduced subsistence harvest opportunity in 2007 and complete closures of subsistence harvest in 2021. En route mortality during freshwater migration as high as 45-50% has also been implicated in recent years. The factors for these recent unprecedented declines and en route mortality are unknown, but they coincided with high prevalences of infection and disease caused by the parasite *Ichthyophonus*. This fungal-protozoan-like parasite has previously been implicated in large declines and en route mortality of Yukon River Chinook salmon in the early 2000's. Yukon Chinook salmon are more susceptible to the disease and associated mortality than Chinook from other stocks. Yukon Chinook salmon become infected in the marine environment by consuming infected tissues, but the primary prey item in this system is currently unknown. Juvenile salmon surveys in the northern Bering Sea have been used as a sampling platform to sample both juvenile and immature Chinook salmon and their prey. We have monitored infections in both Bering Sea juvenile (≤320mm; first summer at-sea) and immature Chinook salmon since 2021 and found that immatures have heavy infections and clinical disease while no juveniles have been infected. Chinook salmon switch prey during warm-water years due to changes in forage assemblages and there was an extreme warm-water anomaly in 2017-2019 that coincided with *Ichthyophonus* outbreaks in subsequent years. We surveyed infections in known Chinook salmon prey to assess the primary infection source, including Pacific herring, capelin, pollock, rainbow smelt, sandlance, and saffron cod throughout the Northern and Southern Bering Sea. None of the prey tested positive for *Ichthyophonus*, so the primary source of *Ichthyophonus* infection has not yet been identified. However, recent preliminary data indicates that spawning products from walleye pollock may be implicated. Our *Ichthyophonus* disease monitoring work has immediate application to collaborative marine and freshwater research programs designed to provide actionable salmon harvest and conservation advice to fishery managers.

Poster Presentations



Poster Presentation-1

Topic 1. Linking climate-ocean variability to salmon population dynamics

Forecasting Southeast Alaska Pink Salmon Harvest

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Pink salmon *Oncorhynchus gorbuscha* runs are notoriously difficult to forecast due to their strong sensitivity to marine environmental conditions, the species' alternating odd–even year abundance cycles, and the fact that only a single age class returns each year. The National Oceanic and Atmospheric Administration (NOAA) Alaska Fisheries Science Center, Auke Bay Laboratories, initiated the Southeast Alaska Coastal Monitoring (SECM) project in 1997 to quantify relationships between juvenile salmon year-class strength and the biophysical factors influencing their growth, survival, prey and predator interactions, habitat use, and stock composition in marine waters. The environmental and oceanographic time series developed through SECM is now one of the longest continuous datasets of its kind in the North Pacific.

A central finding from SECM is that the relative abundance of juvenile pink salmon in June or July is strongly correlated with the harvest of returning adults the following year. The SECM project and the resulting Southeast Alaska pink salmon harvest forecasts are conducted cooperatively by NOAA and the Alaska Department of Fish and Game (ADF&G), using the ADF&G research vessel *Medeia*. The current forecasting approach applies a multiple linear regression model that includes peak juvenile pink salmon CPUE (June or July) and a temperature index. The temperature index is derived from either SECM water-column temperature measurements or satellite-based sea surface temperatures. Additional variables currently under investigation include a vessel factor to account for changes in survey platforms through time and an odd–even year factor to capture potential brood-line cyclical dynamics.

Poster Presentation-2

Topic 1. Linking climate-ocean variability to salmon population dynamics

Common Low-frequency Signal in Long-term Body Size Dynamics of Chum Salmon (*Oncorhynchus keta*) Along Eastern Sakhalin (1991–2024)

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Declining body size in Pacific salmon is increasingly recognized as a pan-North Pacific phenomenon, yet quantitative assessments linking this trend to large-scale climate variability remain limited for northwestern Pacific stocks. We present a 34-year record (1991–2024) of fork length (FL), body mass, and Fulton's condition factor (K-factor) for chum salmon from seven hatcheries across four fishing regions of eastern Sakhalin: Northeast Sakhalin, Terpeniya Bay, Southeast Sakhalin, and Aniva Bay (total n > 81,000).

Mann–Whitney tests confirmed significant inter-regional differences in body mass, with the highest values in the northeast and the lowest in Aniva Bay. ANOVA across decadal periods (1991–2000, 2001–2010, 2011–2024) revealed significant decreases in most regions. Extreme-event analysis showed clustering of high FL and mass before 2005 and low values in the recent period, particularly since 2018.

A three-stage approach was applied to test whether the decline reflects a common external signal. First, Theil–Sen regression confirmed negative trends of the same sign in all regions. Second, Pearson cross-regional correlations demonstrated significant synchrony for FL and mass, though weaker for K-factor. Third, wavelet coherence revealed a dominant shared periodicity at the 8–14-year scale, consistent with decadal climate oscillations.

The climate origin of this signal was tested against three indices: PDO (Pacific Decadal Oscillation), Nino 3.4 (an ENSO index), and GLB.Ts+dSST (NASA combined land-surface and sea-surface temperature anomaly). PDO showed the fastest response (0–2-year lag), strongest in southern regions for body mass and K-factor, while Nino 3.4 operated predominantly with a 3-year lag across all regions. Spectral analysis confirmed overlapping periodicity (8–12 years) between climate and biological series, though biological spectra exhibited additional peaks at 5–7 and 10–15 years. Regression models explained up to 54% of interannual variance in body mass (best model: all regions pooled with region as a fixed effect), indicating a substantial but not dominant climate contribution.

We conclude that chum salmon body size decline along eastern Sakhalin is partly driven by a common low-frequency climate signal at decadal scales. The unexplained variance likely reflects density-dependent effects, local oceanography, and hatchery practices.

Poster Presentation-3

Topic 1. Linking climate-ocean variability to salmon population dynamics (1-2 Decoding Extreme Population Fluctuations)

Marine Heat Waves in the Northwest Pacific and Far Eastern Seas in 1995–2024 Based on ERA5 Reanalysis Data

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Extremely high surface temperatures in salmon feeding and wintering areas can have negative consequences for their populations. The most likely cause of population declines at this stage of their life cycle is the impact of parasites and sea lice on the health of the fish. Therefore, a statistical analysis of extreme ocean surface temperature events—marine heatwaves—was conducted. Based on an analysis of a 30-year ocean surface temperature dataset, it was established that MHWs are distributed relatively uniformly across the Northwest Pacific Ocean and the Far Eastern seas, with no areas of significantly higher or lower frequency of their formation. The average frequency of events varied over most of the water area within very narrow limits, from 1 to 2.5 cases per year. In the main part of the studied water area, the values of the average duration of the MHW also varied within narrow limits, from 7 to 11 days. The same can be said about the average number of days with heat waves, with a range of variations from 20 to 35 days. Zones with higher MHW intensity are more clearly defined; in the last two years, it has increased significantly in the zone of influence of the warm Kuroshio Current. In some years, there are vast areas where MHWs are absent; this could be any part of the studied region. In some cases, MHWs can shift smoothly, primarily in a southeasterly direction, but in many situations, they emerge and disappear in approximately the same location. The most pronounced MHWs typically occupy a large area and cannot be considered eddy structures.

Poster Presentation-4

Long-term Dynamics for Some Biological Parameters of Pink Salmon from Asiatic Herds

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Relationships of year-to-year dynamics are analyzed between the body size of pink salmon and their regional and total abundance and between the size of juveniles and the size of returned adults. The dependencies are estimated for odd and even year-classes, separately, and for different periods of years. The body size variations relate closer with changes of regional abundance than with changes of total abundance for pink salmon from almost all regional herds except those reproduced in East Sakhalin and southern Kuril Islands. Variations of the body size correlate well between the juveniles and adults returning for spawning for the herds from East and West Kamchatka (both for odd and even year-classes) and East Sakhalin (for high abundance odd years-classes). Sustainability of some size-weight features formed in the early period of life during the further stages of feeding and spawning migration is assumed for pink salmon.

Poster Presentation-5

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

Enhanced Biological Pumping at Submesoscale Edge Fronts

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The Arctic Norwegian Sea is a key gateway for the transport of heat, nutrients, and biomass from the Atlantic to the Arctic Ocean. While large-scale slope currents have long been considered the dominant control on ecosystem structure, the mechanisms sustaining persistently high biomass in this region remain unclear. By integrating five years of glider observations with over two decades of biogeochemical station data, we identify intense vertical motions concentrated along mesoscale eddy edges, with horizontal scales below 10 km and vertical extents exceeding 500 m. These motions are driven by submesoscale, geostrophic strain–induced secondary circulations that transport nutrients from the ocean interior to the surface during the spring bloom and Calanus finmarchicus swarm seasons. This enhanced biological pumping forms high-nutrient rings along eddy edges, sustaining elevated phytoplankton and zooplankton biomass and highlighting the critical ecological role of submesoscale processes.

Poster Presentation-6

Topic 2. Data integration frameworks: harmonizing oceanographic, ecological, and fisheries datasets (Tools, standards, and case studies for cross-disciplinary synthesis)

NGS-based Insights into Population Differentiation and Genetic Baseline Development for Asian Coho Salmon

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Coho salmon (*Oncorhynchus kisutch* Walbaum) is one of the most important species for commercial fisheries and hatchery enhancement in the Russian Far East and is widely distributed across the North Pacific. Within the Asian part of its range, it is the fourth most abundant species of the genus Oncorhynchus. To examine fine-scale population structure, we applied ddRAD sequencing to samples covering nearly the entire Asian range of the species. Our analysis revealed a clear genetic separation of the northern Sea of Okhotsk and Sakhalin groups from the remaining populations. Compared with previous microsatellite studies, population differentiation within the Kamchatka Peninsula was resolved in greater detail. Most Kamchatkan samples formed a single cluster including rivers of the western coast and the Avacha River (southeastern Kamchatka). In contrast, the Kamchatka River sample constituted a distinct cluster, suggesting an independent colonization history. Notably, the Apuka River sample occupied a central position in PCA space. We previously hypothesized that Asian coastal colonization by coho salmon occurred from North America via Beringia. Among the sampled rivers, the Apuka River represents the first point along this putative colonization route. We therefore propose that subsequent dispersal along the Asian coast radiated from the Apuka River. Our results support a scenario of parallel expansion in four directions. Finally, we are identifying highly differentiating SNP markers among these populations to develop a robust genetic baseline for population assignment and fisheries management in the Russian Far East.

Poster Presentation-7

Topic 3: Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Variability of Korean Salmon Resources and Otolith Analysis of Returning Salmon

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Returning Chum salmon (Oncorhynchus keta) to Korean rivers have shown pronounced interannual variability in abundance over recent decades. Although artificial propagation through hatchery production has been a central component of salmon resource management in Korea, quantitative field-based evidence demonstrating the contribution of hatchery-produced individuals to population recovery remains limited. This gap constrains objective evaluation and refinement of current management strategies.

The objective of this study was to identify hatchery-produced individuals among returning salmon using otolith analysis and to quantify the contribution of artificial propagation to recent fluctuations in Korean salmon resources. Field surveys were conducted in four major salmon-spawning rivers in Korea, and an average of approximately 760 returning adults per year were analyzed over recent years. Otolith microstructure analysis was used to detect otolith marks, enabling discrimination between hatchery-produced and non-marked individuals. The proportion of hatchery-produced salmon was then compared among rivers and years.

Results showed that, during the most recent three-year period, hatchery-produced individuals accounted for approximately 40.0–50.5% of returning salmon across the four rivers. These findings demonstrate that a substantial proportion of released juveniles survived to adulthood and successfully returned to their natal rivers, indicating that artificial propagation currently plays a critical role in the recovery of Korean salmon resources. Furthermore, otolith marking was confirmed as a practical and robust method for directly verifying release effectiveness based on field observations.

This study provides quantitative evidence that hatchery-based artificial propagation contributes substantially to salmon resource recovery in Korea. Otolith-based identification of returning adults offers a reliable foundation for evaluating management performance and improving stock enhancement strategies. Integration of otolith mark data with release and return monitoring under the NPAFC framework will strengthen adaptive, science-based management of salmon resources under ongoing environmental change.

Poster Presentation-8

Topic 3: Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Freshwater Hydrology Emerges as the Strongest Predictor of Phenological Variability in a Southeast Alaska Steelhead Trout (*Oncorhynchus mykiss*) Population

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Phenological variation, such as the migration trends of salmonids, may provide resilience against trophic asynchronies, influencing individual survival and population productivity. Phenological shifts may be particularly consequential for anadromous species that rely on seasonal cues for migration between freshwater and marine habitats, and may reflect underlying environmental changes. Steelhead trout (Oncorhynchus mykiss), the anadromous life history variant of rainbow trout, may undergo these migrations multiple times in their life as an iteroparous species. However, studies on steelhead phenology in Alaska, including potential shifts and environmental drivers, are lacking. By examining 21 years of data on steelhead in a Southeast Alaska system (Sashin Creek), we found that migration midpoint shifted significantly earlier across the time series for returning adult steelhead, particularly females, by two weeks, with no change in migration duration. There was no significant change in smolt migration, although we observed a slight trend toward an earlier midpoint. We then combined local environmental and regional climate data to investigate potential drivers of phenological shifts. Freshwater temperature and year were the strongest predictors of adult upstream migration midpoint, while snowfall, precipitation, and fork length (which decreased significantly across the time series) were the strongest predictors of duration. For steelhead smolts, freshwater temperature, year, condition factor, and chlorophyll were the strongest predictors of outmigration midpoint, and freshwater temperature and snowfall were the strongest predictors of duration. With projected increases in temperature and precipitation in Southeast Alaska and projected decreases in snowfall, the observed shift toward earlier migration timing of adults may intensify in this system and others in the region in the future. Consequently, shifting steelhead phenology may affect the resilience of this population to environmental change, and could have cascading impacts on the system through interspecific interactions. This study highlights a knowledge gap in steelhead, which are an under-studied salmonid in comparison to the Pacific salmon species. While these findings provide valuable insights into steelhead phenology in Alaska, the dataset is spatially and temporally restricted. Comparisons with other steelhead systems in Southeast Alaska would more holistically capture phenological shifts in steelhead in this region. Additionally, the observed decline in adult size warrants further research to determine whether the change is driven by shifting age structure of the population or declining growth rates.

Poster Presentation-9

Topic 3. Identify critical knowledge gaps and prioritize research to forecast salmon responses under future climate scenarios

Rapid Emergence of Thiamine (Vitamin B1) Deficiency in Pacific Salmon Illustrates the Need for Continued Ecosystem Research

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Thiamine (vitamin B1) deficiency is an emerging issue in the Pacific Ocean affecting salmon from California to Alaska through elevated fry mortality and sublethal effects across their lifecycle. Salmon acquire thiamine through their diet and require it for basic cellular metabolism. Thiamine deficiency is caused by shifts in marine prey resources, and in California has been tied to diets dominated by northern anchovy, which contain thiaminase—an enzyme that breaks down thiamine in the gut of predators. In the first large scale survey of British Columbia salmon, we observed thiamine deficient eggs across eight Chinook populations sampled in 2023-2024 and three Coho populations in 2025. Although thiamine deficiency is a widespread concern for BC salmon, population level differences suggest distinct drivers and risks based on ocean distribution and migration length. For locally distributing populations that interact with northern anchovy, thiamine deficiency is linked to trophic markers of anchovy consumption. Thiamine deficiency has the potential to disrupt reproductive success by decreasing fry survival or through carryover effects, shifting relationships between returning adults and subsequent recruits. Its occurrence is likely driven by interactions between salmon ocean distributions, shifting prey communities, and the drivers of prey thiamine / thiaminase levels, which require further research. Thiamine deficiency in Pacific salmon is an example of an ecological surprise that arises from a complex food web interacting with novel ocean conditions. It illustrates the continued need for ecological research on the food web interactions that underpin models and ecological indicators used in salmon forecasts.

About NPAFC

Who?

The North Pacific Anadromous Fish Commission (NPAFC) was established by the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean. Member countries include Canada, Japan, the Republic of Korea, the Russian Federation, and the United States.

Where?

The Convention Area is the North Pacific Ocean and its adjacent seas, North of 33°N and beyond the 200-mile zones of coastal states.

Why?

The primary objective is to promote conservation of anadromous stocks (Pacific salmon and steelhead trout) in the North Pacific Ocean. Conservation measures in the Convention Area include:

- prohibit directed fishing for anadromous fish
- minimize incidental catch of anadromous fish
- prohibit retention of incidental catch of anadromous fish

How?

Enforcement: Member countries take action against activities contrary to the provisions of the Convention and cooperate in enforcement activities. Each member ensures its fishing vessels comply with the Convention and has the authority to board, inspect, and detain vessels found in violation of the Convention. Members coordinate and dispatch patrol vessels and aircraft to the Convention Area to enforce conservation measures.

Science: Scientists acquire, analyze, and disseminate information related to anadromous stocks and ecologically related species in the North Pacific. Specialists cooperate in collecting anadromous fish for scientific purposes in research programs approved by NPAFC and researchers report and exchange fisheries data, samples, and other relevant information.

The primary goal of the 2023–2027 NPAFC Science Plan is to: “Establish a research framework to develop a mechanistic understanding of the impact of changing climate on salmon abundance and distribution trends in the North Pacific Ocean.” There are five research themes:

(1) Status of Pacific salmon and steelhead trout (Present Knowledge);
(2) Pacific salmon and steelhead trout in a changing North Pacific Ocean (Forward Action);
(3) New technologies;
(4) Management systems; and
(5) Integrated information systems.

For more information

on anadromous stocks in the North Pacific, visit our website https://npafc.org where the following items can be downloaded:

- Bulletins—peer-reviewed proceedings of NPAFC scientific symposia
- Technical Reports—extended abstracts from NPAFC workshops
- Catch and Hatchery Release Statistics
- Annual Reports (1993–Present)
- Newsletters