SALMON IN A RAPIDLY CHANGING WORLD

Synthesis of the International Year of the Salmon and a Roadmap to 2030

Abstract Booklet

The IYS Synthesis Symposium was planned by the Symposium Steering Committee and is hosted by the North Atlantic Salmon Conservation Organization and the North Pacific Anadromous Fish Commission.

ORGANIZING COMMITTEE

Dr. Ed Farley (NPAFC, NOAA Fisheries, Alaska Fisheries Science Center, United States of America)
Ms. Livia Goodbrand (NASCO, Fisheries and Oceans Canada, Gulf Fisheries Centre, Canada)
Dr. Emma Hatfield (NASCO Secretariat, Scotland)
Dr. Vladimir Radchenko (NPAFC Secretariat, Canada)
Mr. Mark Saunders (NPAFC Secretariat, Canada)
Dr. Alan Walker (NASCO, Centre for Environment Fisheries and Aquaculture Science, England)
Mr. Aidan Schubert (NPAFC Secretariat, Canada)
Mr. Tor Kitching (NPAFC Secretariat, Canada)

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North Pacific Anadromous Fish Commission (NPAFC, https://npafc.org)
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North Pacific Anadromous Fish Commission
Suite 502, 889 West Pender Street
Vancouver, BC, V6C 3B2
Tel: 604-775-5550
Fax: 604-775-5577
E-mail: secretariat@npafc.org

Preface

The North Pacific Anadromous Fish Commission (NPAFC) and North Atlantic Salmon Conservation Organization (NASCO) will synthesize the achievements of the International Year of the Salmon (IYS) initiative and build a Roadmap to 2030 to address the challenges and opportunities in salmon conservation. The IYS is a five-year (2018 – 2022) initiative which set out to establish the conditions necessary for the resilience of salmon and people in a rapidly changing world. The IYS Synthesis Symposium *Salmon in a Rapidly Changing World: Synthesis of the International Year of the Salmon and a Roadmap to 2030* engages over 50 live presentations touching on a range of diverse topics organized under the five IYS research themes: Status of Salmon, Salmon in a Changing Salmosphere, New Frontiers, Human Dimensions, and Information Systems. This symposium is taking a collaborative approach to produce a Roadmap to 2030 which will be informed by the synthesis projects included in this book of abstracts.

Symposium Themes and Sub-Themes

Status of Salmon

Theme Objective: The present status of salmon and their environments is understood.

Sub-theme: The Status of Salmon across the Northern Hemisphere

Increased variability in the abundances of salmon populations has been observed across the Northern Hemisphere over the past two decades. Many populations have experienced significant and persistent declining trends while others have experienced major increases. Understanding the status of salmon on a hemispheric and regional level is of fundamental importance to inform decision making, research and communication with key stakeholders and the broader public. This sub-theme will provide an overview of salmon status and trends by species and geographic scale, as well a review of the different methods used to determine status throughout the Northern Hemisphere.

Sub-theme: Changing Climate, Changing Status: Understanding Shifts in Salmon Distribution, Productivity and Abundance Under Climate Change

Climate change is causing major shifts in the distribution, abundance, and productivity of salmon across the Northern Hemisphere. Understanding the changes in these factors to date, modelling future changes and adequately accounting for ecological and climate uncertainties is critical to support research and management. This sub-theme will include presentations on the observed and expected changes in salmon distributions across the Northern Hemisphere, current and emerging modelling approaches for producing annual forecasts and future scenarios, and the incorporation of climate and ecological uncertainty into these approaches

Information Systems

Theme Objective: Freely available information systems contain historic and current data about salmon and their environment.

Sub-theme: Towards a Data driven Future: Progress and Future Requirements for Data Mobilization across the Salmosphere

A major challenge experienced across the Northern Hemisphere is ensuring that data related to salmon and associated ecosystem domains are made readily available to scientists and decision makers. Despite the plethora of existing salmon-related data, only a small portion adheres to the FAIR (Findable, Accessible, Interoperable, and Reusable) principles. This sub-theme will include presentations that review and synthesize data mobilization successes, current barriers to data mobilization and provide an outlook for data mobilization over the next decade.

Salmon in a Changing Salmosphere

Theme Objective: The effects of natural environmental variability and human factors affecting salmon distribution and abundance are understood and quantified.

Sub-theme: Examining the Likely Suspects: Developments in a Wholistic Understanding of Salmon Marine and Freshwater Survival

The effective management of salmon in the context of their associated ecosystems requires an understanding of the cumulative impact of the drivers of salmon survival across life history stages. A holistic lifecycle approach will inform annual forecasts, recovery planning, and management strategy evaluations to support resource management decisions and climate change risk assessments. The Likely Suspects Framework (LSF) concept was proposed in 2017 by a group of salmon researchers from the Atlantic and the Pacific basins, as such a process with the goal of providing practical advice to managers and decision makers by identifying the main sources of salmon mortality and their cumulative effects across the lifecycle for a salmon population of interest. This sub-theme will include presentations on the LSF in the Atlantic and Pacific ecoregions and developments in comprehensive lifecycle modelling.

Sub-theme: Opening the Black Box: Advances in Understanding the Marine Phase of the Salmon Lifecycle

There remain significant gaps in our understanding of the mechanisms that regulate the distribution and survival of Pacific and Atlantic salmon in coastal and especially in high seas environments. During the IYS, there have been significant efforts to better understand the marine phase of the salmon lifecycle, such as the 2018, 2019 and 2022 IYS High Seas Expeditions examining winter ecology. In this sub-theme, advances in the understanding of the marine ecology of salmon and priority areas for future research will be presented.

Sub-theme: The Future for Salmon Aquaculture: Understanding the Impacts of Aquaculture and Considering Emerging Approaches to Mitigation

Aquaculture has had documented detrimental impacts on wild salmon populations. This sub-theme will include presentations on recent advancements in understanding of the impacts of aquaculture on salmon populations and the environments they inhabit, as well as synthesizing current and emerging approaches to improve the environmental and ecological sustainability of aquaculture.

Sub-theme: Hatching Plans: The Future of Fisheries Enhancement Programs

Hatcheries have been a widely applied, but controversial management tool. As salmon populations across the Northern Hemisphere face the intensifying effects of climate change, what role will hatcheries play in conserving wild populations and supporting fisheries? This sub-theme will include presentations on recent and emerging developments in research on the risks and benefits of hatcheries.

Sub-theme: Back to the Future: Advances in Understanding the Value of Fresh and Brackish Water Habitats, their Future with Climate Change, and the Efficacy of Habitat Restoration

Freshwater and brackish habitats are vital to salmon populations and their conservation and restoration remains central to direct salmon management efforts across the Northern Hemisphere. Climate change poses significant risks to salmon and these habitats, and adapting restoration strategies to account for these changes will be critical. This sub-theme will include presentations on the advances in our understanding of how fresh and brackish water habitats influence salmon populations, and the efficacy of habitat restoration and connectivity solutions in the context of climate change.

New Frontiers

Theme Objective: New technologies and analytical methods are advanced and applied to salmon research. Research is carried out to fill gaps in poorly studied regions of the salmosphere.

Sub-theme: Are Uncrewed Vessels the Key for Practicable Monitoring of Salmon and their Ecosystems?

From Saildrones to underwater gliders, the ability of autonomous vehicles and remote systems to survey marine and freshwater environments and help us better understand the effects of climate change is becoming more and more sophisticated. Previously, autonomous vehicles were mostly used to help understand aquatic conditions, like temperature, salinity, and currents. However, the latest autonomous vehicle technologies allow us to start to study entire ecosystems, using tools such as acoustics and environmental DNA. This sub-theme will include presentations on the latest applications of uncrewed vehicles in the research of salmon and their ecosystems, and what they will likely be able to achieve in 10 years' time.

Sub-theme: Tiny Clues, Big Insights: The Use of Genomics in Salmon and Ecosystem Research

The use of technologies that employ DNA and RNA to support research aiming to better understand the origins, abundances, distributions, and health of salmon have grown in popularity in recent years and will likely play a more central role in informing management in the future. This sub-theme will include presentations on the current advances in the applications of salmon genomics in research and management across the Northern Hemisphere, as well as those highlighting promising emerging genomic technologies.

Sub-theme: Tracking the Epic Journeys of Salmon: Advancements in Telemetry and Microchemistry

Despite the rapid development of new genetic technologies, techniques such as telemetry and microchemistry continue to provide invaluable data that allow researchers to gain insights into salmon distributions and life histories. Researchers also continue to find new techniques and applications for these approaches. This sub-theme will include presentations on current and future applications of telemetry and microchemistry.

Human Dimensions

Theme Objective: Communities, Indigenous Peoples, youth, harvesters, scientists and resource managers across the Northern Hemisphere share knowledge and collaborate in the development of new tools and approaches to restoring, managing and sustaining salmon.

Sub-theme: Managing Salmon Fisheries in a Rapidly Changing Salmosphere: The Future of Management

With rapidly changing environmental conditions and consistent declines in many salmon populations across the Northern Hemisphere, it is critical that management systems can adapt to meet dynamic environmental, social, and economic objectives at different spatial scales. This sub-session will include presentations demonstrating the strengths and weaknesses of present and emerging salmon management systems as well as outlining the requirements for climate-resilient management systems.

Sub-theme: Communication of, and Community Engagement in, Salmon Research and Management

Effectively communicating salmon research and management to the broader community is of fundamental importance to ensure salmon conservation receives the social, economic and political support it requires. Furthermore, ensuring that the broader community trusts and feels adequately considered in research and management decisions is also of high importance. This sub-theme will explore successes and challenges related to the communication of salmon research and management, as well as investigating ways in which local communities and individuals outside of science and government have been engaged in the processes of salmon research and management.

Sub-theme: Managing Salmon Fisheries with Indigenous Knowledge and Western Science

Indigenous salmon management and knowledge systems have been sustaining salmon and people across the Northern Hemisphere for millennia. These systems have been replaced by salmon management practices largely rooted in Eurocentric worldviews and Western science. In recent decades, there has been a push to combine Western science and Indigenous Knowledge, but this has seen limited success. Presentations in this sub-theme will explore the conditions necessary and barriers for Indigenous-led management and bridging Western science and Indigenous Knowledge.

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Theme 1: Status of Salmon

Geographic Variation in Plasma Insulin-Like Growth Factor 1 from Salmon Collected in the 2022 Pan-Pacific Expedition

Brian Beckman[1], Meredith Journey[1], Laurie Weitkamp[2], Jackie King[3], Cameron Freshwater[3], and **Ed Farley[4]**

[1]Northwest Fisheries Science Center, National Marine Fisheries Service (NMFS), Seattle, WA, USA

[2]Newport Research Station, NMFS, Newpor,t OR, USA

[3]Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC, Canada

[4]Auke Bay Laboratories, NMFS, Juneau, AK, USA

Insulin-like growth factor 1 (IGF1) is a hormone produced in the liver that directly stimulates cell division and growth. Several studies have demonstrated that plasma levels of IGF1 are correlated with feeding and growth of salmonids, validating that IGF1 can be used as a biomarker for growth in salmon. Plasma samples were obtained from salmon captured in both the US and Canadian legs of the in the 2022 Pan-Pacific Expedition (about 400 samples total), encompassing much of the eastern Gulf of Alaska. As of the writing of this abstract, laboratory analysis has yet to occur for these samples. We will present results at the meeting in October.

All correspondence should be addressed to Brian Beckman.
email: brian.beckman@noaa.gov

Salmon Status in Washington State, USA

Thomas Buehrens[1], Neala Kendall[1], and Scott Boettcher[2]

[1]Washington Department of Fish and Wildlife, 1111 Washington St. SE, Olympia, WA, USA

[2]SBGH Partners, LLC, 2601 Capitol Way S, Olympia, WA, USA

As part of the State of Salmon in Watersheds report for Washington State (https://stateofsalmon.wa.gov/), we produced a quantitative, statistically-sound analysis of salmon and steelhead status and trends using adult abundance times series data. This analysis employs data that consistently represent defined populations and recovery-specific objectives defined by NOAA Fisheries and partners; data that are equivalent across populations and populations groupings so adult abundance findings and results can be readily compared; an analytic method that is consistent with those used by other salmon recovery organizations (e.g., NOAA, tribal co-managers, and regional recovery organizations); an analytic method that is thorough, accurate, and readily reproducible to enable easy updating and sets the stage for live and continuous updating (i.e., cloud and code-based); and an analytic method that is collaborative, collegial, and transparent to further spur cross-organization collaboration across salmon recovery partners. We present our analysis and results to describe the status and recent trends of salmon and steelhead in Washington State and a method that can be used for other regions and salmonid populations.

All correspondence should be addressed to Naela Kendall.
email: Neala.Kendall@dfw.wa.gov

A Data-Driven Approach to Assessing Pacific Salmon Population Status, Habitat Status, and Climate Change Vulnerability

Katrina Connors, Eric Hertz, Katy Kellock, and **Steph Peacock**

Salmon Watersheds Program, Pacific Salmon Foundation, 300 - 1682 West 7th Ave, Vancouver, BC, Canada

Climate change is emphasizing the need to consider the status of Pacific salmon in the context of changes in their freshwater and marine habitats. Fishing pressure alone—and management to restrict fishing—is insufficient to explain and recover continued declines for many populations. Prioritization of efforts to recover and increase resilience of salmon populations requires broad-scale information on the status of both populations and their habitats, paired with forward-looking assessments of climate change vulnerability.

The Pacific Salmon Foundation has taken a data-driven approach to providing this information for all salmon populations in British Columbia. Population status assessments of Pacific salmon Conservation Units and their freshwater habitats were initiated in the Skeena region in 2013, and have since been expanded to include over 90% of salmon populations in BC. Though data quality and availability vary throughout the province, these assessments have significantly advanced the understanding of salmon status in less-studied regions and provided complementary information to expert-based assessments throughout the province.

We found biological status was green for 20%, amber for 7%, and red for 12% of the Conservation Units that could be assessed. Data deficiencies prevented biological status assessments for most sockeye (62%), Chinook (80%) and coho (55%) Conservation Units. The major freshwater habitat pressures vary significantly from region to region throughout the province. Using these results, we tested for relationships between population trends and freshwater habitat status across multiple species, but found limited correspondence between the population and freshwater habitat status at province-wide scales.

Looking forward, we continue to promote the application of these status assessments in recovery planning for at-risk salmon populations. As climate change is emerging as a primary driver of salmon population dynamics, we are working to expand our assessments to include information on climate indicators and Climate Change Vulnerability Assessments for salmon Conservation Units throughout BC.

All correspondence should be addressed to Steph Peacock.
email: speacock@psf.ca

Evidence for Non-stationary Survival and Age of Chinook Salmon Differ Among Marine Regions

Cameron Freshwater[1], Charles Parken[2], Strahan Tucker[1], Antonio Velez-Espino[1], and **Jackie King[1]**

[1]*Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd., Nanaimo, BC, Canada*

[2]*Fraser River and Interior Area Office, Fisheries and Oceans Canada, Kamloops, BC, Canada*

The abundance of many Chinook salmon stocks has declined despite reductions in harvest. We used state-space models parameterized with data from 57 Chinook salmon indicator stocks to quantify long-term (since 1972 release year) changes in juvenile marine survival rate and mean age-at-maturity, as well as identify stock groupings with coherent dynamics. We found that juvenile marine distribution—rather than freshwater life history, run timing, or adult marine distribution—was the best predictor of trends in both survival and age. Only subyearling stocks that enter the Strait of Georgia showed evidence of transitioning to a low juvenile survival regime, other groupings exhibited low and stable or cyclical patterns in survival. Conversely, declines in mean age-at-maturity were widespread and do not appear to have stabilized, suggesting future declines in Chinook salmon population productivity may be influenced by earlier maturation or increased adult mortality, rather than further reductions in juvenile marine survival.

All correspondence should be addressed to Cameron Freshwater.
email: cameron.freshwater@dfo-mpo.gc.ca

The State of Pacific Salmon Stocks in the Russian Far East and its Relation to Climate Variations

Andrey Krovnin and **Albina Kanzeparova**

Russian Federal Research Institute of Fisheries and Oceanography, 19 Okruzhnoi Proezd, Moscow, Russian Federation

Pacific salmon stocks in the Russian Far East remain at the high level. The tendency to the northward shift of salmon distribution appeared several years ago, continues. In 2017–2021, the share of northern stocks in the total Russian pink salmon catch ranged from 80% to 94%, with the main catches off Kamchatka. The shift was associated with substantial warming in the northern North Pacific. On the Sakhalin Island and in the Amur River basin pink salmon stocks decreased essentially that is associated with both the climatic variations at different life stages and excessive fishery pressure (legal and illegal). During the last two years the pink salmon fishery in the Amur River is closed. The growth of chum salmon stocks in the Far East Region began from the mid-2000s, and now they remain at a relatively high level. The same is true for sockeye and coho salmon stocks, about 90% of which are reproduced in Kamchatka. However, in 2020–2021, a decrease in sockeye salmon catches down to the level of 30,000–32,000 metric tons is observed. Also, after the high-abundant approaches of coho salmon in 2014–2015 the decrease in their stocks is noted. In the South Kurils area, there is a growth of pink and chum salmon stocks. The increase in pink salmon abundance is associated with both peculiarities of local hydrological conditions off the Iturup Island and character of climatic variations in the southern Okhotsk Sea during the last years. The growth of chum salmon stock is related to both the increasing volume of hatching and favorable climatic conditions during the marine period of life. It should be noted that during the last years the dynamics of pink and chum salmon stocks in the South Kurils coincided with that off the East Sakhalin Island. The variations in the Far East salmon catches during the last 5 years brings into question the reliability of existing long-range forecasts of their stock state. This, to a large extent, may be associated with the increased short-term climate variability in the North Pacific region. The cooling in the northern North Pacific region in winter seasons resulted in decrease in the Kamchatka pink salmon catches in 2020–2021. We expect the further lowering of Far East salmon stocks in the first half of the 2020s, and the forecast of the total catch for 2022 is 320,000 t that is two times lower than in the record 2018 year.

All correspondence should be addressed to Andrey Krovnin.
email: akrovnin@vniro.ru

Status of Chinook Salmon on the West Coast of Vancouver Island, British Columbia, Canada

Erin L. Rechisky[1], Isobel Pearsall[2], James Irvine[3], Jessica Hutchinson[4], Christian Carson[4], and **Wilf Luedke[1]**

[1]South Coast Stock Assessment, Fisheries and Oceans Canada, 3225 Stephenson Point Road, Nanaimo, BC, Canada

[2]Pacific Salmon Foundation, 1682 7th Ave W Suite 300, Vancouver, BC, Canada

[3]Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd, Nanaimo, BC, Canada

[4]Redd Fish Restoration Society, 286 Main Street P.O Box 641, Ucluelet, BC, Canada

West Coast Vancouver Island (WCVI) Chinook salmon in southern British Columbia, Canada consist of three Conservation Units (CUs): South West Vancouver Island, the Nootka-Kyuquot region, and North West Vancouver Island which were collectively identified as a stock of concern early 30 years ago. To supplement natural spawning populations, about twenty WCVI populations receive some form of hatchery enhancement and currently release approximately 21 million Chinook smolts annually. In recent years, the total annual abundance (catch plus escapement) of adult WCVI Chinook has averaged approximately 250,000; however, about 90% of these fish are of hatchery origin. Despite supplementation efforts, in 2020 two CUs were considered threatened and the third data deficient by the Committee on the Status of Endangered Wildlife in Canada.

To inform a rebuilding plan, a series of workshops in 2021 and 2022 assessed freshwater and marine factors limiting the production of natural fish using the Risk Assessment Methodology for Salmon (RAMS). Numerous Indigenous and multi-stakeholder groups along with Fisheries and Ocean Canada, academic scientists, and other subject matter experts participated in facilitated, multi-day meetings that assessed potential limiting factors to WCVI Chinook including straying of hatchery fish which likely compromises the genetic composition of spawners, contaminants, loss of fresh water and marine habitat, marine heatwaves and climate change, pathogens and parasites, harvest, competition, and predation. This structured process will guide future efforts intended to rebuild these and other populations while considering long-term climate impacts.

We will present WCVI Chinook stock status, methods currently used to assess stock status, as well as preliminary results from the risk assessment.

All correspondence should be addressed to Erin Rechisky.
email: erin.rechisky@dfo-mpo.gc.ca

Distribution and Migration Characteristics of Juvenile Chum Salmon (*Oncorhynchus keta*) in the Coastal Waters of Gangwon Province, Korea

Byoungsun Yoon[1], Dooho Kim[2], Jongkuk Choi[2], and **Jukyoung Kim[2]**

[1]*Researcher, Dahan Ecological Research Institute, Gangwon 25430, Korea*

[2]*Researcher, Aquatic Living Resources Center of East Sea, Korea Fisheries Resources Agency, Gangwon, Korea*

In order to analyze the distribution characteristics and migration characteristics of juvenile chum salmon, a survey was conducted 4 times from March to April 2019 using the surface water pair trawl in the coastal waters of Gangwon province. The survival rate per unit area of juvenile chum salmon averaged 2,302 individuals/km^2 (1,625 to 2,984 individuals/km^2), and the stock increased over time. The total length of juvenile salmon was 5.4±1.2 cm in the 1st survey, 5.8±0.9 cm in the 2nd survey, 6.6±0.9 cm in the 3rd survey, 6.8±0.9 cm in the 4th survey and the total length of juvenile chum salmon increased sharply between the 2nd and 3rd surveys. The condition factor of salmon was highest in the 1st survey, and showed a tendency to decrease in the 2nd and 3rd surveys, but increased in the 4th survey. As a result of analyzing the marked patterns of juvenile chum salmon otoliths, out of a total of 259 individuals, the 3-3-4H pattern accounted for 26 individuals (10.0%) and the 4n-4-2H pattern accounted for 2 individuals (0.8%).

All correspondence should be addressed to Byoungsun Yoon.
email: mzmmz@naver.com

An Updated Baseline for Genetic Stock Identification of Chum Salmon Captured in the International Year of the Salmon High Pan-Pacific Winter High Seas Expedition

Andy Barclay[1], Tyler Dann[1], Sara Gilk-Baumer[1], Heather Hoyt[1], Chris Habicht[1] and **others[2]**

[1]*Alaska Department of Fish and Game, Gene Conservation Laboratory, 333 Raspberry Road, Anchorage, Alaska, USA*

[2]*Additional co-authors are forthcoming, we anticipate authors from Korea, Russia, Japan, Canada, and USA*

Interannual variation in ocean survival among chum salmon stocks has been observed in recent years across the Pacific-wide range of the species, leading to questions about the mechanisms driving these changes. The International Year of the Salmon Pan-Pacific Winter High Seas Expedition offers an unprecedented opportunity to examine stock-specific migration patterns of Pacific salmon in the northeastern Pacific Ocean from February through April. These geographic distributions, combined with oceanographic, trophic, and fish condition data collected during the surveys, should provide insights into the mechanisms behind observed variation in productivity among stocks. Genetic stock identification is the premier method for distinguishing among stocks in fishery mixtures. This method requires a baseline representing all potentially contributing stocks screened for genetic markers that have adequate levels of variation in allele frequencies among stocks. These tissue collections represent a huge international effort with contributions from Korea, Japan, Russia, U.S. and Canada possible through organizations like the NPAFC and PacSNP over the past 36 years. Building on the many baselines that preceded it, the baseline presented here is currently the most comprehensive representation of chum salmon populations that might be found within the survey area. Here we provide an updated single-nucleotide polymorphism (SNP) baseline containing genetic data from over 42,000 fish that includes newly collected populations better representing Pan-Pacific stocks. We provide novel visualization methods to interpret correct allocations to stock and directionality and magnitude of incorrect allocations for individual assignments of fish. This new baseline can distinguish 25 reporting groups making it a useful tool for estimating the contribution of stocks present in mixtures of fish caught on the high seas. This baseline confirms previously identified population structure, resulting in similar reporting groups.

All correspondence should be addressed to Chris Habicht.
email: chris.habicht@alaska.gov

Potential Bottom-Up Effects on Survival of Atlantic Salmon (*Salmo salar*) Inferred by Contrasted Marine Growth Profiles of Salmon at West Greenland and as Survivors to Homewaters

Cindy Breau[1], Gérald Chaput[1], Timothy Sheehan[2], and **Katherine E. Mills[3]**

[1] *Fisheries and Oceans Canada*

[2] *National Marine Fisheries Service*

[3] *Gulf of Marine Research Institute*

The abundances of Atlantic salmon in the North Atlantic have declined since the early 1990s despite extensive fisheries management interventions. Growth at sea of Atlantic salmon is expected to be largely determined by bottom up factors (prey quantity and quality) and survival of salmon is inferred to be dependent upon growth rates and accumulated energy reserves of individual fish. There have been concurrent changes in the physical and biological components of the ecosystem of the North Atlantic, many associated with climate change, which are linked to variations in biological characteristics and sea survival of Atlantic salmon. This project investigated whether the marine growth profiles of Atlantic salmon, inferred from patterns on scales, sampled at West Greenland differ and/or have changed relative to the growth profiles of surviving 1SW and 2SW salmon sampled in rivers. The project made use of an existing collection of Atlantic salmon scales gathered at West Greenland and at two index rivers of eastern North America over the past 50 years to address questions related to the mortality of salmon at sea.

All correspondence should be addressed to Cindy Breau.
email: cindy.breau@dfo-mpo.gc.ca

Before Climate Change: Can Changes in the Continental Origin of Atlantic Salmon in Fisheries Samples at West Greenland be Explained by Reduced Marine Survival or by Changes in Navigational Cues?

Gérald Chaput[1], and **Ian Bradbury**[2]

[1]*Fisheries and Oceans Canada, 343 University Avenue, Moncton, NB, Canada*

[2]*Fisheries and Oceans Canada, 80 East White Hills Road, St. John's, NL, Canada*

Atlantic Salmon (*Salmo salar*) originating from North America (NAC) and Europe (NEAC) are broadly distributed in the North Atlantic and aggregations west of Greenland (WG) during the second year at sea support directed marine fisheries. Many navigational cues, including the magnetic field, are used by salmon during distant marine migrations. The return to natal rivers and this migration ability must be inherited as outmigrating smolts are naïve to the marine environment.

The time series of continent of origin of salmon in fisheries catches at WG, published in the Working Group reports of ICES, show an increased proportion of NAC origin fish; 40% to 60% during 1970 to 1989 versus 70% to 95% since 1995. The increased proportions of NAC origin fish in catches contrasts with the decreasing proportions that the NAC salmon represent of the total reconstructed prefishery abundances (PFA).

Errors in the assumed total mortality rates of salmon after the WG fishery could explain the changes in the proportions of the continent complexes in the catches. The PFA reconstructions assume a fixed mortality rate of 3% per month from the period at WG to returns to homewaters. If the total mortality rate of NAC salmon had increased over time from 3% to >10% per month while the mortality rate on NEAC salmon had remained unchanged, the proportions in the catches would be consistent with the reconstructed PFAs.

An alternate explanation is that the proportion of the PFA from NEAC that goes to WG has decreased over time. The earth's north magnetic pole moves in unpredictable ways and the annual drift has accelerated since the 1990s. The drift results in changes in the magnetic field components potentially used by salmon for orientation. Over the extended period of 1590 to 2020, the declinations (degree between the main axis of the magnetic force and the geographic north pole) at the NAC locations have been consistently directed west of geographic north, pointing to WG. This contrasts with the NEAC locations where the declinations have alternated from east of geographic north, west towards southeast Greenland, and increasing again since the late 1900s to declination values directed toward northeast Greenland. These relatively rapid changes in the geomagnetic field components would produce differing navigation cues to salmon resulting in migration and aggregation to different areas of the North Atlantic.

All correspondence should be addressed to Gérald Chaput.
email: Gerald.Chaput@dfo-mpo.gc.ca

Adapting Pacific Salmon Management Systems to an Increasingly Warm and Crowded Ocean

Brendan Connors[1], Gregory T. Ruggerone[2], and **James Irvine[3]**

[1] *Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, Canada*

[2] *Natural Resources Consultants, Seattle, WA, USA*

[3] *Pacific Biological Station, Fisheries and Oceans Canada, Nanaimo, BC, Canada*

The North Pacific Ocean is warming and overall salmon abundance remains high, in large part due to industrial scale hatchery production. Increasing and more variable temperatures, as well as competition among salmon at sea, have been associated with shifts in salmon productivity, body size, and age-at-maturation. These relationships vary by species, location, and over time, resulting in increased harvest opportunities in some regions and exacerbated conservation risks in others. We summarize the evidence for the effects of ocean warming and competition among salmon at sea on Pacific salmon, identify key knowledge gaps, outline opportunities to fill them, and describe where we expect new fishing opportunities to occur. We conclude with a research prospectus to improve understanding of Pacific salmon responses to changing ocean climate and competition among salmon at sea, and outline how fishery management systems might adapt to better utilize increases in overall salmon abundance while mitigating the adverse consequences of it for at-risk populations. Improved communication and collaboration among North Pacific fishery research and management agencies will be key to balancing the benefits and risks of a warming and more crowded ocean.

All correspondence should be addressed to Brendan Connors.
email: Brendan.connors@dfo-mpo.gc.ca

Chum Salmon in the Canadian Arctic Tell a Story of Resilience Amidst Change

Karen M. Dunmall[1], Darcy G. McNicholl[1], Zander Chila[2], Trevor Lantz[2], Sara Gilk-Baumer[3], Chris Habicht[3], William Templin[3], Vanessa Von Biela[4], and **Chris Zimmerman[4]**

[1] *Freshwater Institute, Fisheries and Oceans Canada, 501 University Cr., Winnipeg, MB, Canada*

[2] *University of Victoria, 8205, School of Environmental Studies, Victoria, BC, Canada*

[3] *Alaska Department of Fish and Game, 333 Raspberry Rd, Anchorage, AK, USA*

[4] *Alaska Science Center, US Geological Survey, Anchorage, AK, USA*

Chum salmon have been present in the Mackenzie River, Northwest Territories, Canada for generations, perhaps even thousands of years. As such, they are resilient, presumably surviving massive freshwater and marine environmental changes, including glacial retreat, fluctuating temperatures, and shifting suitable habitats. Indeed, the presence of chum salmon in the Arctic is not new and is known to Arctic Indigenous peoples. What is perhaps surprising, however, is the apparent ability of chum salmon to respond rapidly to environmental change at the northern edge of their distribution. This is manifesting as spikes in chum salmon harvests, as these fish are caught as bycatch in subsistence fisheries targeting Arctic species in places both with and without a history of salmon harvests. It is these newest arrivals that are concerning to Indigenous harvesters due to potential disruptions to culture and also interactions with Arctic fishes. Indeed, these chum salmon are key indicators of broader ecosystem-level changes. In the marine environment, shifts in habitat suitability are facilitating distributional shifts northward. In the fresh water, these changes may improve spawning success and survival of juvenile phases. An age-0 chum salmon was recently captured in the Alaskan north slope nearshore ecosystem, and is the first juvenile Pacific salmon confirmed in the North American Arctic. Clearly, chum salmon have been present historically, are increasing recently, and can spawn successfully. Arctic habitats are currently suitable, chum salmon can respond rapidly to environmental change, and these changes are presumably generally expanding access. There is no longer a need for scientists to question whether Pacific salmon are established in the North American Arctic. Whether that represents a challenge or an opportunity, however, depends on perspective and that remains an important piece to consider when trying to understand shifts amidst all of the changes.

All correspondence should be addressed to Karen Dunmall.
email: Karen.Dunmall@dfo-mpo.gc.ca

Pacific Salmon in the Atlantic Ocean: Effects Increasing with Climate Change

Kjetil Hindar[1], J. Henrik H. Berntsen[1], Odd Terje Sandlund[1], Eva B. Thorstad[1], and **Kyrre Kausrud[2]**

[1]*Norwegian Institute for Nature Research, NO-7485 Trondheim, Norway*

[2]*Norwegian Veterinary Institute, NO-1431 Ås, Norway*

Pink salmon (*Oncorhynchus gorbuscha*) were for many years transplanted from the Pacific to the Barents and White Sea for increasing opportunities for local fisheries. Transplanted fish survived but did at first not establish. After choosing a donor stock further north in the Pacific Magadan Oblast from 1985 onwards, transplants were successful and soon thereafter established self-sustaining populations in Northwest Russia. Pink salmon were also found in North Norwegian rivers and may have established populations there around 2007. In 2017, an unprecedented expansion of pink salmon was seen in the Atlantic Ocean, including all of Norway, Scotland, Denmark and Sweden, Scotland and elsewhere in the UK, Ireland, Germany, and France. Some pink salmon were observed even further west in Iceland, Greenland, and eastern Canada. In Norway, this was followed by a doubling of catches in 2019 and on top of that, a 10X-increase in 2021. Pink salmon is now the most common anadromous salmonid in Norwegian rivers, and in the northernmost counties, they outnumber the sum of all other anadromous salmonids: Atlantic salmon (*Salmo salar*), anadromous brown trout (*S. trutta*) and anadromous Arctic charr (*Salvelinus alpinus*). Effects on native salmonids include aggressions towards upmigrating individuals, blocking and possibly displacing them from some spawning areas, and competition for food and space among juveniles during early life in the river. Pink salmon may also act as vectors for fish diseases, potentially harmful to both wild and farmed salmon, and they enforce ecosystem effects by transporting nutrients from the ocean to formerly nutrient-poor rivers. Modeling indicates that increasing water temperatures in the north in spring and early summer favor pink salmon survival and increase spawning population size. Climate predictions from current scenarios suggest larger pink salmon populations in the future, and we speculate that warming of Arctic waters can lead to pink salmon establishing as a circumpolar species.

All correspondence should be addressed to Kjetil Hindar.
email: kjetil.hindar@nina.no

Status and Trend of Production of Japanese Chum Salmon Under the Warming Climate

Masahide Kaeriyama

Arctic Research Center, Hokkaido University, N21 W11, Sapporo, Hokkaido, Japan

In this century, Pacific salmon (*Oncorhynchus* spp.) productivity have declined in southern areas but increased in northern areas owing to a warming climate in the North Pacific Ocean. Return of Japanese chum salmon (*O. keta*), mainly hatchery-produced fish, has exponentially decreased in this century. Salmon are roughly divided into two populations: cold-current populations (CCPs) affected by the Oyashio cold current, and warm-current populations (WCPs) affected by the Tsushima warm current in Japan. The decreasing tendency of the population size of CCPs was greater than that of WCPs, suggesting that WCPs are relatively more adaptable to the warming climate. Based on the Lotka–Volterra competition model of intra-specific interactions between Japanese and Russian chum salmon sympatrically distributed in the Sea of Okhotsk, against Russian chum salmon, Japanese chum salmon was the winner until the 2011 brood year, and became coexistent or a loser after that. According to the scale back-calculation of adult chum salmon returning to the Tsugaruishi River, increased fork length (L_c) of juvenile salmon in the coast area showed significantly declining temporal-trend and positive-correlation with survival rate, but their increased fork length (L_o) in the Sea of Okhotsk indicated no temporal-trend and correlation with survival rate. This result supports the size-selective mortality hypothesis. In the Bering Sea, no temporal-trends were observed in increased fork lengths at age-2 and age-3 (L_2, L_3), but that at age-4 (L_4) clearly increased over time and negatively correlated with the survival rate. This may indicate that their final growth at age-4 compensates for the spawning migration. Japanese chum salmon seems to be difficult to adapt well for the extreme warming climate in the near future. Therefore, it is necessary to establish sustainable salmon conservation management under a warming climate regime as following final goals: (1) conservation and recovery of wild salmon, and zoning between wild and hatchery-produced salmon, (2) long-term research and monitoring of interactions between aquatic ecosystems and salmon, and (3) restoration and resilience of wild salmon and river ecosystems.

All correspondence should be addressed to Masahide Kaeriyama.
email: salmon@ab.auone-net.jp

Pink Salmon in the North American Arctic: Natural Expansions from the Pacific or Invasions from the Atlantic?

Elizabeth Lee[1], Tyler Dann[1], Karen Dunmall[2], Sten Karlsson[3], Anthony Gharrett[4], Trent Sutton[4], Kyle Shedd[1], Wei Cheng[1], Chris Habicht[1], and **Sara Gilk-Baumer[1]**

[1]*Gene Conservation Laboratory, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK, USA*

[2]*Freshwater Institute, Fisheries and Oceans Canada, 501 University Cr, Winnipeg, MB, Canada*

[3]*Norwegian Institute for Nature Research, P.O. Box 5685 Torgarden, 7485 Trondheim, Norway*

[4]*College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 2150 Koyukuk Drive, Fairbanks, AK, USA*

Climate and human induced shifts in Pink Salmon distribution have been documented across the Northern Hemisphere, including expansion into Arctic regions. An improved understanding of the origin of invading salmon populations will benefit research and management of the species. We present genetic observations of Pink Salmon (*Oncorhynchus gorbuscha*) expansions into the Alaskan and Canadian Arctic to shed light on the relative roles of climate and human influences on the distribution and establishment of these invading salmon. To do this, we genotyped baseline Pink Salmon collections from the natural range across the Pacific Rim, from Norwegian rivers that represent secondary colonizations from stocking operations in the White Sea, and from the Great Lakes that represent secondary colonizations from an accidental release. We then genotyped samples of invading Arctic Pink Salmon for evidence of: origin, deviation from the strict 2-year life history found in their natal range (but not in some introduced areas), and self-sustaining populations. For origin, we test the hypothesis that North American Arctic individuals originate from natural colonization from the Pacific Ocean, from the Russian stocking in the White Sea (1956–1979; 1985–1999) of Magadan region stocks, or from the Canadian accidental release into the Great Lakes (1955) of a British Columbia stock. We screened 298 amplicons in a genotyping-in-thousands by sequencing panel to examine conformance to Hardy-Weinberg Equilibrium expectations, heterozygosity, and genetic relationships to baseline populations.

All correspondence should be addressed to Elizabeth Lee.
email: elizabeth.lee@alaska.gov

Variation in Natural Coho Life History Expression and Survival Linked to Nearshore Oceanography and Climate Regime

Marisa N.C. Litz and **Mickey Agha**

Washington Department of Fish and Wildlife, 1111 Washington St. SE, Olympia, WA, USA

Effective management of coho salmon begins with accurate annual forecasts of adult abundance. In western Washington, resource management decisions have benefited from a life cycle monitoring program where a full census juvenile and adult trap has operated since 1982. Annually at the trap, all juveniles were marked with a coded wire tag and released. Returns of marked precocious males (jacks) and recoveries of tagged adults in fisheries and at the trap were used to estimate marine survival. Over time, there has been considerable variation in juvenile production, jack rates, and adult returns. Variation in marine survival and life history diversity were evaluated with respect to environmental conditions experienced during both freshwater and marine life history phases using generalized additive mixed models. Results were used to identify limiting life history stages. Juvenile outmigration timing and size did not vary through time, although earlier migrating smolts had higher overall jack and adult survival rates. Notably, the expression of jack life history increased through time, especially following a breakpoint in 2005, a year characterized by delayed upwelling in nearshore habitats. Instream conditions experienced during the juvenile rearing period had minimal effect on life history expression and smolt survival compared to nearshore oceanographic conditions immediately following freshwater emigration, supporting the idea that jack rate and recruitment strength is mostly determined during the early marine period. Forecast models also identified differences in marine survival associated with ecological climate regimes related to El Niño Southern Oscillation. Coho management tools such as forecasting benefit from a holistic perspective that considers environmental variation throughout the entire life history.

All correspondence should be addressed to Marisa Litz.
email: marisa.litz@dfw.wa.gov

Potential changes in biological characteristics of juvenile Atlantic salmon (*Salmo salar*) over the past 50 years and linkages to environmental factors

Jean-Michel O. Matte[1,2], Guillaume J.R. Dauphin[2], Cindy Breau[2], Carole-Anne Gillis[3], André St-Hilaire[1], and **Normand E. Bergeron[1]**

[1] *Institut National de la Recherche Scientifique – Centre Eau Terre Environnement, 490 de la Couronne, QC, Canada*

[2] *Fisheries and Oceans Canada, 343 Université Avenue, Moncton, NB, Canada*

[3] *Gespe'gewaq Mi'gmaq Resource Council, Listuguj, QC, Canada*

Abundances of Atlantic salmon have steadily declined from exposure to various stressors, including increasing thermal stress events with warming water temperatures in freshwater habitats. Temperature is a strong driver of somatic growth, and can induce cascading effects on foraging behavior, competition, and ultimately, population dynamics of salmon. Furthermore, the effect of temperature on growth is often context-dependent and variable among populations, compromising our ability to forecast the potential effects of climate change. Using monitoring data from two Atlantic salmon populations from Eastern Canada (Margaree and Miramichi rivers), we show that incorporating hierarchical structure (in space and in time) can help quantify variability in growth patterns and how they relate to temperature. This flexible and promising approach also allows data-rich sites to inform relationships in data-poor sites.

All correspondence should be addressed to Jean-Michel Matte.
email: jeanmichelmatte3@gmail.com

Embedding Atlantic Salmon Stock Assessment Within a Bayesian Life Cycle Modeling Framework: A Route for an Ecosystem-Based Management for this Species.

Etienne Rivot[1,2], Rémi Patin[1,2], Maxime Olmos[1,2,3], Pierre-Yves Hernvann[1,4,5,6], Marie Nevoux[1,2], Stephen Gregory[7], Etienne Prévost[2,8], and **Gérald Chaput [9]**

[1]*UMR DECOD (Ecosystem Dynamics and Sustainability), Institut Agro, INRAE, Ifremer, Rennes, France*

[2]*Management of Diadromous Fish in their Environment, OFB, INRAE, Institut Agro, Université de Pau et des Pays de l'Adour, Rennes, France*

[3]*School of Aquatic and Fishery Sciences, University of Washington, Seattle WA, USA*

[4]*Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle WA, USA*

[5]*Institute of Marine Sciences, University of California, Santa Cruz, Santa Cruz, CA, USA*

[6]*Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle WA, USA*

[7]*Centre for Environment, Fisheries & Aquaculture Science, United Kingdom*

[8]*ECOBIOP, INRAE, Université de Pau et des Pays de l'Adour, e2s UPPA, Saint-Pée-sur-Nivelle, France*

[9]*Fisheries and Oceans Canada, Moncton, NB, Canada*

Many wild Atlantic salmon populations have declined dramatically over the past decades. Identifying the drivers of such decline and understanding how they affect population dynamics is a prerequisite for sound science-based assessment and management of this species. This raises challenges for this anadromous fish that is exposed to multiple environmental and anthropogenic stressors at different life stages across wide ranging ecosystems and scales. This is even more challenging because available data rarely cover the full range of these scales and ecosystems and are scattered across multiple management jurisdictions. Consequently, so far, most salmon stock assessment models remain mostly phenomenological and have failed to consider ecosystem drivers of population dynamics (e.g., oceanographic conditions, prey availability). Thus, they often have limited forecasting ability, especially under changing conditions such as global warming or altered food supplies.

We developed a new stage-based life cycle model to improve our understanding of the mechanisms that shape the dynamics of Atlantic salmon populations in the North Atlantic basin and to strengthen the scientific basis of stock assessment models used by ICES Working Group for North Atlantic Salmon assessment (WGNAS). The dynamics of all stock units considered by WGNAS are jointly analyzed within a single and unified model. It allows for analyzing historical time-series of data to infer changes in both marine survival and maturation schedule over the last five decades across the North Atlantic basin. It provides a tool for evaluating the synchronicity of the signal in key life history traits among groups of populations impacted by the same drivers, and for testing hypotheses on the influence of environmental drivers in space-time domains occupied by salmon during their marine migration. To facilitate the effective use of this model for stock assessment by ICES, we have developed an online database and a web interface that strengthen the robustness of the workflow from data processing to hindcasting and management scenarios evaluation.

The new modelling framework hence constitutes an important tool for future improvement of our understanding of the drivers and mechanisms that shape the dynamic of Atlantic salmon populations. It is easily expandable, favors data mobilization and the assimilation of new sources of information when they become available. It offers an analytical framework to test ecological hypotheses and to provide more realistic assessments and forecasts based on a more complete understanding of the drivers governing Atlantic salmon productivity.

All correspondence should be addressed to Etienne Rivot.
email: etienne.rivot@agrocampus-ouest.fr

Ocean Basin to Watershed Modeling of the North Pacific Provides a New Basis for Modeling Climate Change Impacts on Salmon

Charles Seaton[1], Antonio Baptista[2], David Graves[1], Alexander Kurapov[3], Greg Seroka[3], and **Y. Joseph Zhang[4]**

[1]Columbia River Inter-Tribal Fish Commission (CRITFC), 700 NE Multnomah St., Suite 1200, Portland, OR, USA

[2]Oregon Health & Science University (OHSU)

[3]NOAA/NOS/OCS Coast Survey Development Lab (CSDL)

[4]Virginia Institute of Marine Science (VIMS)

The Columbia River Inter-Tribal Fish Commission (CRITFC), in partnership with NOAA and academia, has developed a new model for the Pacific Basin that seamlessly represents processes across ocean basin to estuary and watershed spatial scales. Ocean circulation models used to evaluate climate change impacts on salmon in the open ocean and coastal/estuarine domains have previously had fundamental limitations due to different models required for different spatial scales. Recent improvements in the ability of a varying-resolution (unstructured grid) circulation model to represent the eddying regime of the open ocean make it possible to create a continuous representation across basin-scale open ocean processes (such as the North Pacific Gyre currents and eddies), coastal processes (including upwelling and coastally trapped waves) and estuary and watershed processes (including river plumes, salinity intrusion in estuaries, and storm-driven rain runoff). The new model for the Pacific Basin extends from the Bering Strait to 30 degrees South latitude and incorporates high resolution representations of areas of interest, including the Columbia River estuary. It uses the modeling code SCHISM to provide a three-dimensional, tidal, baroclinic representation of the ocean. After minimal calibration, the model demonstrates cross-scale skill in representing ocean and estuary features during a one-year (2018) simulation, including basin-scale currents, coastal upwelling, coastally trapped waves, salinity intrusion within the Columbia River estuary, and basin-wide elevations, both tidal (median complex error in semi-diurnal tide of 0.08 m) and non-tidal (median root-mean-square error of 0.06 m). The Pacific model is forced using atmospheric models, river discharge, harmonic tidal models, and global ocean models at the boundaries, and it can be forced using global climate model results for climate change scenarios. It therefore has the potential to explore cross-scale interactions under climate change scenarios, such as interactions between changes in major currents and changes in coastal river plume size and timing. Although not included in the existing stage of development of this model, it can be extended to incorporate nutrient-phytoplankton-zooplankton-detritus (NPZD) models and its results can be incorporated into salmon life cycle and ecosystem modeling. Because oceanographic conditions experienced by salmon during their immediate entry and first year at sea are critical to overall survival and growth of a given year class, improving the resolution and quality of oceanographic data will help explain more variation in current and projected estimates of salmon productivity.

All correspondence should be addressed to Charles Seaton.
email: cseaton@critfc.org

Theme 2: Information Systems

Predicting Post-Smolt Migration and Orientation Behaviour in the Gulf of St. Lawrence through Individual Based Modeling

Jason Daniels[1], Diane Lavoie[2], Joël Chassé[3], Martin Castonguay[2], and **Jonathan Carr[1]**

[1]*Atlantic Salmon Federation, St. Andrews, NB, Canada*

[2]*Maurice-Lamontagne Institute, Fisheries and Oceans Canada, Mont-Joli, QC, Canada*

[3]*Gulf Fisheries Centre, Fisheries and Oceans Canada, Moncton, NB, Canada*

Atlantic salmon are a long-distance migratory species which has experienced dramatic population declines in the last several decades. There is increasing evidence that high mortality during the post-smolt period may be bottlenecking recovery efforts. Unfortunately, there is little information known about how post-smolts are distributed within the ocean environment and what orientation mechanisms are utilized to undertake these long-distance migrations. Large scale telemetry projects are beginning to provide valuable information with respect to migration timing and early at sea survival for some populations of Atlantic salmon. One such project has been using acoustic telemetry to describe migration survival and timing of Atlantic salmon smolts and post-smolts from several Southern Gulf of St. Lawrence (GoSL) rivers since 2003. Since 2007 an acoustic telemetry receiver line has been installed seasonally across the Strait of Belle Isle (SoBI), the preferred exit from the GoSL for post-smolts migrating to the Labrador Sea. Entry of these fish into the GoSL generally occurs asynchronously between populations from early May to mid June. Interestingly, however, populations exit the GoSL with a surprising temporal overlap. The slope of the relationship between entry and exit of these populations is generally consistent between years, however, some interannual variation exists in the intercept. Furthermore, the interannual variation corelates well with variation of GoSL sea surface temperature. We used an individual based model (IBM) to track simulated particles through an ocean circulation model to refine and/or define potential theories regarding orientation mechanisms of migrating post-smolt. These particles represent acoustically tagged post-smolt observed entering and exiting the GoSL from 2007 to 2018. Contrary to previous studies employing IBM's in relation to Atlantic salmon, we found that neither thermotaxis nor positive/negative rheotaxis alone permit the simulated particles to exit the GoSL through the SoBI. Preliminary analysis suggests that post-smolts are influenced by the 10 ºC isocline in addition to what we interpret as a magnetic attractant towards the Labrador Sea. Recent studies suggest this magnetic orientation mechanism is utilized by several species of salmonids among many other long-distance migratory species. Migration timing does appear to be linked to near surface ocean temperatures with the rate of warming leading to quicker transit times across the GoSL. This could lead to potentially smaller and less fit individuals arriving into the Labrador Sea before the first winter sea.

All correspondence should be addressed to Jason Daniels.
email: jdaniels@asf.ca

Improving Data Mobilization within the Salmosphere

Scott Akenhead[1], Hlynur Bardarson[2], Jennifer Bayer[3], Tom Bird[4], Deirdre Brophy[5], Colin Bull[6,7], Graeme Diack[6], Elvira de Eyto[8], Nora Hanson[9], Brett Johnson[10], Matt Jones[11], Alexis Knight[12], Bryce Mecum[11], Marie Nevoux[13], Tim van der Stap[10], Alan Walker[14], and **Vidar Wennevik[15]**

[1]Fisheries and Oceans Canada (retired), ORCID:0000-0003-1218-3118

[2]Institute of Marine and Freshwater Research, Iceland

[3]United States Geological Survey, USA

[4]Department of Fisheries and Oceans, Canada

[5]Galway Mayo Institute of Technology, Ireland

[6]Atlantic Salmon Trust, Scotland, Battleby House, Redgorton, Perth, PH1 3EW, UK

[7]Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK

[8]Marine Institute, Ireland

[9]Marine Scotland Science, UK

[10]Hakai Institute, PO Box 25039, Campbell River, BC V9W 0B7, Canada

[11]National Centre for Ecological Analysis and Synthesis, USA

[12]Nova Scotia Salmon Association, Canada

[13]National Research Institute for Agriculture and Food, France

[14]Centre for Environment, Fisheries, and Aquaculture Science, UK

[15]Institute of Marine Research, Norway

The population declines faced by many salmon species globally have occurred in spite of massive research and conservation efforts. The capacity to turn these globally distributed efforts into informed management actions is limited by a lack of internationally coordinated publication of data for re-use by others. Useful resources tend to remain minimally accessible outside of their immediate participants, constraining opportunities for researchers to work collaboratively on broad-scale insights and solutions. A significant aspect of this failure to halt population declines therefore lies squarely in the domain of information logistics and management. Creating the environment in which these efforts can be shared and understood for the broader research insights they may provide—or Data mobilization (DM)—has been identified as a key step towards the research insights and informed management actions (knowledge mobilization) needed to address this crisis. Requirements for DM include the FAIR Guiding Principles, which aim to optimize the re-use of data by making them easily discoverable, with rich metadata, standard vocabulary, and clear access protocols. FAIR data practices allow for greater analytical power through improved access to the existing, rich, data resources across diverse contexts, such as those that exist for most salmon species. This wider evidence base can then in turn provide support for more effective, accountable, and reliable application of data insights to management—or knowledge mobilization (KM). While Data mobilization is growing in the research community as a whole, it has yet to penetrate deeply into the culture of salmon research and conservation. To support this transition, we assemble a variety of stakeholder perspectives to provide a salmon-focused definition of mobilized data. We review the spectrum of DM participants and identify modern and innovative methods used as well as barriers and opportunities to mobilize their data for the broader good. We present examples of DM failures and successes, discuss how these illuminate barriers to DM, and discuss approaches to removing these barriers. We broach the problem of representing complex resources within general DM innovations, e.g., Indigenous Knowledges (IK, TEK), and physical samples. Based on these reviews, we sketch a future of salmon DM and propose functional changes required to improve DM throughout the salmon community. Overall, we call for new community practices and progressive cultural adoption that facilitates wide and rapid salmon DM as befits the crisis.

All correspondence should be addressed to Graeme Diack.
email: graeme@atlanticsalmontrust.org

The Atlantic Salmon Research Joint Venture: Opportunities and Challenges of a Collaborative Community Response to Answering Atlantic Salmon's Big Questions

Edmund Halfyard[1], Carole-Anne Gillis[2], Alexis Knight[3], Julien April[4], Normand Bergeron[5], Ian Bradbury[5], Cindy Breau[5], Jonathan Carr[6], Corey Clarke[7], Kathryn Collet[8], Chris Connell[8], Guillaume Dauphin[3], Wendy Epworth[9], David Hardie[3], John Kocik[10], Diane Lavoie[3], Tommi Linnansaari[11], Kristin Loughlin[3], Roseanne MacFarlane[12], Shannan May-McNally[3], Dustin Raab[3], David Reddin[13], Martha Robertson[3], Kurt Samways[11], Andre St. Hilaire[5], and **Fred Whoriskey[14]**

[1]Nova Scotia Salmon Association, 103-321 Amesbury Gate, Bedford, NS B4B 0W8, Canada

[2]Gespe'gewaq Mi'gmaq Resource Council, Listuguj, QC G0C 2R0, Canada

[3]Fisheries and Oceans Canada, 343 Université Avenue, Moncton, NB E1C 9B6, Canada

[4]Ministère des Forêts, de la Faune et des Parcs, 5700 4[e] Av O, QC G1H 6R1, Canada

[5]Institut National de la Recherche Scientifique, 490 de la Couronne, QC G1K 9A9, Canada

[6]Atlantic Salmon Federation, 15 Rankine Mill Rd, Chamcook, NB E5B 3A9, Canada

[7]Parks Canada, 8 Headquarters Campground Road, Alma, NB, Canada

[8]NB Department of Natural Resources, 1350 Regent St, Fredericton, NB E3C 2G6, Canada

[9]Fort Folly First Nations, PO Box 1007, Dorchester, NB E4K 3V5, Canada

[10]NOAA, 166 Water St, Woods Hole, MA 02543-1026, USA

[11]University of New Brunswick, 3 Bailey Dr, Fredericton, NB E3B 5A3, Canada

[12]PEI Department of Fish and Wildlife, 183 Upton Rd, Charlottetown, PEI C1E 1Z5, Canada

[13]Atlantic Salmon Conservation Foundation, 480 Queen St, Fredericton, NB E3B 1B6, Canada

[14]Dalhousie University, 6299 South St, Halifax, NS B3H 4R2, Canada

With both an international distribution and an anadromous life cycle, producing meaningful and broad-ranging Atlantic salmon research has historically been a complex undertaking for the scientific community. Adequate testing of drivers of population decline such as low marine survival and freshwater habitat conditions has been slow to progress due to a lack of sufficient resources, various complexities involved in data mobilization, and a lack of overall coordination in the salmon research and conservation community. In order to respond to these issues, the Atlantic Salmon Research Joint Venture was formed in 2016 as a collective of collaborative partnerships between academic, government, non-profit and indigenous organizations to promote synergistic projects that address three priority research themes: 1) Identifying and comparing trends in abiotic and biotic historical freshwater data to determine influences on smolt condition, outmigration behaviour and marine phase mortality; 2) Investigating whether poor marine survival is the result of a genetic bottleneck selecting for specific traits, and 3) Mobilizing the collection of new information to establish linkages between freshwater conditions and the marine survival of Atlantic salmon. This research relies on combining a backwards-looking approach that collates the abundance of pre-existing high-quality data normally not shared across agencies to address historical data questions, with a forwards-looking approach that identifies understudied sites across the East coast and mobilizes resources to fill the information gaps. By pooling resources and building a sense of trust amongst previously independent stakeholders, the Joint Venture presents an example of an effective strategy for answering salmon's big questions through collaboration.

All correspondence should be addressed to Alexis Knight.
email: alexis.knight@dfo-mpo.gc.ca

The International Year of the Salmon Ocean Observing System

Tim C.A. van der Stap and **Brett T. Johnson**

Hakai Institute, PO Box 25039, Campbell River, BC V9W 0B7, Canada

Data mobilization—the process of making data available for appropriate re-use—remains a key barrier in effective salmon management. Data is often stored in disparate, heterogeneous datasets, and integration across information systems is lacking, limiting our collective capacity to develop a mechanistic understanding of what drives salmon productivity across their complex life histories. To facilitate data sharing, citation, synthesis, meta-analyses, and management-decision support-tools, data mobilization efforts can be improved by publishing metadata records and standardized data to domain-specific repositories to make otherwise disparate salmon data discoverable, interoperable and rapidly synthesized. The International Year of the Salmon (IYS) High Seas Expeditions in 2019, 2020, and 2022 represented a significant challenge and opportunity for data mobilization efforts due to the scale, volume, and diversity of data. The North Pacific Anadromous Fish Commission partnered with the Hakai Institute to develop a strategy to mobilize data collected from the IYS High Seas Expeditions. Given the international nature of the project, a natural alignment to the United Nation's Global Ocean Observing System was realized and the International Year of the Salmon Ocean Observing System was created. Under this framework datasets with Essential Ocean Variables were identified using metadata records and were assigned digital object identifiers to permit and encourage data citation. Metadata records were published to a web accessible data catalogue (iys.hakai.org) developed using federated architecture. Where possible, existing community and international data and metadata standards and controlled vocabularies were adopted and data were published in domain-specific repositories. However, data mobilization barriers are not only technical but also sociocultural. Drawing on lessons from the 2019 and 2020 expeditions, a standard data exchange template and a clear data sharing policy were developed in advance of the 2022 expedition. A small fraction of the data collected in the 2019 and 2020 expeditions have been published in domain-specific repositories, likely as a result of insufficient data sharing policies and clear timelines. We anticipate the 2022 pre-expedition data management guidance, data sharing policy development, and standard data exchange template will significantly improve the sociocultural adoption of data sharing and citation practices. Both the sociocultural solutions and technical infrastructure developed during the IYS lay a foundation and clear path forward for international salmon data exchange and will continue to evolve with the United Nations endorsed Basin Events to Coastal Impacts project, deepening the impact and legacy of the International Year of the Salmon.

All correspondence should be addressed to Tim van der Stap.
email: tim.vanderstap@hakai.org

Theme 3: Salmon in a Changing Salmosphere

The Likely Suspects Framework for Atlantic Salmon: Cooperatively Building the Foundations for a Life-Cycle Approach to Guide Future Management

Colin Bull[1,3], Walter Crozier[1], Graeme Diack[1], Neil Banas[2], and **Emma Tyldesley[2]**

[1]*Missing Salmon Alliance, Atlantic Salmon Trust, Battleby House, Redgorton, Perth, UK*

[2]*University of Strathclyde Department of Mathematics and Statistics, 26 Richmond Street, Glasgow, UK*

[3]*Biological and Environmental Sciences, University of Stirling, Stirling, UK*

This paper outlines the importance, relevance and new opportunities offered by the development of the Likely Suspects Framework approach to the future of Atlantic salmon management. It presents an update on the progress of the programme being led by the UK Missing Salmon Alliance, advancing a series of linked work packages focused upon the provision of new decision-support tools for salmon managers to assist their efforts to address the salmon crisis. It is developing and delivering tools that help strengthen resource sharing and knowledge exchange amongst the research, resource and salmon management communities spanning both the freshwater and ocean stages of the salmons' life.

The programme is advancing multiple components of a mortality framework for Atlantic salmon that highlight the importance of taking a whole life-cycle view when formulating future management plans for threatened salmon resources. This framework is organised around a model representation of state and life stage survival changes, and on using this to focus cooperative attention on advancing our understanding of the processes and controls over salmon survival throughout the lifecycle. By representing stage and lifetime mortality variation, and highlighting potential bottleneck points and influencers, it sets out a theoretical framework for testing priority mortality-hypotheses, linked to key life-stage domains.

New knowledge for the development of the mortality framework and management decision support outputs is being provided by undertaking a use-case implementation study on a sub-set of well-studied southern European salmon stocks. Drawing together novel data synthesis and modelling techniques this programme is testing priority hypotheses concerning the drivers of mortality variation during the initial post-smolt marine migration phase (0–3 months), when mortality is generally considered to be highly variable and potentially influenced by body size and condition. By evaluating newly-synthesized, variously scaled and time-lagged ecosystem signals we are gaining new insights on the possible controls over early marine survival fluctuation, and the potential for utilising new ecosystem condition signals as indicators when building future survival forecasts.

A purpose-built, shared, data repository supports the Likely Suspects Framework programme development. This interoperable resource also promotes wider access to resources by the research and management communities, and the evaluation of novel ecosystem indicators that may play important roles in the movement towards adopting a wider ecosystem-based approach for future salmon management. Advanced user-interface applications are being developed as framework outputs that provide novel scenario-testing capabilities for salmon managers, contributing new and effective decision-support regarding the efficiencies and scale of actions necessary to conserve stocks, and promote recovery.

All correspondence should be addressed to Colin Bull.
email: colin@atlanticsalmontrust.org

Rapid Increase in Invading Pink Salmon (*Oncorhynchus gorbuscha*) Abundance and Distribution Within a Large Barents Sea Catchment, the River Teno/Tana

Jaakko Erkinaro[1], Panu Orell[1], Morten Falkegård[2], Frode Fossøy[3], Jan-Peter Pohjola[4], Jorma Kuusela[4], Karl Gjelland[2], Narve Johansen[2], and **Eirik Frøiland[5]**

[1]*Natural Resources Institute Finland (Luke), Oulu, Finland*

[2]*Norwegian Institute for Nature Research, Tromsø, Norway*

[3]*Norwegian Institute for Nature Research, Trondheim, Norway*

[4]*Natural Resources Institute Finland (Luke), Utsjoki, Finland*

[5]*County Governor in Troms and Finnmark, Vadso, Norway*

Pink salmon (*Oncorhynchus gorbuscha*) was introduced from the Pacific area to the Russian White Sea basin since late 1950s and they have gradually established naturally spawning populations in the rivers of the White and Barents Sea areas. The slow development turned into a rapid, widespread increase in distribution and abundance in the North Atlantic area in 2017, and high abundances persisted especially in the Barents Sea area in 2019, and even higher run sizes were detected the European North in 2021.

Abundance and distribution of pink salmon have been monitored in the River Teno (Tana in Norwegian), a large border river system between northernmost Finland and Norway, in connection with established long term Atlantic salmon monitoring programs. A rapid increase in numbers of pink salmon entering the River Teno started in 2017, and 2021 showed a tenfold increase in pink salmon run compared to 2019 (c. 5000 vs. 50 000 ind.). At the same time, data from sonar and video monitoring and information on fisheries catches revealed expanding pink salmon invasion to several tributaries, which are supporting diverse, genetically distinct Atlantic salmon populations, many of which severely depleted in recent years. Large spawning aggregations of pink salmon were observed for the first time ever in the Teno main stem in 2021.

In addition to the census data from routine Atlantic salmon monitoring programs, eDNA methods were tested and applied across c. 20 tributaries of the Teno system in 2019 and 2021. Spatiotemporal variation in eDNA-concentration differed between Atlantic and pink salmon with the latter species showing higher variation among different tributaries. Pink salmon was also detected in a substantially higher number of tributaries in 2021 compared to 2019, coherent with the large increase in observed run sizes. Accumulating information from the Teno system and its different sub-catchments provide a unique opportunity to study the progress in invasion and distribution of the alien pink salmon and their possible ecological effects in different areas and tributaries of a large subarctic river system supporting a large and diverse population complex of Atlantic salmon and other native salmonid fish species.

All correspondence should be addressed to Jaakko Erkinaro.
email: jaakko.erkinaro@luke.fi

Adaptation of Salmon Body Size After River Regulation

Ingerid J. Hagen[1], Arne J. Jensen[1], Yann Czorlich[1], Geir H. Bolstad[1], Gunnbjørn Bremset[1], Bengt Finstad[2], Kjetil Hindar[1], Øystein Skaala[3], and **Sten Karlsson[1]**

[1]*Norwegian Institute for Nature Research (NINA), NO-7485 Trondheim, Norway*

[2]*NTNU Department of Biology, NO-7491 Trondheim, Norway*

[3]*Institute of Marine Research, NO-5817 Bergen, Norway*

Dams and flow regulation have impacted over half of the world's largest rivers systems, causing fragmentation and habitat alterations to which inhabiting species must adapt or go extinct. Currently, our understanding of adaptation to human alteration of the environment is limited by lack of knowledge on the genetic basis of traits, lack of time series, and little or no information on the change in optimal trait value. Here, we document a case of human induced evolution in an ecologically and culturally important fish species—the Atlantic salmon (*Salmo salar*). The focal population inhabits a river severely impacted by hydropower development, and subsequent reduced waterflow. We found a change in body mass that closely followed the change in waterflow, both decreasing to ~1/3 of their original values. Using historical catch information and a time series of scale samples spanning nearly a century, we show that the observed reduction in body mass is mediated by allele frequency changes in the two large effect loci *vgll3* and *six6*. These genomic regions are associated with size and age at maturation in Atlantic salmon and explain 80% of the observed reduction in body mass. We model how the optimal body mass has changed over time and show how the natural population tracks the optimum at an extraordinary rate before finally catching up, one and a half decade after the last waterflow reduction. Our results provide insight into the temporal dynamics of adaptation in Atlantic salmon and the scope of evolutionary rescue following human disturbance.

All correspondence should be addressed to Ingerid Hagen.
email: ingerid.hagen@nina.no

Piscivorous Brown Trout Does Not Aggregate at a Massive Release Site for Chum Salmon Fry

Kentaro Honda[1], Koh Hasegawa[1], Ikuo Ono[2], and **Kazushi Miyashita[3]**

[1]*Salmon Research Department, Fisheries Resources Institute, Japan Fisheries Research and Education Agency, 2-2, Nakanoshima, Toyohira-ku, Sapporo, Hokkaido, Japan*

[2]*Salmon Research Department, Fisheries Resources Institute, Japan Fisheries Research and Education Agency, 9 Rankoshi, Chitose, Hokkaido, Japan*

[3]*Field Science Center for Northern Biosphere, Hokkaido University, 20-5 Benten, Hakodate, Hokkaido, Japan*

Mobile predators head for denser prey patches in general. For stock enhancement purposes, chum salmon (*Oncorhynchus keta*) fry are frequently released from hatcheries. Therefore, the effects of feeding by riverine predators cannot be disregarded. In the Chitose River, northern Japan, it was believed that a number of exotic piscivorous brown trout (*Salmo trutta*) aggregate near the hatchery to prey on fry during the period when around 30 million fry are released (>1 million at a time). This study investigated the validity of this belief. None of 27 brown trout tracked by acoustic telemetry appeared near the hatchery during the release period. Underwater visual censuses showed that the number of brown trout near the hatchery did not increase during the release period. Dietary analysis showed that brown trout captured both near the hatchery and about 10 km downstream had preyed on >100 fry released the day before their capture. Our results suggest that the lack of aggregation near the hatchery resulted from the rapidly dispersing, large masses of fry provided easy prey for brown trout regardless of proximity to the hatchery.

All correspondence should be addressed to Kentaro Honda.
email: honda_kentaro79@fra.go.jp

Success, Behaviour and Management of Atlantic Salmon (*Salmo salar*) Smolts During Migration through Lentic Systems

Hannele M. Honkanen[1], Jessie Lilly[1], Matthew Newton[1], Danielle Orrell[2,1], Alastair Stephen[3], Joseph M. McCallum[1], Mikolaj Kundegorski[1], Jessica R. Rodger[1,4], R. Alistair Duguid[5], David M. Bailey[6], and **Colin E. Adams[1]**

[1]Scottish Centre for Ecology and the Natural Environment, University of Glasgow, UK

[2]University of Windsor, Windsor, ON, Canada

[3]Scottish and Southern Energy, Perth, UK

[4]Atlantic Salmon Trust, Battleby House, Redgorton, Perth, UK

[5]Scottish Environmental Protection Agency, Perth, UK

[6]University of Glasgow, Glasgow, UK

Anadromous Atlantic salmon (*Salmo salar*) undertake migrations covering vast distances from freshwater to their marine feeding grounds and then back to freshwater to spawn in their natal rivers. Populations of Atlantic salmon have seen significant declines globally over the last few decades; the marine portion of the migration has been shown to incur a high mortality but through the use of telemetry techniques, many studies have highlighted the very high mortality rates that Atlantic salmon smolts experience during their freshwater migration. Certain habitats seem to be particularly risky – such as standing waters (lakes and reservoirs). I will present a synthesis of several studies we have conducted investigating the behaviour and migration success of salmon smolts in standing waters, using telemetry methods, in addition to a lab based experiment investigating the minimum water velocity required for a behavioural change. We have shown that migration through standing waters is associated with low survival and increased travel times, and that this is mostly due to the lack of directional cues available for juvenile salmon, leading to counterintuitive and random movements. This pattern is found both in natural lakes and reservoirs. We suggest that successful migration through standing waters has two contrasting modes; an initial stochastic migration, and thus random survival, followed by cue directed movement after reaching an area close enough to the outflow. The role of water flow as the main navigational cue is highly important, and identifying the minimum water velocity required for smolts to successfully migrate through standing waters has significant management importance, especially in impounded systems. We addressed this question in a study using an artificial flume and found an average velocity of 12 cm/s leading to a directional change. Combined with hydrological surveys in standing waters, the availability of suitable directional cues required for successful migration can be assessed and in some cases, managed.

All correspondence should be addressed to Hannele Honkanen.
email: hannele.honkanen@glasgow.ac.uk

Pacific Salmon Surveying and Monitoring Methods in Russia

Albina N. Kanzeparova[1], Alexey A. Somov[2], Evgeny A. Shevlyakov[2], and **Vladimir V. Sviridov[3]**

[1]*Russian Federal Research Institute of Fisheries and Oceanography, 107140 17 V. Krasnoselskaya, Moscow, Russia*

[2]*Pacific Branch of the Russian Federal Research Institute of Fisheries and Oceanography, 690091 4 Alley Shevchenko, Vladivostok, Russia*

[3]*Khabarovsk branch of the Russian Federal Research Institute of Fisheries and Oceanography, 680038, 13a Amurskij bulvar, Khabarovsk, Russia*

Pacific Salmon are a traditionally valuable resource for the Russian Far East fisheries. Pacific salmon third in catch after pollock and herring. Average harvest of Pacific Salmon for the last twenty years was 358 thousand metric tons. The three most productive years were 2009, 2018, and 2021 with cathes of 552, 667 and 539 thousand tons, respectively. To improve forecasting and overall fisheries goals, annual stock monitoring activities are typically conducted during all salmon life stages – freshwater and marine. The freshwater period monitoring includes spawner abundance estimates (adult escapement past the fisheries measured either at the spawning grounds or in route), as well as seaward migration of juveniles. Counting methods differ depending on the size of watersheds, their accessibility, and a number of other factors. Since early 1950s, helicopters and airplanes have been used in large-scale spawning grounds surveys in certain locations. In the 1980s and 1990s, hydroacoustic counting methods were developed and implemented for the first time. Ground-based survey methods, both walking and counting weirs, are also in use. Recently, the aero-visual monitoring of salmon spawning grounds using aircraft has been supplemented with photogrammetric surveying using unmanned aerial devices (drones). In the spring, juvenile surveys are performed using fyke traps. The smolt outmigration level gives an insight of reproduction success first approximation of the consequent return. The final evaluation of the surviving generation is given by trawl surveys. Currently, the forecasting methods based on the marine survey data are used for Pink Salmon and to some extent Chum Salmon, although such data can be potentially used for other salmon species as well. Genetic and morphometric methods of differentiating mixed aggregations of juveniles provide information on the proportion of stocks of different origin in the total abundance which is also applicable in forecasting the next season Pink Salmon returns and catch volumes. As part of the annual summer trawling surveys in the Kuril coastal waters of the Pacific ocean and in the Bering Sea, abundance data on the accumulations of Pink Salmon pre-spawners of productive generations is gathered, making assessment of the upcoming fishery season returns more precise.

In the future, technical and technological advancement of many monitoring methods appears to be needed, such as spawner and pre-spawner abundance monitoring by means of unmanned arial devices with long-distance capabilities, spawning grounds evaluation, and data analysis including utilizing geoinformation systems and artificial intelligence.

All correspondence should be addressed to Albina Kanzeparova.
email: kanzeparova@vniro.ru

A Synthesis of Farmed to Wild Genetic Introgression and the Consequences for Wild Atlantic Salmon

Sten Karlsson, Tonje Aronsen, Geir H. Bolstad, Ola H. Diserud, Peder Fiske, Ingerid J. Hagen, Kjetil Hindar, Eli Kvingedal, Line E. Sundt-Hansen, Grethe Robertsen, and **Sebastian Wacker**

Norwegian Institute for Nature Research (NINA), NO-7485 Trondheim, Norway

Atlantic salmon farming is one of the fastest-growing food industries and farmed salmon now outnumber wild Atlantic salmon 1000-fold. This unprecedented growth has been accompanied by numerous concerns about the impact it has on wild Atlantic salmon. Genetic introgression from farmed escapees is possibly the most important threat with severe and long-term effects on the productivity and viability of wild Atlantic salmon populations. The magnitude of escaped farmed salmon and level of genetic introgression are well documented. There is a growing body of evidence that genetic introgression leads to changes in important life history characteristics and a reduction in fitness of wild salmon. Because of this knowledge base, Atlantic salmon has emerged as a model organism for understanding the impact of aquaculture on wild fish. Here we present a synthesis of the knowledge gained of genetic interactions and consequences for wild Atlantic salmon, lessons learnt, and advice for sustainable development of aquaculture.

All correspondence should be addressed to Sten Karlsson.
email: sten.karlsson@nina.no

Temperature Criteria for the Estimation of Juvenile Pink Salmon Survival During Early Marine Period of Life

Maksim V. Koval, Oleg B. Tepnin, and **Vladimir V. Kolomeytsev**

Kamchatka Branch of Russian Federal Research Institute of Fisheries and Oceanography (KamchatNIRO), 18 Nabereznaya, Petropavlovsk-Kamchatsky, Kamchatka region, Russia

The early marine period is an important stage in the life cycle of Pacific salmon—especially pink and chum (i.e., species with a short freshwater period of life). For example, it is thought that mortality of pink salmon juveniles during this period may be significant—sometimes over 90–95% of generation. However, there is still few data on actual impact of different limiting factors on the survival rate of juvenile salmon during early marine life. It is generally known, one of the most important environmental factors for fishes is temperature. Exceptional importance of this factor is obvious, especially in conditions of global climate warming and its impact on aquatic ecosystems. In our study we tried to find out—what environmental temperature is the most favorable for survival of pink salmon juveniles in the early marine period of life, and how can temperature changes affect the productivity of their populations? As the basic criterion, we chose average surface water temperature during period of June–September ($SST_{VI–IX}$) for two polygons located in the basic foraging areas of Kamchatka pink salmon juveniles. These are southwestern part of the Bering sea and central part of the Okhotsk sea. For this purpose we used longterm satellite data on sea surface temperature (since 1981) by SST and its anomalies (in 0.25° latitude and longitude intervals) obtained from NOAA website (*ftp://eclipse.ncdc.noaa.gov*). The abundance of pink salmon generations were estimated by data of trawl surveys in the waters adjacent to Kamchatka in September–November, 1981 to 2020; and by longterm statistical information on Kamchatka pink salmon stock status. Our results has shown that the zone of most effective growth and survival of Kamchatka pink salmon juveniles is the temperature range of 8–13°C, and the temperature optimum of habitat is within 10–11°C. Maximum abundance of juvenile pink salmon on fall trawl surveys are usually observed in years when temperature conditions in the foraging areas in the previous summer period ($SST_{VI–IX}$ index) are most shifted towards the temperature optimum (i.e. 10–11°C). Thus, the $SST_{VI–IX}$ index can be used as one of the environmental criteria for evaluating the survival rate of juvenile pink salmon during the early marine life. To the greatest extent this criterion can be applied to assess survival of pink salmon of Northeastern Kamchatka, and to a much lesser extent—for the West Kamchatka. This is due to the large size of the Okhotsk sea basin, the local climatic conditions in some areas of which, during the migrations of pink salmon juveniles from the rivers, can vary significantly. The results of the analysis of longterm data also showed that in the waters adjacent to Kamchatka in recent some decades there has been a general increase of surface water temperature. These changes coincided with general increase of abundance of Kamchatka pink salmon populations. At the same time an increase in average individual weight of pink salmon spawners was also observed. Therefore, it is likely that an overall habitat temperature warming could be favorable for the productivity of pink salmon as one of the most heat-loving species among Pacific salmon—as long as it does not exceed the optimum temperature range for the species, of course.

All correspondence should be addressed to Maksim Koval.
email: koval.m.v@kamniro.ru

The Risk Assessment Method for Salmon (RAMS)

Wilf Luedke[1] and **Isobel Pearsall**[2]

[1]*South Coast Stock Assessment, Fisheries and Ocean Canada, 3225 Stephenson Point Road, Nanaimo, BC, Canada*

[2]*Pacific Salmon Foundation, 1682 West 7th Avenue, Vancouver, BC, Canada*

DFO has developed a risk assessment methodology for salmon (RAMS) to aid in the identification and prioritization of factors that limit salmon production, both now and within the context of climate change anticipated to occur by 2050. This methodology was originally adapted from a framework on "Ecological Risk Assessment for the Effects of Fishing" (ERAEF) initially developed to inform an ecosystem-based approach to fisheries management in Australia (Hobday et al. 2011), with modifications based on work by Roni and Beechie (2013) and many others.

RAMS uses a life history model approach, relating salmon population status to the status of its habitat and ecosystem, informed by habitat state and pressure indicators. Factors limiting to productivity and capacity of the population are identified and ranked, followed by determination of the sources of habitat and ecosystem degradation. The RAMS process and associated tools for its application are designed to be highly scalable such that they can be applied to assess risk of limiting factors focused on a single life-stage of a salmon population, the entire life history of a single population, multiple populations comprising a wild salmon conservation unit (CU) or multiple CUs comprising a fisheries management unit (MU).

The approach uses available species, stock, and local knowledge as well as literature/expert opinion to conduct an initial assessment of risks and identification of knowledge gaps. Results allow for prioritization of research, assessment and fisheries management responses, such as restoration, enhancement and modification of harvest strategies outcomes. The process is iterative whereby directed research improves understanding and likelihood that mitigation will be successful. Moreover, as with the central tenant of Martin *et al. (*2012), the benefit/cost ratio of restoration options is a key outcome.

This talk describes the RAMS process, the application of a simplified life cycle model to examine interaction with physical and biological processes, the iterative approach to assessing risk, identifying and directing research, and developing mitigative options which form the basis of a rebuilding plan. Finally, we provide examples of the application of RAMS in rebuilding processes for Cowichan River and West Coast Vancouver Island Chinook.

All correspondence should be addressed to Wilf Luedke.
email: wilf.luedke@dfo-mpo.gc.ca

Harbor Seal Consumption of Steelhead Upon Marine Entry

Megan E. Moore[1], Austen C. Thomas[2], Michael J. Malick[1], Matthew M. Klungle[3], and **Barry A. Berejikian[1]**

[1]*Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Port Orchard, WA, USA*

[2]*Smith-Root, Vancouver, WA 98686, USA*

[3]*Washington Department of Fish and Wildlife, Olympia, WA, USA*

Predation by harbor seals may be threatening the recovery of ESA-listed steelhead. After freshwater rearing, steelhead smolts experience high mortality during their rapid migration from river mouth to the Pacific Ocean. Previous work indicates that harbor seal predation is a primary source of early marine mortality, but the level of impact exerted by harbor seals on steelhead has not been quantitatively assessed. We estimated the percentage of Nisqually steelhead migrants consumed by harbor seals in 2016, 2017, and 2018 from estimates of (1) the proportion of harbor seal diet comprised of steelhead, (2) the number of smolt outmigrants in the Nisqually River, (3) the downstream survival of smolts to the estuary, and (4) the number of harbor seals residing in South Puget Sound (SPS). Metabarcoding of DNA in harbor seal fecal samples collected in SPS identified small fractions of harbor seal diet comprised of steelhead smolts. Those small fractions, however, translated into substantial mortality on Nisqually River steelhead cohorts when multiplied by the estimated energetic demand of the SPS harbor seal population. Model results indicate that between 9% (2017) and 33% (2018) of outmigrating steelhead were eaten by harbor seals during the 24-kilometer migration through SPS, and that harbor seal predation accounted for 26% (2017) to 70% (2018) of the total mortality incurred over that same distance. Independent estimates of harbor-seal consumption of steelhead during the same years (7-17%), quantified using behavioral metrics of acoustic tagged Nisqually smolts, are comparable to consumption model estimates and indicate that most South Puget Sound mortality takes place in or near the estuary. This study demonstrates the capacity of marine mammal predators to measurably impact survival and potential productivity of small prey populations, and provides information to managers tasked with balancing the impacts of one protected species with the recovery of another.

All correspondence should be addressed to Megan Moore.
email: megan.moore@noaa.gov

Effect of Multiple Pressures on Early Marine Survival of Juvenile Salmon in Puget Sound

Hem Nalini Morzaria-Luna[1], Isaac C. Kaplan[2], Chris J. Harvey[2], Michael Schmidt[1], Elizabeth A. Fulton[3], Raphael Girardin[2], and **Parker MacCready[4]**

[1]Long Live the Kings

[2]NOAA Northwest Fisheries Science Center

[3]CSIRO Oceans and Atmosphere

[4]University of Washington

Cumulative human impacts in Puget Sound have likely contributed to declining trends in juvenile marine survival of Chinook and coho salmon. We use an Atlantis ecosystem model for Puget Sound (AMPS) to identify drivers that most strongly affect Chinook and coho salmon survival. Atlantis is an 'end-to-end' modeling framework for marine ecosystems that integrates oceanographic, geochemical, ecological, and anthropogenic processes in a three-dimensional, spatially explicit domain. The AMPS is initialized to represent recent conditions (c. 2011) and simulates food web dynamics using 73 functional groups, including 21 salmon groups. Hydrodynamics in the AMPS are driven by outputs from a Regional Ocean Modeling System model for Puget Sound. We use the AMPS to test two categories of impacts (1) bottom-up processes including competition with hatchery salmon and with wild pink and chum salmon, increase in gelatinous zooplankton, declines in herring biomass and availability as forage, declining availability of crab larvae in salmon diets, and the shift in release timing of hatchery Chinook; and (2) top-down processes, increased predation by pinnipeds, increased predation by Harbor porpoise, seabirds, dogfish, and predation by and competition from resident Chinook. Over a 30-year simulation, salmon responded strongly in scenarios related to herring, gelatinous zooplankton, and residency (e.g. the proportion of salmon that migrate to the ocean). Forcing the model with declining trends in herring led to 5-10 % declines in most salmon groups, except Chum, while increasing trends in gelatinous zooplankton led to 12-53% percent declines of Chinook and coho salmon groups. Our scenario approach allowed us to rank past drivers of salmon declines, and to identify management actions that are likely to produce improvements in salmon survival. Our results contribute to management of Puget Sound via the Salish Sea Marine Survival Project.

All correspondence should be addressed to Hem Nalini Morzaria-Luna.
email: hemnalini.morzarialuna@noaa.gov

Spatial dynamics of North Pacific zooplankton community structure

Elliott L. Price[1], Evgeny A. Pakhomov[1], and **Brian P.V. Hunt[1]**

[1]*Department of Earth, Ocean and Atmospheric Sciences, 2020 – 2207 Main Mall. Vancouver, BC, Canada*

In the North Pacific, zooplankton are critical for understanding the status of salmon populations as they constitute a major proportion of their diet. Salmon, among other marine organisms, structure part of their life histories around food availability, including migrating to food sources in the marine environment, and timing of spawning to coincide with high food availability. Therefore, understanding how food sources are structured across the North Pacific is critical in developing management strategies for salmon. Our aim is therefore to identify the composition and structure of zooplankton communities in the North Pacific and determine how the communities relate to the physical and chemical environment. Zooplankton specimens were collected from stations in during the IYS Gulf of Alaska expeditions in 2019 and 2020 using bongo nets and Juday nets, and CTD casts were used to define water column characteristics. Size fractionated zooplankton biomass was measured, and all species present were identified, staged and sexed to define the community composition. We present the spatial distribution of zooplankton by defining distinct communities across the North-eastern Pacific using hierarchal clustering and show the environmental associations of these communities using an ordination method. In addition, we show how the zooplankton community composition differed between the 2019 and 2020 expeditions, highlighting the impact of year to year variability in zooplankton biomass as a result of basin top town pressures from planktivores and basin scale climate variability.

All correspondence should be addressed to Elliott Price.
email: eprice01@mail.ubc.ca

Dietary Shifts of Wild and Hatchery Juvenile Chinook (*Oncorhynchus tshawytscha*) in Fraser River Estuary Eelgrass (*Zostera marina*) Habitat, British Columbia, Canada

Paige Roper[1,2], David C. Scott[1,2], Misty MacDuffee[2], and **Scott G. Hinch[1]**

[1]*Pacific Salmon Ecology and Conservation Laboratory, Department of Forest and Conservation Science, University of British Columbia, Vancouver, BC, Canada*

[2]*Raincoast Conservation Foundation, Sidney, BC, Canada*

Diet affects early growth and can impact the early marine survival of juvenile salmon, and several factors may influence the type of prey consumed and energetic reserves of individuals in the early marine environment. The Fraser River is the largest producer of Pacific salmon in Canada with millions of juveniles out-migrating each spring. Estuaries are crucial stopover areas for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) that can reside in this habitat for over a month. In the Fraser estuary, eelgrass (*Zostera marina*) habitat provides diverse prey, refuge from predators, and is a transition zone to acclimate to saline conditions for out-migrating juvenile Chinook. To gain a comprehensive understanding of wild and hatchery juvenile Chinook diet in eelgrass habitat, we analyzed stomach contents and stable isotopes values from the tissue of 103 individuals captured in eelgrass habitat on Roberts Bank during the summer of 2021. Size of juvenile Chinook varies between wild and hatchery production types and can result in differences in prey choices during residency in eelgrass habitat. We sampled Chinook that ranged in size from 50-mm to 140-mm in fork length and found that some individuals began switching from a diet of invertebrates and zooplankton to larval fish at 85-mm. Additionally, we found that the stable isotope values from the tissue of juvenile Chinook differ between populations. These results to date suggest that size is an indicator of juvenile Chinook's transition to a more piscivorous diet and differences in early diet can be seen between populations through stable isotope analysis.

All correspondence should be addressed to Paige Roper.
email: paigeroper8@gmail.com

Adult Return Rates of the Anadromous Atlantic Salmon: Influences of Smolt Length Across a Latitudinal Gradient

Olivia Simmons[1,2], Robert J. Britton[1], Phillipa Gillingham[1], Marie Nevoux[3,4], Etienne Rivot[3,4], John Armstrong[5], Mathieu Buoro[6], Patrick Gargan[7], Tormod Haraldstad[8,9], Michael Millane[7], Thilo Reich[10], William Riley[11], Øystein Skaala[12], and **Stephen Gregory[2,13]**

[1]*Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, Poole, Dorset, UK*

[2]*Salmon and Trout Research Centre, Game and Wildlife Conservation Trust, FBA River Laboratory, Wareham, Dorset, UK*

[3]*DECOD (Ecosystem Dynamics and Sustainability), Institut Agro, INRAE, Ifremer, 35042 Rennes, France*

[4]*MIAME–Management of Diadromous Fish in their Environment, OFB, INRAE, Institut Agro, University Pau & Pays de l'Adour/E2S UPPA, Rennes, France*

[5]*Freshwater Fisheries Laboratory, Marine Scotland Science Faskally, Pitlochry, Perthshire, UK*

[6]*Universite de Pau et des Pays de l'Adour, E2S UPPA, INRAE, ECOBIOP, Saint-Pée-sur-Nivelle, France*

[7]*Inland Fisheries Ireland, Dublin, Ireland*

[8]*Norweigan Institute for Water Research (NIVA), Grimstad, Norway*

[9]*Laboratory for Freshwater Ecology and Inland Fisheries (LFI) at NORCE, Norwegian Research Centre, Kristiansand, Norway*

[10]*Department of Computing and Informatics, Faculty of Science and Technology, Bournemouth University, Poole, Dorset, UK*

[11]*The Centre for Environment, Fisheries and Aquaculture Sciences, Lowestoft, Suffolk, UK*

[12]*Institute of Marine Research, Bergen, Norway*

[13]*The Centre for Environment, Fisheries and Aquaculture Sciences, Weymouth, Dorset, UK*

Populations of anadromous Atlantic salmon *Salmo salar* ('salmon') have decreased dramatically across much of their geographic range in recent decades. It is posited this is being driven by low marine survival, resulting in reduced adult return rates to natal rivers. We hypothesised that marine return rates of adult salmon are positively influenced by their body lengths as seaward-migrating juveniles ('smolts'), so larger smolts will be more likely to survive at sea and return as spawning adults to the natal river. We also suggest that the magnitude of this effect decreases with latitude, with its effect being weaker in more northerly populations. These were tested using individual capture-mark-recapture data from seven salmon populations in Western Europe spanning 13 degrees of latitude and 12 years of smolt cohorts. We used a multi-state state-space model to test whether marine return rates were influenced by smolt body length and latitude, and their interaction. Across the seven populations, smolt length had a significant positive effect on the probability of adult return, which was stronger in southern versus northern populations. Atlantic salmon smolt body length is thus an important indicator of their marine return rates, especially among populations in the warmer, southern part of their geographic range, with this having important implications for conserving declining salmon stocks. It suggests that management in their freshwater juvenile stages can increase MRR and should focus not only on the numbers of seaward-migrating juveniles, but also their individual quality, as indicated by their body length.

All correspondence should be addressed to Olivia Simmons.
email: osimmons@bournemouth.ac.uk

Impact of Parasitic Infections on the Marine Survival of Wild Salmon: A Review

Shigehiko Urawa[1] and **Shinya Mizuno**[2]

[1] *Salmon Resources Department, Fisheries Resources Institute, Japan Fisheries Research and Education Agency, 2-2 Nakanoshima, Toyohira-ku, Sapporo, Japan*

[2] *Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido, Japan*

The year class strength of salmon population is largely determined during early marine residence. Pathogens may occasionally play a significant role in regulating salmon populations. Several hundred species of parasites have been recorded from anadromous salmon within their native range in the North Pacific and Atlantic oceans, and some cause growth reduction and mortalities of hatchery-reared juveniles. However, our knowledge is limited for the impact of parasites on the survival and fitness of wild salmon in the ocean. The aim of this paper will review case studies to imply possible marine mortalities of Pacific (*Oncorhynchus* spp.) and Atlantic salmon (*Salmon salar*) caused by different parasites such as the ectoparasitic protozoan (*Ichthyobodo salmonis*), digenean trematode (*Nanophyetus salmincola*), and sea lice (*Lepeophtheirus salmonis* and *Caligus* spp.). The euryhaline flagellate *I. salmonis* is distributed in the North Pacific and Atlantic coasts, infecting the skin and gills of specific anadromous hosts: chum (*O. keta*) and Atlantic salmon. The heavy parasite infection destructs the skin epidermis of juvenile chum salmon, which causes a breakdown in the osmoregulation. These juveniles result in significant mortalities when they migrate into the coastal ocean, mainly due to a failure in seawater adaptation. The parasite remains infecting the survivors throughout the freshwater and ocean life of anadromous host for reproduction. The metacercarial stage of digenean *N. salmincola* is primarily found in the kidney and muscle of freshwater fishes including Chinook (*O. tshawytscha*) and coho salmon (*O. kisutch*) in coastal rivers of the Pacific Northwest. The parasite has negative effects on the swimming performance, growth, osmoregulation, immune function, and disease resistance of juvenile salmon, and parasite-associated host mortalities occur during early marine residence. Like *I. salmonis*, the salmon louse *L. salmonis* is found both from the Pacific and Atlantic oceans. The parasite has a major risk for sustainable aquaculture production of Atlantic salmon, but the impact of sea lice on wild salmon populations is debated. Multiple factors affect parasite-infected salmon in the ocean. Field and laboratory experiments are essential to quantify the impact of parasites in natural environments.

All correspondence should be addressed to Shigehiko Urawa.
email: urawa@affrc.go.jp

Changing Outmigration Phenology and Phenological Mismatch in Juvenile Salmon

Samantha M. Wilson, and **Jonathan W. Moore**

Earth to Ocean Research Group, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada.

Climate change may be shifting the timing of animal migrations and their prey availability at different rates and it is unclear how this may impact survival (i.e., the match/mismatch hypothesis). For example, juvenile salmon migrate from freshwater to the ocean and rely upon seasonally abundant marine prey. Yet climate change may be altering juvenile salmon migration timing, possibly increasing the frequency of mismatches with prey. Here we address two key questions: 1) is the timing of juvenile salmon migration shifting and could this lead to mismatches with prey? 2) How do mismatches between juvenile salmon and their prey in the early marine environment influence marine survival? We collated a dataset on smolt outmigration timing of 66 populations of at least 20 years in length for six species of Pacific salmon ranging from Oregon to Alaska. We found that the magnitude of shifts in outmigration timing varied between species and across populations. Key freshwater variables (e.g., temperature, latitude) were not predictive of rates of shifts in outmigration timing suggesting local response diversity may complicate prediction of shifts in outmigration timing under climate change. We then examined how timing of marine prey availability relative to migration timing of juvenile steelhead trout influenced ocean survival in a focal population. We found that larger steelhead trout always had higher marine survival and when prey availability peaked earlier, survival was higher. Differing rates of phenological change across species and populations may result in more phenological mismatches which could impact salmon survival. Importantly this body of work shows that traits determined in freshwater (e.g., size, migration timing) can impact survival in the marine environment (i.e., carryover effects).

All correspondence should be addressed to Samantha Wilson.
email: swilson471@gmail.com

Distribution and Abundance of Salmon Prey Species in the Eastern Gulf of Alaska as Observed by the Winter 2022 IYS Pan-Pacific Expedition

Nicholas Ens[1], Stéphane Gauthier[1,2], and **John Dower[1]**

[1]*University of Victoria, Department of Biology, 3800 Finnerty Road, Victoria, BC, Canada.*

[2]*Institute of Ocean Sciences, Fisheries and Oceans Canada, 9860 W Saanich Road, Sidney, BC, Canada*

Low prey availability during winter months has been posited as a limiting factor of salmon biomass in the Pacific Ocean. As such, appreciable efforts have been made to quantify patterns of spatiotemporal distribution and abundance of prey species consumed by salmon during their oceanic phase. Sampling for salmon prey has historically been limited to discrete fishing events with poor spatial resolution across large sampling areas. As a result, the characteristically patchy distributions of these species (i.e. large zooplankton and micronekton) has resulted in poor estimates of where these prey are concentrated and in what abundance they occur. During the International Year of the Salmon (IYS) 2022 Pan-Pacific Expedition, the Canadian Coast Guard Ship *Sir John Franklin* undertook direct sampling at discrete stations for small prey species consumed by salmon along the eastern Gulf of Alaska using a depth-stratified Tucker trawl, and collected echosounder backscatter intensity data along the entire survey track using a Simrad EK80 multi-frequency echosounder system. By directly sampling for species while concurrently collecting continuous echosounder data, we were able to quantify the major taxa in the Gulf of Alaska at a greater spatial resolution than has previously been achieved, while also maintaining excellent taxonomic resolution. Preliminary analyses of the community composition of large zooplankton and micronekton collected by Tucker trawl during the expedition will be presented, highlighting salmon prey taxa including euphausiids and myctophids. “Hot spots” of zooplankton and micronekton biomass as observed by the onboard EK80 echosounder system will be shown, and the behaviour of these species in scattering layers will be discussed. Differences in community composition, distribution, and behaviour of these zooplankton and micronekton species observed during the 2022 winter expedition will be compared to observations made during previous expeditions. These results will form the basis for an investigation into the extent to which the availability of prey in the Gulf of Alaska is a limiting factor for Pacific salmon abundance.

All correspondence should be addressed to Nicholas Ens.
email: nens@uvic.ca

Using Satellite-Tagged Salmon Sharks to Make Inferences about Predation on Pacific Salmon

Sabrina Garcia[1], Cindy A. Tribuzio[2], Andrew C. Seitz[3], Michael B. Courtney[3], Julie K. Nielsen[4], Jim M. Murphy[2], and **Dion S. Oxman[5]**

[1]*Alaska Department of Fish and Game, Division of Commercial Fisheries, 333 Raspberry Rd, Anchorage, AK, USA*

[2]*National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Pt. Lena Loop Road, Juneau, AK, USA*

[3]*University of Alaska Fairbanks, College of Fisheries and Ocean Science, 2150 Koyukuk Drive, Fairbanks, AK, USA*

[4]*Kingfisher Marine Research, LLC, 1102 Wee Burn Dr., Juneau, AK, USA*

[5]*Alaska Department of Fish and Game, Mark, Tag, and Age Laboratory, 10107 Bentwood Place, Juneau, AK, USA*

The role of predation on Pacific salmon (*Oncorhynchus* spp.) during their marine life stage is part of the "black box" in understanding salmon life history. Salmon sharks (*Lamna ditropis*) have been identified as a major salmon consumer with the potential to impact both population abundance and demographics, such as age at return. Salmon sharks are a widely distributed apex predator in the North Pacific Ocean and known to feed on salmon in summer months when they are concentrated in coastal areas during their return migration to natal spawning streams. However, the importance of salmon in salmon shark diets throughout the year is unknown. To assess the potential impact of salmon shark predation on salmon, information on salmon shark migration and distribution is needed to assess the degree of overlap between predator and prey. Salmon sharks in the eastern North Pacific Ocean, specifically Prince William Sound, Alaska, have been satellite-tagged and tracked for many years. These sharks, all female, tend to make repeat migrations between coastal Alaska and the California Current ecosystem. To date, only four salmon sharks, all males, have been satellite-tagged and tracked outside of the eastern North Pacific Ocean. Three of these tagged sharks migrated between the central Pacific Ocean and the Bering Sea. Although the satellite-tagging technology employed here cannot determine feeding habits of salmon sharks, information on salmon distribution and tracks from satellite-tagged sharks may be used to assess potential predator-prey spatio-temporal overlap. Winter research cruises in the high seas, like the 2022 Pan-Pacific expedition, are important as they provide a platform to opportunistically satellite tag salmon sharks. The broad geographic areas sampled during these surveys, which overlap with potential salmon shark habitat, provide information on prey density that can be used alongside satellite tag data to understand salmon shark movements. If salmon shark predation on Pacific salmon is to be quantified, additional movement information is needed for salmon sharks from the Bering Sea and western North Pacific along with region- and species-specific migration patterns of salmon during their marine residence. Additionally, diet studies conducted outside summer months, from salmon sharks across their geographic range, and of varying sizes are needed to determine diet composition. Finally, estimates of salmon shark abundance would help determine if salmon shark predation on salmon has increased in concert with decreasing salmon abundance, but abundance estimates are currently not available for salmon sharks in the North Pacific Ocean.

All correspondence should be addressed to Sabrina Garcia.
email: Sabrina.garcia@alaska.gov

Getting Started: Genetic Stock Identification of Pink, Sockeye, and Chum Salmon from the Western Portion of the 2022 Pan-Pacific Winter Expedition

Sara Gilk-Baumer[1], Andy Barclay[1], Tyler Dann[1], Chris Habicht[1], Kathrine Howard[1], Kyle Shedd[1], William D. Templin[1], and **others[2]**

[1]Gene Conservation Laboratory, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK, USA

[2]Additional co-authors are forthcoming. We anticipate authors from NOAA, Japan, and Russia.

Pacific salmon species in the North Pacific are facing challenges due to changing ocean conditions. Unfortunately, there are significant gaps in our understanding of the mechanisms that regulate salmon distribution and survival in coastal and high seas environments. The goal of the 2022 Pan-Pacific winter high seas expedition is to understand how an increasingly extreme climate and the associated environmental variability can influence the abundance, distribution, growth, and survival of Pacific salmon, and the ecosystem that supports salmon. The initial step to investigate the marine distributions of salmon and the limiting factors in the ocean is to determine the origins of individual salmon caught on the high seas. Assembling genetic stock identification data for all species of Pacific salmon from the entire IYS survey area will provide the most comprehensive picture of stock-specific distributions ever constructed. Here we present results from genetic stock identification of sockeye, chum, and pink salmon samples collected by scientists on the NOAA *Bell M. Shimada*, R/V *Tinro*, and F/V *Northwest Explorer* during the 2022 survey. For sockeye salmon, stock compositions were determined using a baseline consisting of 96 SNP markers and 520 populations ranging from Asia to Washington State, U.S. For pink salmon, stock compositions were determined using a baseline consisting of 262 SNP markers and 16 locations representing broad-scale regional groups ranging from Asia to Washington State, U.S. For chum salmon, stock compositions were determined using a baseline consisting of 96 SNP markers and 383 populations ranging from Asia to Washington State, U.S. When paired with additional data obtained from the surveys, this information will be the foundation for further analyses, and will allow an increased understanding for a wide diversity of salmon populations.

All correspondence should be addressed to Sara Gilk.
email: sara.gilk@alaska.gov

Catching Trawl Nekton and CTD,O Classes with their Parametrization in 2019, 2021, 2022 Winters in the Gulf of Alaska & Vicinities

Gennady A. Kantakov

Far-Eastern Ecological Center, Ltd. office 404, 426 Mira ave., Yuzhno-Sakhalinsk,, Russian Federation

CTD,O data collected during nekton and salmonids trawling on oceanographic winter expeditions were analyzed to understand the ecological conditions of salmon habitats in the composition of nekton collected on 2019-2022 IYS winter expeditions. The idea was to classify the abiotic conditions of the ocean in forms of their basic calculated parameters with following comparing with biological trawl data. The intrigue was to understand how effective the standard routine methods of oceanography for ichthyological problems are for, as example, searching prospective of box models in applying, in particular, with studies of salmonids (1). The second point was the methodological uncertainty of the usual speed of data collection in the ocean biotops, exceeding the scale of their temporal (synoptic) and biological variability (2). Perhaps, the time has come to begin gradually collect oceanography in nekton/salmonids life-cycle phenomena researching using remote methods and developing autonomous drones and sensors. In fact, in search of an answers to both questions, the present work conceived.

All correspondence should be addressed to Gennady Kantakov.
email: npodeco@gmail.com

A Century of Ecosystem Change in the North Pacific Ocean: Using Isotopes to Investigate Trophic Dynamics of Sockeye Salmon

Celeste Kieran[1], Michael Price[1,2], Eric Hertz[3], Michael Richards[1], and **John Reynolds[1]**

[1] *Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada*

[2] *SkeenaWild Conservation Trust, Terrace, BC, Canada*

[3] *Pacific Salmon Foundation, Vancouver, BC, Canada*

Changes in the trophic dynamics of marine ecosystems are driven by large scale climate events and increasingly unpredictable ocean conditions. To develop effective conservation management goals and protocol for key marine species and their ecosystems, we must understand how ecosystems are influenced by environmental and climate variation. We used stable isotope analysis of fisheries-collected salmon scales from the Skeena Watershed to investigate trophic dynamics of sockeye salmon (*Onchorynchus nerka*) throughout the last century (1913–2021), and examined relationships between temporal variation of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ and known environmental and climate variables. We found considerable inter-annual variation for all isotopes from 1913 to 2021, suggesting variation in foraging ecology and ocean conditions experienced by Skeena sockeye salmon. Carbon isotope composition of sockeye scales showed an overall decrease throughout time even once corrected for the atmospheric rise in fossil-fuel derived CO_2. Fish size and age were positively correlated with $\delta^{34}S$ of scales, likely due to increased time spent in the marine environment. Potential relationships exist between climate indices and temporal isotope variability, with abrupt changes in mean annual nitrogen and carbon isotope composition of scales occurring near periods of temperature regime shift in the North Pacific Ocean. These results show considerable variation in the foraging ecology and ocean conditions experienced by Skeena sockeye salmon throughout the last 100 years and suggest important links between environmental variation and marine ecosystem dynamics.

All correspondence should be addressed to Celeste Kieran.
email: celestekieran@gmail.com

Spawning Migration Strategies of Chum Salmon (*Oncorhynchus keta*) with Marine Environment Change in the Coastal Water of Korea

Beom-sik Kim[1], Ju Kyoung Kim[2], Na Ri Kim[3], Se Un Ki[4], Yong-woo Jung[1], Woobo Kim[1], and **Chung Il Lee[1]**

[1]*Department of Marine Ecology and Environment, Gangneung-Wonju National University, Gangneung, Korea*

[2]*Aquatic Living Resources Center of West Sea, FIRA, Korea*

[3]*Livestock and Marine Industry, Ulju-gun, Korea*

[4]*Institute of Ocean & Fisheries Science, Jeollanam-do, Korea*

The eastern coastal water of Korea, southern limit of Chum salmon (*Oncorhynchus keta*) distribution in the north Pacific Ocean, has the largest density of salmon migrating to Korean rivers. The coastal water forms the boundary between a low saline, cold water mass flowing from the north to the south and a high saline, warm water mass flowing from the south to the north. Spawning migration strategies of salmon in the coastal water is important for spawning success with energy reserve. We analyzed the relationship between marine environment change (sea water temperature, tidal elevations) and spawning migration of salmon in the coastal water. In the coastal water, the salmon actively moved between upper and lower layer and migrates into the river at night when sea level rose during high tide. Salmon migrated into the river when sea surface water temperature was between 12-20ºC, and actively migrated into the river when sea surface water temperature decreased below 18ºC. The number of salmon ascending the river peaked when the water column was vertically mixed by spring tides. The latitudinal distribution of salmon from northern part to the southern part in the coastal water was changed according to the distribution of sea surface water temperature along the coastal water, and timing of migrate into river from the coast was highly related with tides. In conclusion, in the process of reaching the spawning grounds, salmon chooses strategies to reduce energy expenditure by using optimal environmental conditions. This study provides important information in understanding of the mechanisms that regulate the distribution of salmon in coastal and river during spawning migration.

All correspondence should be addressed to Beom-sik Kim.
email: leeci@gwnu.ac.kr

Interannual Changes of the Phytoplankton Functional Groups in the Northern Pacific

Marta Konik[1], Vishnu Perumthuruthil Suseelan[1], Christian Marchese[2], Angelica Peña[3], Toru Hirawake[4], Brian Hunt[2], and **Maycira Costa[1]**

[1]*University of Victoria, Victoria, BC, Canada*

[2]*University of British Columbia, Vancouver, BC, Canada*

[3]*Fisheries and Oceans Canada, Sidney, BC, Canada*

[4]*National Institute of Polar Research, Tokyo, Japan*

Phytoplankton is the first level in the food web that affects salmon. Changes in phytoplankton biomass, distribution, and species composition lead to implications for the entire food web, with short and long-term consequences for salmon populations. Our goal is to distinguish bioregions of varying environmental conditions with a particular focus on phytoplankton composition. Substantial changes in time may be identified earlier within smaller regions since the pace of changes may differ significantly between the areas. To accomplish this, we compiled historical in situ measurements of pigment composition with recent data collected in the scope of IYS High Seas Expeditions. This data set allowed for the evaluation and adaptation of satellite-based models dedicated to deriving phytoplankton functional types focusing on the Northern Pacific areas where the major Pacific salmon stocks reside. The initial tests revealed that 25km resolution satellite products are optimal for the open-ocean areas because it retains natural variability and provides well-founded input for the advanced data analysis, e. g. neural networks. The spatial distribution of the main phytoplankton groups observed during the 2022 Pan-Pacific Winter High Seas Expedition will be presented, with particular attention paid to haptophytes, which we found to be a key group in the area. Those results are only one of the aspects to assess the overall salmon-well being but should not be underestimated due to the relatively fine cover of satellite information.

All correspondence should be addressed to Marta Konik.
email: martakonik@uvic.ca

Life on the High Seas: New Insights into the Marine Distributions of Pacific Salmon

Joseph A. Langan[1], Curry J. Cunningham[1], Jordan T. Watson[2], and **Skip McKinnell[3]**

[1]*College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 17101 Point Lena Loop Road, Juneau, AK, USA*

[2]*Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Pt. Lena Loop Road, Juneau, AK, USA*

[3]*Salmoforsk International Environmental Consulting, 2280 Brighton Ave, Victoria, BC, Canada*

Illegal, unreported, and unregulated (IUU) fishing presents a major challenge for global fisheries management, but increasingly available vessel tracking data primarily describe legal and legitimate activities. In vast ocean regions like the North Pacific, this makes the detection of IUU fishing difficult and leaves valuable species with uncertain distributions particularly vulnerable to exploitation. Pacific salmon spend a large part of their life cycle in the open ocean, where climatic and oceanographic conditions are thought to strongly influence habitat selection and survival. Although salmon as a group are abundant in the surface waters of the North Pacific, critical knowledge gaps regarding their ocean ecology and distributions persist. As a result, it is difficult to assess how high seas environmental conditions and IUU fishing impact the culturally and socioeconomically important fisheries salmon support throughout their range. To address this issue, we assembled a novel database of historic high seas survey data collected by Pacific Rim nations and fit species distribution models to: 1) describe the marine spatial distributions of six salmon species, 2) characterize how distributions evolve seasonally, and 3) evaluate species-specific temperature preferences. Sea surface temperature was found to significantly influence the seasonal distribution of all species, where tolerances for warm temperatures were more similar than predicted for cold temperatures. Furthermore, the results suggest the distributions of some salmon species are more responsive to temperature than others. These results develop an expanded understanding of salmon ocean distributions and thermal niches, providing a unique window into this often unobserved but crucial portion of the life cycle, and serve as a baseline for future investigations into the mechanisms influencing salmon spatial ecology and vulnerability to harvest in the North Pacific.

All correspondence should be addressed to Joseph Langan.
email: jalangan@alaska.edu

Understanding What Drives Marine Energy Accumulation in Chinook Salmon, *Oncorhynchus tshawytscha*

Jacob E. Lerner and **Brian P.V. Hunt**

Institute for the Oceans and Fisheries, University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada

Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, 2039-2207 Main Mall, Vancouver, BC, Canada

Hakai Institute, P.O. Box 309, Heriot Bay, BC, Canada

All salmon must accumulate enough energy during their life to successfully reach their spawning grounds and reproduce. Lipids are the primary form of energy storage in salmon and Chinook (*Oncorhynchus tshawytscha*) accumulate more lipids than all other Pacific salmon species. Virtually all this energy is derived from the marine environment. Despite the significance of this ocean derived energy, the impact of marine foraging and ocean conditions on energy accumulation in Chinook salmon has been difficult to determine. This is due, in part, to the difficulty in disentangling the impact of ocean conditions on Chinook from heritable physiological differences inherent between stocks with diverse life histories. Within a Chinook stock, however, there can be substantial variation in total lipid accumulation. In this study we determined the whole-body lipid content of individuals from a single stock of southern British Columbia Chinook. We used bulk and compound specific stable isotope analysis to investigate differences in foraging habits and spatial distribution across the spectrum of lipid levels within this stock. By sampling within a stock, we controlled for some of the innate heritable differences in lipid accumulation. We discuss the impact of trophic level, basal food web resources, and spatial patterns in driving differences in marine lipid accumulation in Chinook salmon. These results have significant implications for a species facing both changing ocean and freshwater migration conditions.

All correspondence should be addressed to Jacob Lerner.
email: j.lerner@oceans.ubc.ca

Environmental Drivers of the Early Marine Migration of Atlantic Salmon (*Salmo salar*)

Jessie Lilly[1], Jessica R. Rodger[1,2], Hannele M. Honkanen[1], David Bailey[1], Diego del Villar[3], Richard Kennedy[4], Robert Rosell[4], Amy Green[1], William Roche[5], Lorna Wilkie[2], Samantha Beck[6], Jim Henderson[7], Debbie Parke[7], Colin Bean[1], and **Colin Adams[1]**

[1]*Scottish Centre for Ecology and the Natural Environment, Institute of Biodiversity, Animal Health and Comparative Medicine, University of Glasgow, UK*

[2]*Atlantic Salmon Trust, Battleby House, Redgorton, Perth, UK*

[3]*Loughs Agency, Victoria Road, Derry ~ Londonderry, Northern Ireland*

[4]*Agri-food and Biosciences Institute, Large Park, Hillsborough, Northern Ireland*

[5]*Inland Fisheries Ireland, Lake Drive, Citywest Business Campus, Dublin, Ireland*

[6]*Galloway Fisheries Trust, Station Industrial Estate, Newton Stewart, UK*

[7]*The Nith Catchment Fisheries Trust and The Nith District Salmon Fishery Board, Dumfries, UK*

The drivers of salmonid migration in freshwater have been well studied, however relatively less is known about migration and the environmental drivers in the early marine environment, particularly for post-smolts. Upon entering the marine environment post-smolts from UK waters are thought to migrate towards the Norwegian Sea. Most studies to date have relied on fisheries trawl data to predict the migratory patterns of post-smolts and particle tracking studies to determine the main environmental drivers of movement. Furthermore, particle tracking studies have indicated that post-smolts likely rely on shelf currents to reach their feeding grounds. This study is the first to ground truth the existing particle tracking studies by undertaking a large-scale acoustic telemetry study in the Irish Sea region. Telemetry methods can provide more accurate and detailed information on the location and timing of migration. During 2021, 938 Atlantic salmon smolts were acoustically tagged in 13 rivers in Scotland, Northern Ireland and England and a large marine array consisting of 108 receivers was deployed in the seas of the North Channel between Scotland and Ireland. Using a hydrodynamic model of the Scottish west coast this study investigated whether current speed and direction accurately predicted the spatial and temporal patterns of post-smolt distribution through the North Channel and determined if and how these patterns differed within and between river systems. The results of this study highlight the importance of cross-organisation collaboration and data sharing in order to answer questions related to salmonid migratory behaviour.

All correspondence should be addressed to Jessie Lilly.
email: j.lilly.1@research.gla.ac.uk

Nutritional Ecology of Juvenile North Pacific Salmon During Winter Existence: Results from the 2022 International Year of the Salmon Surveys

Todd W. Miller[1], Emily A. Fergusson[1], Charles D. Waters[1], Edward Farley Jr. [1], Wil Licht[2], Sydney King[2], and **Bryan Cormack[1]**

[1]*Auke Bay Laboratories, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Juneau, AK, USA*

[2]*Azura Consulting LLC Juneau, AK, USA*

Using proximate composition (percent lipid and protein) and stable isotope analyses, we assessed the nutritional condition and isotopic (trophic) life histories of Pacific salmon from the 2022 International Year of the Salmon (IYS) winter month surveys across the North Pacific, a period of reduced prey availability and potentially higher resource competition. Relationships of percent lipid and protein with body length were used to project the gain/loss of fat and protein with growth, trends that can reveal anabolic and catabolic processes driving nutritional condition. Isotopic life histories were reconstructed from bulk stable isotope analysis (carbon and nitrogen) of muscle, liver, and eye lens layers (laminae) to provide high-resolution measures of trophic overlap from stock origin of ocean entry (lens core) to time of capture (outer lamina). Relationships between isotopic overlap of salmon and their proximate composition-based nutritional condition were also explored.

All correspondence should be addressed to Todd Miller.
email: todd.miller@noaa.gov

Unraveling the Demographic Response of Atlantic Salmon to a Rapidly Changing Marine Environment by the Analysis of Their Scales

Marie Nevoux[1,2], Cécile Tréhin[1,3], Rémi Patin[1], Quentin Queiros[1], Frédéric Marchand[1,2,3], Ludivine Lamireau[3], Stephen Gregory[4,5], Jean-Marc Roussel[1,2], and **Etienne Rivot[1,2]**

[1]DECOD (Ecosystem Dynamics and Sustainability), INRAE, Institut Agro, IFREMER, Rennes, France

[2]Management of Diadromous Fish in their Environment, OFB, INRAE, Institut Agro, Université de Pau et des Pays de l'Adour, e2s UPPA, Rennes, France

[3]INRAE, pôle OFB-INRAE-Institut Agro-UPPA MIAME -Management of Diadromous Fish in their Environment, U3E, F-35042, Rennes, France

[4]Salmon and Trout Research Centre, Game and Wildlife Conservation Trust, River Laboratory, Wareham, Dorset, UK

[5]Centre for Environment, Fisheries and Aquaculture Science (Cefas), Weymouth, Dorset, UK

The deteriorating environmental conditions at sea is of major concern for salmon conservation and management, with suspected role in the widespread change in salmon population abundance and demographic structure. Yet, the vast majority of knowledge and data relate to the freshwater phase of the life cycle while only weak information and direct observation at sea are available. Nevertheless, long-term monitoring programs at counting stations during the migration, combined with information on catches by anglers, can provide a better understanding of salmon response towards changes in the marine environment. In this study, we collect, analyze, catalog, and integrate knowledge about the marine life of Atlantic salmon in an original multi-population approach.

We analyze microstructures of returning Atlantic salmon scales from five South European populations (France and England) to disentangle between global and population-specific responses to global change, focusing on seasonal growth during marine phase. We highlight the key role of the first summer at sea, following the migration of smolts, on salmon life at sea. This period is critical in explaining change in the size of returning salmon, with a noticeable decline in growth since 2005 in all five South European populations. Over the same period, changes in the isotopic composition of scales may suggest modifications of migration route and/or trophic ecology of salmon at sea. We also highlight that growth during the first summer at sea partly determines the age at maturation, and thus the age at return to the river. Moreover, the genetic sexing of samples brings a new and contrasted vision on the marine life of salmon. If growth at sea is similar in females and males, females need to reach a larger size than males to initiate maturation. Thus, any change in growth condition is likely to influence size, age and sex ratio in returning salmon. By explicitly incorporating key sex-specific demographic processes into a life cycle model, we quantify the relative contribution of observed changes in growth to salmon population demographic structure and dynamics. This work explores the empirical response of Atlantic salmon populations towards a rapidly changing world in the light of ecological and demographic mechanisms. It provides a coherent framework to study the marine phase of the salmon life cycle across large spatial scales.

All correspondence should be addressed to Marie Nevoux.
email: marie.nevoux@inrae.fr

Consequences of Variation in Body Size, Condition, Physiological State, and In-River Conditions for Spawning Migration Success by Alaskan Salmon: a Three-Year Telemetry Study of Copper River Sockeye

Pete Rand[1], Kristen Gorman[2], Karia Kaukinen[3], Tobi Ming[3], Shaorong Li[3], and **Kristi Miller[3]**

[1]*University of Alaska Fairbanks*

[2]*Prince William Sound Science Center*

[3]*Department of Fisheries and Oceans Canada*

Nearly all species of Pacific salmon (*Oncorhynchus* spp.) in Alaska have been returning to spawn at smaller body sizes in recent years. Studies suggest that the combined effects of a changing ocean climate and competition at-sea due to higher salmon abundance are key factors influencing the body size of adult Pacific salmon at return. Environmental conditions are also changing within freshwater systems, creating more variable and challenging migratory conditions for returning salmon. We present results from a three-year radio telemetry study that evaluated potential biological and environmental factors shaping spawning migration success by sockeye salmon of the Copper River, in southcentral Alaska – a highly glaciated watershed that supports commercial, subsistence, and personal-use sockeye fisheries. Over three field seasons (2019-2021), we radio tagged over 800 adult sockeye salmon in the lower Copper River and evaluated the effects of body size and condition, transcriptomic response, and pathogen diversity and loads on migration success. During 2019, air temperatures were very high, and accelerated glacial melting resulted in a high rate of water discharge. Sockeye radio tagged during 2019 had elevated transcriptomic responses for hypoxia stress (possibly resulting from physical exertion) and viral disease development (apparently associated with Infectious Hematopoietic Necrosis Virus, IHNV, infection) and a low rate of passage through Wood Canyon. However, transcriptomic responses for thermal stress were nearly twice as high in 2021 than in 2019. We hypothesize that migration could be impeded and enroute mortality possibly elevated in years with high rates of glacial melting, causing greater stress and potential for disease in migratory salmon. We detected a positive relationship across all years between sockeye body size and energy density and the likelihood of successful passage through Wood Canyon, suggesting that long-term declines in sockeye body size and energetic condition may translate into lower migratory success in-river. Several pathogens detected in our study are known to be associated with premature mortality in other salmon systems. Understanding the interplay of how ocean and in-river conditions are simultaneously affecting salmon fitness is important for future management of this fishery and others that experience significant glacial input.

All correspondence should be addressed to Pete Rand.
email prand@pwssc.org

Early Phase of the Marine Migration of Atlantic Salmon (*Salmo salar*) Post-Smolts from Twenty Rivers Across Scotland, England and Northern Ireland

Jessica R. Rodger[1,2], Jessie Lilly[1], Hannele H. Honkanen[1], Amy Green[1], Diego del Villar[3], Lorna Wilkie[2], Richard Kennedy[4], Andrea Barkley[4], Robert Rosell[4], William Roche[5], Ross McGill[3], Samantha Beck[6], Jim Henderson[7], Debbie Parke[7], Alan Kettle-White[8], Lucy Ballantyne[9], Shona Marshall[10], Paul Hopper[11], James Thorburn[12], Fred Whoriskey[13], Niall Ó. Maoiléidigh[14], Ken Whelan[2], Angus Lothian[1,2], and **Colin Adams[1]**

[1]*Scottish Centre for Ecology and the Natural Environment, Institute of Biodiversity, Animal Health and Comparative Medicine, University of Glasgow, UK*

[2]*Atlantic Salmon Trust, Battleby House, Redgorton, Perth, UK*

[3]*Loughs Agency, Victoria Road, Derry ~ Londonderry, Northern Ireland*

[4]*Agri-food and Biosciences Institute, Large Park, Hillsborough, Northern Ireland*

[5]*Inland Fisheries Ireland, Lake Drive, Citywest Business Campus, Dublin, Ireland*

[6]*Galloway Fisheries Trust, Station Industrial Estate, Newton Stewart, UK*

[7]*The Nith Catchment Fisheries Trust and The Nith District Salmon Fishery Board, Dumfries, UK*

[8]*Argyll Fisheries Trust, Cherry Park, Inveraray, UK*

[9]*Lochaber Fisheries Trust, Torlundy, UK*

[10]*West Sutherland Fisheries Trust, The Gardeners Cottage, Scourie, UK*

[11]*Outer Hebrides Fisheries Trust, The Sawmill, Marybank, Isle of Lewis, UK*

[12]*Scottish Oceans Institute, East Sands, St Andrews, UK*

[13]*Department of Biology, Dalhousie University, Halifax, NS, Canada*

[14]*Marine Institute, Furnace, Newport, Co. Mayo, Ireland*

The evidence suggests that the decline in Atlantic salmon populations from across Europe are, at least in part, due to increasing losses occurring during the marine phase of migration. Emerging data suggests that migration success of out-migrating fish may be poor, particularly in the earliest stages of their migration when they may be in close proximity to human activity. Yet this stage of the migration remains very poorly understood.

In this study we aimed to determine the migration pathways of Atlantic salmon post-smolts during the early phase of their marine migration through the waters surrounding the western British Isles and Ireland. 1649 salmon smolts migrating from 20 rivers in Scotland, England and Northern Ireland were tagged with acoustic transmitters during spring 2021. 457 receivers were deployed in curtain arrays in the seas of the North Channel between Ireland and Scotland, off the Hebrides and mainland Scotland. Our results show that Atlantic salmon post-smolts migrated in multiple directions and in complex patterns during the early phase of their marine migration. There were significant between-river differences in the pathways adopted by post-smolts from different regions. The timing of passage and migration speed of post-smolts through coastal marine waters also varied markedly, with mean movement rates ranging between 4.32 and 39.94 km/day. This study is the first to establish a wider picture of the migration pathways of Atlantic salmon post-smolts during the early coastal phase of their marine migration in the western British Isles and Ireland. The results show complex patterns of Atlantic salmon post-smolt migration, with multiple pathways and waters utilised during the early phase of their marine migration. This study has significant consequences for our understanding of the potential conflict between migrating salmon and human activities in coastal zones.

All correspondence should be addressed to Jessica Rodger.
email: Jessica.Rodger@glasgow.ac.uk

Status of Pacific Salmon Stocks in the Summer Bering Sea Based on Long Monitoring Survey by Japanese Research Cruises in 2007–2021

Shunpei Sato[1], Tomoki Sato[1], and **Kentaro Honda[1]**

[1]*Fisheries Resources Institute, Japan Fisheries Research and Education Agency, 2-2 Nakanoshima, Toyohira-ku, Sapporo, Japan*

Pacific salmon, particularly chum and sockeye salmon, are mainly distributed in the summer Bering Sea to their growth. Since 2007, Japanese salmon research cruises have been annually conducted by R/V *Hokko maru* in the summer Bering Sea in order to monitor the abundance, growth and feeding of Pacific salmon and their habitat environments. Our monitoring research has been carried out at 17 stations in the central Bering Sea using surface trawl net (1-hour trawl per station). Mean total number of Pacific salmon (sockeye, pink, chum, coho, and Chinook salmon) caught was 2,981 fish (range: 1,904-4,016 fish) between 2007 and 2021. Chum salmon were most abundant species (average: 2399 fish, 80.5%), followed by sockeye salmon (average: 486 fish, 16.3%), Chinook salmon (average: 75.4 fish, 2.5%), pink salmon (average: 16.7 fish, 0.6%), and coho salmon (average: 3.4 fish, 0.1%). Chum salmon were caught at all monitoring stations since 2007, however, their collected numbers fluctuated annually. Particularly, there were lowest level in 2014, 2015, and 2021 seasons. Collected numbers of sockeye salmon tend to increase since 2013, while number of Chinook salmon showed low level since 2016. Although mean sea surface temperature fluctuated between 9–12 °C among years, no significant correlation with salmon abundance was found to date. However, water temperature anomalies below the thermocline tended to be high since 2014. Zooplankton biomass monitored by bongo net was fluctuated through the monitoring periods, and they were tended to be low in recent year. Our long monitoring survey will contribute continuously to understand status of Pacific salmon in a changing salmosphere.

All correspondence should be addressed to Shunpei Sato.
email: sato_shunpei50@fra.go.jp

Preliminary Findings of the International Year of the Salmon Expedition to the Central Part of the North Pacific

A.A. Somov[1], A.H. Starovoitov[1], D.N. Chulchekov[1], K.K. Kivva[2], A.S. Chleborodov[1], V.I. Poljanichko[1], Ju. Ju. Korolev[1], A.O. Bezverchnjaja[1], S.V. Novokrechennyh[3], V.A. Soshnina[2], I.N. Muchametov[3], V.F. Parhomchuk[1], G.A. Kantakov[1], V. Radchenko[4], and **E.A. Pakhomov[5]**

[1]*Pacific Branch of the Federal Research Institute of Fisheries and Oceanography "VNIRO" (TINRO), Shevchenko Alley 4, Vladivostok, Russia*

[2]*Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), Verkhnyaya Krasnosel'skaya Ulitsa 17, Moscow, Russia*

[3]*Sakhalin Branch of the Federal Research Institute of Fisheries and Oceanography "NVIRO" (SakhNIRO), Komsomolskaya St. 196, Yuzhno-Sakhalinsk, Russia*

[4]*North Pacific Anadromous Fish Commission, 889 West Pender Street, Vancouver, BC, Canada*

[5]*Department of Earth, Ocean and Atmospheric Sciences, & the Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, BC, Canada*

During February-March 2022, RV *TINRO* conducted the oceanographic survey south of the Aleutian Islands in the North Pacific. The expedition was an integrative part of the 2022 Pan Pacific survey of the International Year of the Salmon. The main aims of the expedition were: (i) to evaluate oceanographic dynamics in the central part of the North Pacific; (ii) to estimate composition and biomass of the pelagic zooplankton and micronekton; and (iii) to assess of the winter distribution, abundance and biomass of the Pacific salmon. In total, 32 oceanographic stations were completed covering area of 530,000 km^2. During the trawl survey, 26 macroplankton, micronekton and nekton species were identified including 11 fish, 7 squid, 6 jellyfish and 2 salp species. Preliminary total abundance and biomass was calculated to be 19.3 billion individuals and 429,000 tons. In terms of wet mass, biomass dominated by gelatinous macroplankton (55% of jellyfish and 25% of salps) followed by fish (16%, including 15% salmonids) and squid (4%). The total standing stock of Pacific salmon in the investigated area was assessed to be ~ 147 million individuals or 60,800 tons. Sockeye salmon accounted for 80% of the total abundance. Preliminary acoustic data showed that while salmon was observed in the top 100 m water layer, 65% of all salmon concentrated in the top 30 m layer. The findings of this survey showed that during winter Pacific salmon are typically found in low to modest concentrations within the Subarctic Frontal system. Occasionally, subadults Pacific salmon may form locally high concentrations. Overall, the feeding intensity of Pacific salmon was not very high and gut fulness indices generally ranged from 50 to 100 ‰, indicating rather maintaining foraging feeding activity. This was confirmed by generally good fish condition factor of all species, with exception of pink salmon.

All correspondence should be addressed to Aleksey Somov.
email: aleksey.somov@tinro-center.ru

Illuminating the Black Box of North Pacific Salmon Food Webs: Identifying Trophic Pathways and Interspecific Competition through an Ecosystem Approach

Genyffer C. Troina[1], Evgeny A. Pakhomov[1,2,3], Aleksey Somov[4], and **Brian P.V. Hunt[1,2,3]**

[1] *Institute for the Oceans and Fisheries, University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada*

[2] *Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, 2039-2207 Main Mall, Vancouver, BC, Canada*

[3] *Hakai Institute, P.O. Box 309, Heriot Bay, BC, Canada*

[4] *Pacific Scientific Research Fisheries Center (TINRO-Center) 4, Shevchenko Alley, Vladivostok, Russia*

Understanding food web structure and dynamics is key to accurately quantifying species interactions, identifying the main trophic pathways that sustain salmon and apex predators, and evaluating the effects of climate changes on ecosystem stability. Oceanographic and trawl sampling completed during the 2019 International Year of the Salmon expedition to the Gulf of Alaska (GoA) provided a rare opportunity to assess high seas salmon food webs in the eastern North Pacific. Using samples collected during this expedition our main goal was to characterize the trophic connections within the GoA food webs that sustain salmon during winter (Feb–Mar), and how they vary spatially according to gradients in oceanographic conditions. We analyzed salmon stomach contents, as well as carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotopes in samples of particulate organic matter, zooplankton, jellyfish, squids, and fish (including salmon). Isotope data were used to estimate the trophic position (TP) of the different food web components, and their isotopic niche areas as a proxy of trophic niche. Two different subareas were identified within the GoA based on a hierarchical cluster analysis using oceanographic data. Lower temperatures, higher salinity and nutrient concentrations were found in the northwestern Gulf of Alaska (NW-GoA) in comparison to stations sampled in the southeast (SE-GoA), the former reflecting the influence of the Alaska Gyre. In both regions, three main trophic groups were identified: primary consumers—mesozooplankton taxa / size fractions (TPs 2.0–2.8); secondary consumers—chum, squids, and jellyfish (TPs 2.8–3.3); and tertiary consumers—myctophids, pink, sockeye, chinook, coho, and spiny dogfish. Salmon TP did not differ between those caught in the NW-GoA and their SE-GoA conspecifics. In the NW-GoA, euphausiids appeared to be the dominant pathway between phytoplankton and salmon. High isotopic similarity and niche overlap among myctophids, squids, chum and sockeye in the NW-GoA indicated that they consumed isotopically similar prey and might compete for resources. Conversely, in the SE-GoA salmon consumed a greater variety of prey and this appeared to allow for more resource segregation among species, with only pink salmon seeming to compete with myctophids and squid. This study builds on previous works on the feeding ecology of salmon in the high seas, and takes a step forward through an ecosystem-based approach that sheds light on direct and indirect trophic relationships, including competition with non-salmonid species, that might cascade through the food web and affect salmon growth and survival.

All correspondence should be addressed to Genyffer Troina.
email: g.troina@oceans.ubc.ca

A Multi-Scale View of the Ocean Environment Along a 3,000 km Post-Smolt Migration Corridor

Emma Tyldesley[1], Neil Banas[1], Colin Bull[2], and **Graeme Diack[2]**

[1]*University of Strathclyde Department of Mathematics and Statistics, 26 Richmond Street, Glasgow*

[2] *Atlantic Salmon Trust, Battleby House, Redgorton, Perth*

Return rates of adult Atlantic salmon (*Salmo salar*) to many European rivers have declined in recent decades. The first months at sea are thought to be a critical for survival such that changes in ecosystem conditions during this phase could drive overall patterns of returns.

In this study, we seek to explain variability in marine survival of salmon from a set of southern European stocks for which time-series of adult return rates, smolt migration timing, and river conditions are available. During the spring and summer, post-smolts from these rivers utilise shared Atlantic shelf edge and North Sea migration routes to feeding grounds in the Norwegian Sea and are thus influenced by environmental drivers on a range of scales from stock-specific to global.

We evaluate competing hypotheses that marine survival is driven by (i) changes in the plankton prey of the post-smolt's forage fish prey *during* the early marine phase, (ii) plankton conditions *integrated* over a larger space-time domain reflecting accumulation of energy up the food chain, or (iii) direct physiological impacts of changes in ocean temperature.

We compile a suite of ecosystem indicators describing the "salmonscape" experienced by post-smolts. Indicators include water mass type, temperature, primary production and prey energy availability. Novel techniques are used to extract both a "simultaneous" and "ecosystem integrated" representation of conditions.

To allow examination of the relative importance of local, regional and global drivers, use is made of new regional ocean model hindcasts—the Atlantic Margin Model reanalysis and the Scottish Shelf Waters Reanalysis Service. Continuous Plankton Recorder abundance data are reanalysed to estimate zooplankton energy available to the post-smolt's forage fish prey. This gives high spatial and temporal resolution in potentially relevant variables such as the timing of the spring bloom and zooplankton energy.

We show there have been significant changes in the environmental and feeding conditions experienced by post-smolts during their early marine phase. Regions of the migration area have seen a decline in zooplankton energy available to post-smolt prey species. The degree of change varies geographically, affecting some stock groupings more than others. We also highlight important data gaps that hinder our ability to quantify the salmon ecosystem, particularly at the level of forage fish.

This project is an implementation case-study of the Likely Suspects Framework. It draws on the newly developed data repository and will inform the stage-structured salmon mortality model and decision support tools also under development within the framework.

All correspondence should be addressed to Emma Tyldesley.
email: emma.tyldesley@strath.ac.uk

A Trans-Range "Weight of Evidence" Model for Atlantic Salmon Post-Smolt Oceanic Migration and Distribution: A First Step Toward Addressing Data Scarcity

Eric Verspoor[1], John Gilbey[2], Vidar Wennevik[3], Kjell Utne[3], Ian Bradbury[4], Jonathan Carr[5], Jason Daniels[5], Timothy Sheehan[6], David Reddin[7], Jan Arge Jacobsen[8], Sigurður Már Einarsson[9], Guðni Guðbergsson[9], Johan Östergren[10], and **Philip McGinnity[11,12]**

[1]Rivers and Lochs Institute, University of Highlands and Islands Inverness, Campus, 1, Inverness, Scotland, UK

[2]Marine Scotland Science, Freshwater Fisheries Laboratory, Faskally, Pitlochry, UK

[3]Institute of Marine Research, Bergen, Norway

[4]Science Branch, Fisheries and Oceans Canada, 80 East White Hills Road, St. John's, NL, Canada

[5]Atlantic Salmon Federation, 15 Rankine Mill Road, Chamcook, NB, Canada

[6]NOAA Fisheries Service, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA, USA

[7]Atlantic Salmon Conservation Foundation, 670 Old Broad Cove Road, St. Philips, NL, Canada

[8]Faroe Marine Research Institute, Tórshavn, Faroe Island

[9]Marine and Freshwater Research Institute, Hafnarfjörður, Iceland

[10] Swedish University of Agricultural Sciences, Department of Aquatic Resources, Institute of Freshwater Research, Stångholmsvägen 2, SE-178 93, Drottningholm, Sweden

[11]Aquaculture & Fisheries Development Centre, School of Biological, Earth and Environmental Sciences, University College, Cork, Ireland

[12]Marine Institute, Mayo, Ireland

Accurate accounts of species distributions and their spatial-temporal dynamics are essential for effective conservation management. In oceanic habitats, gaining such insight presents a colossal logistic challenge due to the vast, largely alien, and often inclement, oceanic environment. Thus, data is generally scarce, patchy, and heterogeneous, especially for rare, wide-ranging, and migratory aquatic species such as the Atlantic salmon. This makes advancing understanding by statistical modelling approaches problematic. Toward addressing data scarcity in the early marine post-smolt phase, using an evolutionary framework, we undertook within a critical interpretive synthesis across all available information sources and constructed a general range-wide migration-distribution model based on the collective "weight of evidence". The model builds on a consideration of evolved variation in migration behaviour among salmon stocks, existing general and stock specific distributional and migrational information (including tagging and telemetry data), observed associations of distribution and migration with key environmental factors, and insights gained from particle tracking studies. While, as posited by the existing "merry-go-round" hypothesis, ocean currents are indicated to be a major proximal distributional factor, various lines of evidence indicate the involvement of multiple proximal environmental drivers. It also strongly argues that the effect of proximal conditions varies among phylogeographic groups due to evolved heritable differences and leads to variation among groups in their migration syndromes. This provides the only coherent evolutionary framework for the widely varying migrational and distributional patterns seen among early marine phase post-smolt salmon stocks. It further argues that differential migrational and distributional responses of stocks to global warming related environmental change are likely to occur. The conceptual model constructed, while far from definitive, provides the only existing comprehensive evidence-based migration dynamics hypothesis. It provides a basic framework to help guide current oceanic conservation management of post-smolt Atlantic salmon, and focus limited research resources on key data, that can best test the model structure and assumptions, and further advance understanding.

All correspondence should be addressed to Eric Verspoor.
email: eric.verspoor.ic@uhi.ac.uk

Towards a Better Understanding of the Winter Energetic Status and Fitness of Pacific Salmon in the Gulf of Alaska: Results from the 2019 IYS Expedition

Charles D. Waters[1], Todd Miller[1], Emily Fergusson[1], Dion Oxman[2], Beverly Agler[2], and **Edward Farley Jr.[1]**

[1]*Auke Bay Laboratories, Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Juneau, AK, USA*

[2]*Mark Tag and Age Laboratory, Division of Commercial Fisheries, Alaska Department of Fish and Game, Juneau, AK, USA*

A comprehensive understanding of factors that regulate the productivity of Pacific salmon is needed for their effective management and conservation, particularly with changing environmental conditions such as the recent marine heatwaves in the North Pacific Ocean. Winter is considered to be a critical period for Pacific salmon, where overwinter survival is likely dependent on their ability to acquire sufficient lipid reserves in the preceding summer and fall. Yet, we do not fully understand the winter energetic status and fitness of the different age classes for each species or the extent to which intra- and inter-specific competition may exist. Competition may be further intensified by large-scale hatchery releases of pink and chum salmon. Here, we assessed the winter energetic status and fitness of Pacific salmon by estimating their energy density, lipid content, and protein content from samples of muscle tissue collected in the Gulf of Alaska in winter 2019. We then estimated the hatchery component of chum and pink salmon by examining otoliths to determine the presence of a thermal mark (hatchery origin), which allows us to better understand the potential for competition between hatchery and wild salmon that may occur in the marine environment. Energy densities between chum, coho, pink, and sockeye salmon were similar despite different prey preferences and feeding intensities, which may reflect general winter energetic conditions in the Gulf of Alaska. Lipid and protein content suggest that chum salmon were in moderate condition during winter 2019, whereas coho, pink, and sockeye salmon were in poor condition. No differences in energy density were observed between hatchery and wild chum salmon from Alaska, suggesting that fish of both origins may be responding similarly to winter conditions. These results provide important insight regarding the fitness of Pacific salmon during the critical winter period, although our findings must be paired with data from additional years before more definitive interpretations can be made.

All correspondence should be addressed to Charles Waters.
email: Charlie.Waters@noaa.gov

Rapid Growth in Salmonids: Effects Across Biological Scales, from the Individual Level to Ecosystem Functions

Line E. Sundt-Hansen [1], Julien Cucherousset[2], Mathieu Buoro[2], Libor Závorka[2], Knut A.E. Bækkelie[1], August E. Høyland[3], Grethe Robertsen[1], Eli Kvingedal [1], and **Kjetil Hindar[1]**

[1]Norwegian Institute for Nature Research (NINA), Trondheim, Norway

[2]CNRS, Université Toulouse III Paul Sabatier, ENFA; UMR5174 EDB (Laboratoire Évolution & Diversité Biologique); 118 route de Narbonne, F-31062 Toulouse, France

[3]University of Oslo (UiO). Problemveien 7, 0315 Oslo, Norway

Humans have a long history in manipulating growth in animals for our advantage, through selective breeding for rapid growth in farmed salmon and developing genetically modified salmon reaching a larger size faster than wild fish. Breeding programs for many salmonids have focused on developing more extreme phenotypes (e.g. faster growth rate, and/or larger size at reproduction), which may disproportionally impact wild salmonids if they are released or escape into the wild.

Impact of escaped farmed salmon into the wild have often focused on interactions between wild and farmed salmon, at the individual or population level. However, there is a lack of knowledge considering the impact of escaped farmed salmon on aquatic ecosystems and ecosystems functions.

In a series of experiments in semi-natural facilities at NINAs research station at Ims, we have tested how rapid growth (potential) of farmed Atlantic salmon affects their behaviour and competition and interaction with wild Atlantic salmon. Further, we have tested how this competition is influenced by population density, food abundance and predation. Moving from the individual to an ecosystem approach, we have tested how Atlantic salmon with a rapid growth potential, impact the ecosystem and ecosystem function. Our results show that not only does rapid growth impact the individuals and other conspecifics, but also other organisms in the ecosystem and their functions.

All correspondence should be addressed to Line Sundt-Hansen.
email: line.sundt-hansen@nina.no

Effects of Stocking at the Parr Stage on the Reproductive Fitness and Genetic Diversity of a Wild Population of Atlantic Salmon (*Salmo salar L.*)

Raphaël Bouchard.[1,2], Kyle Wellband[2], Laurie Lecomte[1,2], Louis Bernatchez[1,2], and **Julien April[3]**

[1]*Département de Biologie, Université Laval, QC, Canada*

[2]*Institut de Biologie Intégrative et des Systèmes, (IBIS), Université Laval, QC, Canada*

[3]*Direction de l'expertise sur la faune aquatique, Ministère des Forêts, de la Faune et des Parcs du Québec, QC, Canada*

Captive-breeding programs are among the most adopted conservation practices to mitigate loss of biodiversity, including genetic diversity. However, both genetic and nongenetic changes occurring in captivity can reduce fitness of supplemented individuals which complicate rehabilitation efforts. In the case of Atlantic Salmon, the intensity of changes that occur in captivity and their impact on fitness will vary with the stocking practice adopted. In this study, we test whether salmon stocked at the parr stage have reduced reproductive success compared to their wild conspecifics and if they contribute to increase genetic diversity in the targeted population. To do so, we use high-throughput microsatellite sequencing of 38 loci to accurately assign 2381 offspring to a comprehensive set of possible parents from a supplemented Atlantic salmon population in Québec, Canada. Captive-bred salmon stocked at the parr stage had fewer mates than their wild conspecifics as well as a reduced relative reproductive success compared to their wild counterparts. Nonetheless, in comparison with previous studies, stocking at the parr stage significantly improved relative reproductive success compared to salmon stocked as smolts and they displayed a reduction of reproductive success similar to salmon stocked as fry which spend less time in captivity than parr. Moreover, supplementation of captive-bred salmon significantly contributed to increasing genetic diversity. These results should contribute to informing resource managers in determining the best stocking practice to enhance Atlantic salmon populations.

All correspondence should be addressed to Raphaël Bouchard.
email: raphael.bouchard.3@ulaval.ca

If You Don't Know What It Does, Then Don't Do It: Equilibrium Modelling to Assess the Potential Risks and Benefits of Supplementation to Augment Wild Salmon Abundance

Gérald Chaput[1]

[1]*Fisheries and Oceans Canada, 343 University Avenue, Moncton, NB, Canada*

Hatchery supplementation of Atlantic Salmon has a long history and continues to be advocated as an effective intervention to support fisheries or to prevent population extirpations. In the most recent decade, hatchery interventions have changed from the collection of wild broodstock and stocking of juvenile stages to the collection of juvenile salmon from the wild, rearing in captivity to maturity, and releasing the captive-reared adults back to the river to spawn. Equilibrium population modelling can be used to explicitly formulate the population dynamics of salmon through multiple generations and to assess the risks and benefits to wild salmon of intervening or not using supplementation programs.

An equilibrium population modelling approach was used to assess a proposal to undertake a large smolt to adult captive rearing supplementation in the Northwest Miramichi River (New Brunswick, Canada). The predicted outcome from the supplementation in terms of overall anadromous abundance and abundance of wild anadromous salmon relative to the baseline condition in which there is no supplementation is illustrated. If there is lower expected marine survival of progeny from one or two captive-reared parents compared to pure wild progeny, there can be an increase in total anadromous returns as long as the supplementation program continues but there is a negative gain in anadromous fish when the supplementation ends. For the pure wild component of anadromous salmon, there is a decrease in abundance during the intervention which may continue after the end of the supplementation. The consequence of the marine survival fitness parameter on relative abundance of wild anadromous salmon can be different for population trajectories that are stable versus ones that are declining.

Equilibrium modelling can provide insights into the population dynamics that are the most uncertain, that could be affected by the intervention, and that should be more fully studied. It also provides critical information and a tool for managers to assess the risks and benefits to the valued component, the wild salmon, of supplementation as well as the scale of the intervention prior to proceeding. As the old adage goes, if you don't know what it does then don't touch it, but more importantly out of sight should not be out of mind.

All correspondence should be addressed to Gérald Chaput.
email: Gerald.Chaput@dfo-mpo.gc.ca

Supplementation Using 0+ Parr in the East Machias River. Performance of Naturalized Parr Provides Significant Positive Results in Contrast to Stocking Using Various Other Life Stages and Methods

Dwayne Shaw and **numerous NGO and Governmental partners**

Downeast Salmon Federation, Columbia Falls, ME 04623, USA

The stocking programs in Maine's endangered salmon rivers have focused on the use of eggs, unfed fry, accelerated smolt and captive reared adults with very limited success. A collaboration of federal, state and NGO partners have implemented and assessed the use of 0+ parr stocking reared using naturalized methods developed by Peter Gray on the Tyne River in England. The results of 10+ years of parr stocking show significant positive results including smolt to adult return rates exceeding 20 times that of stocked, accelerated (1 year old) smolts. The success of the use of these naturalized rearing and stocking methods indicates that continued experimentation must be pursued when stocking is deemed necessary to recover endangered populations.

All correspondence should be addressed to Dwayne Shaw.
email: dwayne@mainesalmonrivers.org

Alaska Hatchery Research Program: A Comprehensive Approach to Investigating Hatchery/Wild Interactions

William D. Templin[1] and **Chris Habicht**[2]

[1]*Division of Commercial Fisheries, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK, USA*

[2]*Gene Conservation Laboratory, Division of Commercial Fisheries, Alaska Department of Fish and Game, 333 Raspberry Road, Anchorage, AK, USA*

Throughout the natural range of Pacific salmon, hatchery production has been important for either managing the human uses of this important resource or for mitigating the effects from human uses of other natural resources. Hatchery programs are implemented for a wide range of purposes, from rescuing to multiplying populations, and no single standard for application nor metric for measurement can encompass all programs. In Alaska, hatchery programs are designed to provide additional salmon for harvest while maintaining sustainable production from wild populations. Requests for hatchery production are approached by asking whether an increase in production can be managed with consideration of potential risks to wild stocks. One risk to wild stocks is the interaction of hatchery fish on wild fish in streams. While hatchery pink salmon and chum salmon are produced for commercial harvest, hatchery-origin fish are found in wild spawning streams. In 2012, Alaska designed and started a large-scale, decade-long, multi-species project to answer three questions fundamental to evaluating the risk posed by these hatchery strays. Information is now available to answer the first two questions concerning the underlying genetic structure of the wild populations and the magnitude and pattern of straying of hatchery fish in wild streams. The third question concerning the potential effect of hatchery-origin spawners on the fitness of wild production is nearing completion. While most of the results are publicly available, the hard work of assimilating this new information into policy is just beginning. When considering changes to existing programs that can affect the cultural, subsistence, and economic uses of the resource by individuals and communities it is necessary first to possess the basic information needed to make wise and appropriate decisions.

All correspondence should be addressed to Bill Templin.
email: bill.templin@alaska.gov

Juvenile Salmon Use of Habitat Mosaics Across a Gradient of Estuarine Degradation

Julian C.L. Gan[1] and **Jonathan W. Moore** [1]

[1]*Earth to Ocean Research Group, Simon Fraser University, 8888 University Dr, Burnaby, BC, Canada*

Estuaries function as critical nursery habitat for many different fish species by providing food and protection. Several species of juvenile salmon use estuaries as stopover habitat in the course of their migration from natal freshwaters to the ocean. However, these ecosystems face multiple stressors from climate change and anthropogenic development which could degrade the complex and connected habitats that comprise estuaries. For instance, oncoming sea-level rise may drown tidal marsh habitat and alter vegetation community composition, and coastal development prevent upland migration of marsh habitat. This study aims to examine the linkages between the estuarine habitat mosaic and juvenile Pacific salmon (*Oncorhynchus spp.*), the broader fish community, and by conducting sampling across eight estuaries on Vancouver Island that varied in their degree of degradation. Three distinct habitat types were identified based on vegetation, substrate, and tidal influence: beach, estuarine marsh, and estuarine meadow. We focused on two levels of metrics: relative abundance of salmonid species and individual fork-length of juvenile salmon. Early results indicate that juvenile Chinook (*O. tshawytscha*), Chum (*O. keta*)., and Coho (*O. kisutch*) salmon were more abundant in different estuarine habitats and that these habitats hosted distinct fish communities. Additionally, bimodal distributions of juvenile coho fork-length were observed in several estuaries and suggest that different age-classes of fish favour different habitat types. Illuminating how juvenile salmon and other fish use current habitats can shed light on the potential impacts of current and oncoming estuary change and inform prospective and proactive restoration and conservation actions.

All correspondence should be addressed to Julian Gan.
email: julian_gan@sfu.ca

Spawning Life Stage as a Critical Period for Yukon River Chinook Salmon in a Changing Climate

Kathrine G. Howard[1] and **Vanessa von Biela**[2]

[1]*Alaska Department of Fish and Game, 333 Raspberry Road Anchorage, AK, USA*

[2]*USGS Alaska Science Center, 4210 University Drive Anchorage, AK, USA*

Chinook salmon originating in the Yukon River are among those at the northernmost extent of the species range in both freshwater and marine habitats. Historically these stocks supported important commercial, recreational, and subsistence food economies. But, Yukon River Chinook salmon populations declined in the 1990s and have remained at low abundance, taking a serious toll on communities. Existing research suggests Yukon River Chinook salmon run abundance is determined very early in their life: before the end of a juvenile cohort's first summer at sea (2-year-old fish). Factors driving the magnitude of juvenile cohort abundance are less clear. Therefore, we leveraged multiple existing datasets spanning adult and juvenile life history stages in freshwater and marine habitats, respectively. We analyzed environmental data in association with the production of offspring that survive to the marine juvenile stage (juveniles per spawner; J/S). These exploratory analyses suggest more than 50% of the variability in production of juvenile Yukon River Chinook salmon is associated with river temperatures or water discharge levels during the parent spawning migration ($p<0.01$). Over the past two decades, parents that experienced warmer water temperatures and lower discharge in the mainstem Yukon River produced fewer juveniles per spawning adult. We propose a conceptual model that can explain this association using independent data focused on marine nutrition and freshwater heat stress. Altered trophic dynamics due to Bering Sea ice loss may help explain recent evidence of thiamine deficiency in some Yukon River Chinook salmon eggs, which is linked to reduced offspring survival. Freshwater migration temperatures are now consistently warm enough to induce heat stress in Yukon River Chinook salmon, raising concern for premature mortality of parents. The combined effects of these marine and freshwater stressors may be contributing to the prolonged, depressed productivity of these stocks. It is sobering to consider that some of the northernmost Pacific salmon habitats may already be unfavorable to this cold-water species. These findings have immediate implications given the common assumption that northern ranges of Pacific salmon offer refugia from climate stressors.

All correspondence should be addressed to Kathrine Howard.
email: Kathrine.howard@alaska.gov

Conserving Salmon at the Southern End of their North American Range: Challenges and Opportunities

Steve Lindley, Rachel Johnson, Nate Mantua, and **Eric Danner**

Santa Cruz Laboratory, National Marine Fisheries Service, 110 McAllister Way, Santa Cruz, CA, USA

The southernmost populations of Chinook salmon, coho salmon, and steelhead occur in California, a highly populous, developed and increasingly climatically variable region. Not surprisingly, many salmon populations are in poor condition, yet California watersheds contribute significantly to West Coast salmon fisheries, and salmon populations continue to flourish in certain times and places in California. In this paper, we review the historical and current state of salmon in California, the processes that have led to the current state, and key research findings that point the way for conservation and recovery of salmon in California, as our climate warms and becomes more variable. California's watersheds are under human influences that range from benign to extreme, and are at the southern edge of species' ranges where conditions may be at the limits of physiological tolerance. Given these conditions, California may offer a preview of things to come for salmon elsewhere and a test-bed for strategies to cope with climate change and other anthropogenic impacts. Various lines of evidence support the idea that restoring habitat complexity, connectivity, and extent will allow for increased life history variation that in turn will improve the resistance and resilience of salmon to climate extremes. Where process-based restoration is not practical, conservation may be more dependent on active management (for example, water management in highly regulated rivers). A portfolio of science-based strategies is needed to ensure salmon are able to cope with the rapid pace of changing climate conditions.

All correspondence should be addressed to Steve Lindley.
email: steve.lindley@noaa.gov

Environmental and Biological Factors Influencing Residence Duration of Wild Sub-Yearling Chinook Salmon in a Fjord Estuary of the Salish Sea Using Micro-Acoustic Transmitters

Stephanie Lingard[1], Scott G. Hinch[1], Arthur Bass[1], and **Katrina Cook[2,3]**

[1]*Pacific Salmon Ecology Conservation Laboratory, University of British Columbia, 2424 Main Mall Vancouver, BC, Canada*

[2]*Squamish River Watershed Society*

[3]*InStream Fisheries Research, Inc.*

Estuary habitat restoration is commonly undertaken as a conservation initiative for Chinook Salmon; however, planning effective restoration requires intimate knowledge of species and life-stage specific ecology and behaviour. Using newly developed miniaturized transmitters (Innovasea V3), we monitored movement ecology of wild sub-yearling (n = 46) Chinook Salmon in a fjord estuary undergoing restoration. Biological (size, growth rate) and environmental factors (temperature, discharge, tide elevation) were also measured. Fish implanted with transmitters ranged in size from 67 to 90 mm. Using time-to-event analysis we obtained a median residence duration of 11.2 days (95% CI 6.5-15.2). Model selection was used to identify biological and environmental factors influencing residence duration. This research provides the first direct measure of estuary residence duration in sub-yearling salmon. These insights can be used to guide selection of habitat-based conservation actions.

All correspondence should be addressed to Stephanie Lingard.
email: steph_lingard@hotmail.com

Warming Rivers in the Atlantic Coast; Is this the End of Atlantic Salmon (*Salmo salar*)?

Tommi Linnansaari[3], Antóin M. O'Sullivan[2], Emily Corey[1], Ryan Carrow[2], R. Allen Curry[3], and **Richard A. Cunjak[3]**

[1]*Department of Biology, University of New Brunswick, Fredericton, NB, Canada*

[2]*Faculty of Forestry and Environmental Management University of New Brunswick, Fredericton, NB, Canada*

[3]*Canadian Rivers Institute, University of New Brunswick, Fredericton, NB, Canada*

The freshwater production capacity of Atlantic salmon (*Salmo salar*) is progressively affected by increasing water temperature, especially in the species' southern North American range. Through a series of studies stemming over the last >15 years, our objective has been to unravel the effects of warming rivers on the future resiliency of A. salmon in eastern North America. We have examined both juvenile and adult life-stages in multiple Atlantic Canadian rivers using a variety of methods including thermal infrared and optical orthophotographic imaging, novel inexpensive underwater video camera systems, thermal-sensor radiotracking, two-person antenna Passive Integrated Transponder tracking systems, and geospatial and mathematical modeling.

We have documented that juvenile Atlantic salmon parr utilize a wide range of thermal refugia and can travel distances > 8 km in extremely stressful (> 27 °C) thermal conditions to reach these refugia. The spatial distribution of juvenile salmon at river reach scale appears to be linked to the presence of thermal refugia. Our data suggests this fidelity to reaches with thermal refugia remains constant as long as there is a risk of further thermally taxing events during a given summer. However, the effect on juvenile salmon distribution is alleviated by autumn when the risk of further thermal events is no longer present. Initiation of behavioural thermoregulation appears to be different between populations, such that juvenile salmon from a relatively cooler river are triggered by lower temperatures than juveniles from a relatively warmer river. Additionally, the behavioural thermoregulation within a river appears to be predicted by the process of thermal hysteresis; that is, the water temperature triggering behavioural thermoregulation is adjusted downward during repeated events due to physiological thermal "loading", unless the time between events allows "unloading" of thermal threshold recovery curve.

For adult A. salmon, we have documented that some adults initiate thermoregulatory behaviour in ambient water temperature of 19 °C, with salmon seeking colder refugia as the ambient water temperature further increases. Interestingly, adult A. salmon form distinct geometric formations—thermal-pelotons—when in thermal aggregations, presumably attenuating hydraulic-drag and thereby reducing energetic expenditure of individuals.

Our work has shown the importance of understanding how and where warming freshwater will have its most critical impact, with future work to be focused on effective mitigation measures. It will be important to differentiate separate but potentially interacting drivers of increasing water temperatures (role of climate change *vs* role of landscape activities) and focus on the most critical areas.

All correspondence should be addressed to Tommi Linnansaari.
email: tommi.linnansaari@unb.ca

Seasonal Variation of Wetland Connectivity, Water Quality, and Use by Juvenile Coho on the North Thompson River

Brittany Milner[1], and **Douglas Braun[2]**

[1]*Simon Fraser University, Burnaby, BC, Canada*

[2]*Fisheries and Oceans Canada, Simon Fraser University, Burnaby, BC, Canada*

The importance of freshwater wetlands to juvenile salmon in large river networks is not well known.

Juvenile salmon use of wetland habitats depends on the connectivity between rivers and wetlands which can change seasonally. During months of low precipitation and flows, wetlands may become disconnected from other riverine rearing habitats, preventing juvenile salmon from moving in and out of wetlands. These drier conditions can also lead to a reduction in wetland habitat area and water quality, making juvenile salmon more vulnerable to high temperatures and low dissolved oxygen concentrations. We studied three wetland sites in the North Thompson watershed to understand how seasonal variation in wetland connectivity and water quality influence juvenile coho salmon habitat use. Dissolved oxygen, temperature, and water level loggers were deployed to monitor seasonal variation in water quality. Monthly mark-recapture sampling of juvenile coho salmon was used to estimate juvenile coho salmon densities. Wetland connectivity to the main stem was directly influenced by main stem discharge and physical habitat characteristics. We observed high temperatures and low dissolved oxygen concentrations in our wetland sites during July and August, when sites were disconnected. Densities of juvenile coho were low in April and May in all three sites; however, fish were larger, indicating they had recently overwintered. Densities peaked in July and August and decreased in September and October, suggesting young of the year enter the wetlands in late spring and early summer. Our findings indicate that inland wetlands may be important rearing habitat for early life stages of juvenile coho as these habitats are used year-round.

All correspondence should be addressed to Brittany Milner.
email: brittany_milner@sfu.ca

Salmon Futures: Climate Change, Multiple Stressors, and Resilience of Salmon Watersheds

Jonathan Moore

Simon Fraser University, Vancouver, BC, Canada

In watersheds of western North America, migratory salmon support ecosystems, economies, and cultures. However, these fish and their fisheries are threatened by climate change and multiple stressors. Here I will overview emerging science on how the symptoms of climate change and other human pressures are cumulatively challenging the resilience of salmon systems. With climate change and multiple human activities, flow regimes are changing and lower summer flows are harming stream-rearing salmon in working watersheds. Coastal development is challenging the nursery function of estuaries for young outmigrating salmon with sea level rise oncoming. Warming river temperatures are exposing migrating adult salmon to thermally-stressful temperatures in some regions and populations. Glacier retreat is posing new challenges for water flows and temperatures, but also creating thousands of new river habitats for salmon. In all examples, there are critical opportunities for local management actions to increase the resilience of these complex socio-ecological systems. In this era of rapid global change, there is an urgent need for forward-looking and collaborative science to help inform forward-looking conservation and management.

All correspondence should be addressed to Jonathan Moore.
email: jwmoore@sfu.ca

Importance of Pink Salmon Reproduction for Freshwater Ecosystems

Vladimir Radchenko[1]

[1]*North Pacific Anadromous Fish Commission, Vancouver, BC, Canada*

The role of Pacific salmon in freshwater ecosystems is mainly assessed on observations of their spawning run attracting attention by high spawner biomass. The role played by juvenile salmon in freshwater ecosystems has received less attention, and limited research is conducted in a wide network of spawning streams. Meanwhile, migration of juvenile pink salmon *Oncorhynchus gorbuscha*, one of the most abundant species of Pacific salmon, is a significant event in small water bodies within this salmon range that determines the functioning of freshwater ecosystems and trends in biomass and abundance of many ecologically related species. This report is based on observations of the food composition in stomachs of mass fish species caught during recreational fishing in the small lake (about 60,000 m^2) in the Harrison lake-river system in southern British Columbia: cutthroat trout *Oncorhynchus clarkii*, lake whitefish *Coregonus clupeaformis*, and northern pikeminnow *Ptychocheilus oregonensis*. Tiny (tenths of a gram) schooling, inactively swimming pink salmon outmigrants are easy prey for those fish in stream estuaries. Up to 164, 126, and 28 pink salmon fry, respectively, were found in the stomachs of the listed fish specimens during the season of downstream migration of pink salmon (April–early May). Since fry were poorly digested, almost intact, we consider this amount as close to the maximum daily intake by piscivorous fish. Pink salmon downstream migration lasts there about a month as well as a time of cutthroat and whitefish occurrence. For later migrating pikeminnow, time of co-dwelling with juvenile pink salmon in that small lake is estimated as two weeks. During this time, three listed species can consume a significant part of their annual diet, especially in terms of energy. This is especially important for whitefish and pikeminnow, which usually feed upon low calorie benthic food during the rest of year. In one small lake under consideration, three piscivorous species can eliminate a number of pink salmon fry from spawning of 2,500–3,000 pink salmon in the small inflowing creek. In addition to these species, coho salmon *O. kisutch*, Dolly Varden *Salvelinus malma*, bull trout *Salvelinus confluentus*, longnose sucker *Catostomus catostomus*, and piscivorous birds also prey upon salmon fry there. Since only odd-year pink salmon broodline reproduces in the southern British Columbia, this creates a significant difference in forage conditions for the listed fish species in even and odd years.

All correspondence should be addressed to Vladimir Radchenko.
email: vlrad@npafc.org

Fundy Salmon Recovery: An Innovative Collaboration Turning the Tide in Wild Atlantic Salmon Restoration

Kurt M. Samways[1], Corey Clarke[2], Tim Robinson[3], Matthew Ingersoll[4], and **Betty House[5]**

[1]*University of New Brunswick, 100 Tucker Park Road, Saint John, NB, Canada*

[2]*Parks Canada, Fundy National Park, 8 Headquarters Campground Road, Alma, NB, Canada,*

[3]*Fort Folly Habitat Recovery, 88 Bernard Trail, Fort Folly First Nation, NB, Canada*

[4]*Cooke Aquaculture Inc. 1228 HWY-776, Grand Manan, NB, Canada*

[5]*Atlantic Canada Fish Farmers Association, 226 Limekiln Road, Letang, NB, Canada*

In Canada, as around the world, the rate at which wild salmon populations are facing extirpation exceeds the pace at which management interventions can address declines. Despite considerable efforts, various enhancement methods are either abandoned in the absence of demonstrable population improvement or continued for decades without clear links to effectiveness. Atlantic Salmon populations in the inner Bay of Fundy rivers are critically low and listed as endangered under the Canadian Species at Risk Act. Fundy Salmon Recovery is a diverse collaboration of federal and provincial governments, aquaculture industry, First Nations, law enforcement, and academia, united by a common goal, to restore historic wild Atlantic Salmon populations to the inner Bay of Fundy. Fundy Salmon Recovery is the first to create and implement a new and innovative approach to Salmon conservation, in that it captures wild Atlantic salmon seaward migrating smolts from inner Bay of Fundy rivers, rears them at World's First Wild Salmon Marine Conservation Farm, and subsequently releases them back into their natal rivers to spawn naturally. Since it began in 2015, over 9000 wild origin adult Atlantic Salmon have successfully been released to inner Bay of Fundy rivers. As a direct result of the Fundy Salmon Recovery program, Fundy National Park is seeing record numbers of smolts, increasing wild juvenile salmon densities, a 30-year high in adult Salmon returns, and improved ecosystem function and productivity. The potential effects of adult supplementation on fish fitness and ecosystem health are widely applicable to all salmon rivers suffering from low numbers.

All correspondence should be addressed to Kurt Samways.
email: kurt.samways@unb.ca

Potential Factors Influencing Variation in Freshwater and Estuarine Growth Rates of Juvenile Chinook Salmon in the Fraser River, B.C.

David C. Scott[1,2], Misty MacDuffee[2], Lia Chalifour[3], and **Scott G. Hinch[1]**

[1]*Pacific Salmon Ecology and Conservation Laboratory, Department of Forest and Conservation Science, University of British Columbia, Vancouver, BC, Canada*

[2]*Raincoast Conservation Foundation, Sidney, BC, Canada*

[3]*Department of Biology, University of Victoria, Victoria, BC, Canada*

Juvenile Pacific salmon must grow quickly to obtain a size at ocean entry that will result in a higher probability of early marine survival. Juvenile Chinook salmon with ocean type life histories migrate to the ocean after a brief freshwater or estuary rearing stage during which they must grow quickly to access preferred prey resources, and there are many factors which can influence growth rates during this period. We studied juvenile Chinook salmon in the lower Fraser River and estuary over six years (2016-2021) to understand variation in estuary use between two major populations of ocean type Chinook which differ in their early life history. We collected 3,244 genetic samples from individual Chinook over six years and found that the timing of migration to the estuary did not significantly vary across years despite significant variation in climatic conditions in each year. However, we found significant variation in relative fork lengths between years, which followed the same overall trends across years with the smallest individuals occurring in 2017 and 2020 in both populations and the largest fish in 2019 in both populations. These differences were shown to be statistically significant with larger fish in 2019 and statistically smaller fish in 2017 and 2020. We found the largest individuals in 2019 and 2016, both years which experienced relatively warm and dry winter and spring conditions, and the smallest individuals in both populations in 2017, a year with a particularly cold and snowy winter and average spawner abundance. As climate change is predicted to result in warmer and milder winters it may result in increased early growth for these individuals which could result in increased early survival for sub-yearling migrants and potentially explain increases in productivity of the South Thomspon population in recent decades. However, these effects are likely counteracted but negative changes to upwelling and marine productivity associated with the same climate trends therefore, it will be important to understand how these various factors interact to determine overall marine survival.

All correspondence should be addressed to David Scott.
email: dcscott@mail.ubc.ca

Effects of Stream Habitat Restoration Through Fishway Construction on Masu Salmon Population in a Small Tributary in Hokkaido, Japan

Mitsuru Torao[1], Kazutaka Shimoda[1], Hirokazu Urabe[1], and **Hiloshi Kawamula[2]**

[1]*Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido, Japan*

[2]*Obirame Restoration Group, 315-198 Niseko, Niseko, Hokkaido, Japan*

Since the early 1970s, river-crossing structures have been built in Hokkaido, Japan. A relationship has been noticed between the rising number of river structures causing a decrease in masu (or cherry) salmon, *Oncorhynchus masou*, populations. Recognizing the deterioration in fish populations, environmental restoration efforts, such as the installation of fishways, have been conducted in rivers of Hokkaido in recent years. This study assesses the effects of such fishways on the masu salmon population in the Shirai river system, a small tributary in southwestern Hokkaido. The Shirai river had 11 impassible structures for salmon. From the end of 2007 to the end of 2009, fishways were installed at 10 structures in order from the downstream side, except for uppermost structure. We surveyed the distribution of spawning redds from 2007 to 2021. Furthermore, we conducted population density and body size surveys of juvenile masu salmon in June and October, and calculated the daily growth-rate in summer each year. A stepped extension of the distribution of spawning redds was observed with the installation of the fishways. Masu salmon generally have a 3-year lifecycle, and each generation is considered to change every 3 years. As a result of the fishway installation, a twofold increase was observed in the number of spawning redds in the second generation (defined by the 2011–2013 period) when compared to the first generation (defined by the 2008–2010 period). Consequently, the number of spawning redds increased rapidly until 2019, which corresponds to the fourth generation of masu salmon. In the fourth generation (2017–2019), however, the number of spawning redds fluctuated widely. Spawning redds was observed during the fifth generation (in 2020 and 2021). The population density of juveniles was monitored at a station in the middle reaches of the river in June and was found to correspond well with the number of spawning redds observed in the Shirai river system. As a result of fishway installations, the population density of masu salmon increased gradually corresponding to the increased spawning redds observed until the third generation. In the fourth generation, population density fluctuated in response to large fluctuations in the number of spawning redds. Summer growth rates declined slowly with increasing population density, but fluctuated significantly in the fourth generation. This study indicates the importance of reducing the effects of density-dependent growth depression through environmental restoration for the recovery of masu salmon populations.

All correspondence should be addressed to Mitsuru Torao.
email: torao-mitsuru@hro.or.jp

Environmental Characteristics of Lagoons as a Nursery Habitat for Juvenile Chum Salmon in Eastern Hokkaido, Japan

Hirokazu Urabe[1], Shuichi Mano[1], Yosuke Koshino[2], Kiyoshi Kasugai[2], Hajime Omori[1], Hiroaki Suzuki[3], Kenji Nishina[3], Toshikazu Kizuka[3], Satoru Ono[3], Yasuhito Uchida[3], Kazuhiro Hamahara[3], Akane Nishi[4], and **Satoshi Katayama[4]**

[1] Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido, Japan.

[2] Salmon and Freshwater Fisheries Research Institute, Doto research Branch, Hokkaido Research Organization, 3-1-10 Maruyama, Nakashibetsu, Hokkaido, Japan.

[3] Research Institute of Energy, Environment and Geology, Hokkaido Research Organization, Kita19, Nishi12, Kita-ku, Sapporo, Hokkaido, Japan.

[4] Graduate School of Agriculture Division of Biological Resource Sciences, Tohoku University, 468-1 Aramaki aza Aoba, Aoba-ku, Sendai, Miyagi, Japan.

Lagoons, which are widely distributed in the eastern Hokkaido region, are generally shallow and easily warmed by rising air temperatures and solar radiation. Thus, they tend to maintain higher water temperatures during the spring season than that in the coastal areas. In addition, lagoons often contain brackish water, and are considered to have higher productivity than rivers or coastal areas. As a result, lagoons are considered to have suitable environmental conditions as a nursery habitat for juvenile chum salmon. However, their detailed environmental characteristics and effects of those conditions on juvenile chum salmon survival are still unknown. We surveyed feeding habits, growth rates, timing of migration to the coastal area of chum salmon juveniles, and water temperature in two lagoons, Mochirippu and Poroto, located in eastern Hokkaido. In both lagoons, the water temperature rose quickly after melting of ice and exceeded 8 °C towards the middle and end of April. This is considered to be the lower limit of optimal temperatures for juvenile chum salmon growth in the ocean. In contrast, coastal water temperatures exceeded 8 °C in mid to late May, approximately one month later than in the lagoons. The peak timing of migration of fish from the lagoons to the coastal area coincided with the timing of the coastal water temperature exceeding 8 °C. The stomach content index and growth rate of fish in the lagoons were higher than those of fish at the reference site (cultured fish in the net-pen in the coastal area). These results suggest that lagoons function as a nursery habitat for juvenile chum salmon until the coastal waters reach suitable temperatures for feeding and growth. This would lead to higher survival rate of fish at an early marine life stage when mortality could be highest in their life history.

All correspondence should be addressed to Hirokazu Urabe.
email: urabe-hirokazu@hro.or.jp

A Broad-Scale Prediction of Reduction in Spawning Habitats for Salmonids by Dams

Taihei Yamada[1], Hirokazu Urabe[2], and **Futoshi Nakamura[1]**

[1] *Graduate School of Agriculture, Hokkaido University, N9 W9, Sapporo, Hokkaido, Japan*

[2] *Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kita-kashiwagi, Eniwa, Hokkaido, Japan*

Habitat fragmentation by dams inhibits spawning migration of anadromous fishes, resulting in population declines and biodiversity degradation. River restoration activities such as installation of fish passage and partial removal of dams have been promoted to eliminate these negative impacts, but assessing the effectiveness of the restoration activities has been limited to only a few projects in Japan. Clarifying the negative influences of fragmentation on the spawning of the anadromous fish on a broad scale will provide preliminary information for river restoration projects in various rivers. In this study, we estimated the spawning habitat for three anadromous salmonid species (pink salmon, chum salmon, and masu salmon) throughout Hokkaido, Japan and assessed how dams reduced the extent of their spawning habitat. Suitable spawning habitats for these species are mainly determined by the particle size of the riverbed, and the optimum particle size varies among the three species. We evaluated the distribution of suitable spawning habitats throughout Hokkaido using particle size data provided by the Hokkaido Regional Development Bureau. We constructed a particle size prediction model using neural network and generalized linear model with ten explanatory variables related to climate, geomorphology, and geology. The prediction accuracy of the constructed models was evaluated using test data, and then we selected the model with the highest prediction accuracy. We mapped the suitable spawning habitat for the three species using the selected model and then overlaid the map with the dam location data to determine the river segment where dam impedes salmons from reaching spawning habitat for each of the three species. The prediction model using neural networks had the highest prediction accuracy. Estimated suitable spawning reach lengths throughout Hokkaido were 14,558 km for pink salmon, 17,786 km for chum salmon, and 30,054 km for masu salmon. In addition, 42.5% of suitable spawning habitats for pink salmon, 49.6% for chum salmon, and 59.5% for masu salmon were not available by dams. Since the spawning habitat of masu salmon was located further upstream than those of other species, the spawning habitat may have been severely damaged. When planning river restoration projects, it is important to consider the potential recovery of suitable spawning habitats for multiple species based on these results.

All correspondence should be addressed to Taihei Yamada.

email: thymd8@gmail.com

Audit of Remediated Culvert Barriers in the Interior Fraser River Watershed

Patrick ML. Zubick[1], Zachary T. Sherker[1], Nicolas W.R. Lapointe[2], and **Scott G. Hinch[1]**

[1]Pacific Salmon Ecology Conservation Laboratory, University of British Columbia, 2424 Main Mall Vancouver, BC, Canada

[2]Canadian Wildlife Federation, Kanata, ON, Canada

Pacific salmon habitat has been targeted for culvert barrier remediation projects due to broad declines in their populations across their range, attributed in part to habitat fragmentation. Small-scale barriers like culverts fragment more linear stream habitat than dams and are a major issue for Pacific Salmon. In British Columbia, there are over 200,000 barrier culverts that restrict fish passage. Two techniques are used to restore fish passage at barrier culverts (retrofit or replacement), and best practices to restore fish passage have been developed. However, it is unknown whether culvert restorations continue to meet best practices or if fish passage changes through time. To address this knowledge gap, we performed a post-treatment audit on culvert barrier restorations in British Columbia. We hypothesized that the technique applied will affect how a restoration meets best practices and that fish passage will be impacted if not met. Furthermore, we expected retrofit sites to meet best practices less frequently as they will not have addressed the original cause of barrier development. At each site, we collected data on the restoration structure and habitat. We assessed these data against current best practices for culverts and performed a fish passage assessment. We found that the conditions at all sites do not fully meet best practices and that 45% of sites are fish-passage barriers. These results show that the techniques used to restore fish passage at culverts are prone to failure, and that post-restoration monitoring should be prioritized to ensure fish passage is maintained.

All correspondence should be addressed to Patrick Zubick.
email: zubickp@gmail.com

Theme 4: New Frontiers

Profiles of Circulating Insulin-Like Growth Factor-1 in Chum Salmon in the Bering Sea in Summer and the Gulf of Alaska in Winter

Momoka Arimoto[1], Kentaro Honda[2], Ayaka Izutsu[3], Shigehiko Urawa[2], Christoph M. Deeg[4], and **Munetaka Shimizu[5]**

[1]*Graduate School of Fisheries Sciences, Hokkaido University, Hakodate*

[2]*Salmon Resources Department, Hokkaido National Fisheries Research Institute, Japan Fisheries Research and Education Agency, Sapporo*

[3]*Graduate School of Environmental Science, Hokkaido University, Sapporo, Japan*

[4]*Department of Forest & Conservation Sciences, University of British Columbia, Vancouver, BC, Canada*

[5]*Field Science Center for Northern Biosphere, Hokkaido University, Hokkaido, Sapporo, Japan*

Evaluating growth status in salmon at high seas is important for better understanding their survival and age of maturation. A growth-promoting hormone insulin-like growth factor (IGF)-1 is emerging as an index of growth in salmonids. Under laboratory settings, circulating IGF-1 level reflects recent (past one to two weeks) growth rate, which makes it a good complement with growth estimation using the scale and otolith. The objectives of the present study were to observe spatial variations in circulating IGF-1 levels in high-seas chum salmon in the summer and winter and search for its possible link with environmental variables such as surface seawater temperature (SST). Blood of chum salmon were collected during surveys by the R/V *Hokkou maru* in the summer 2021 and from the IYS expedition by the R/V *Professor Kaganovskiy* in the winter 2019. One hundred and seventy plasma samples were obtained from 17 stations (SST: 8.9–10.8 ºC) in the Bering Sea and 84 samples were obtained from 31 stations (SST: 5.0–7.7 ºC) in the Gulf of Alaska. IGF-1 levels in plasma were quantified by time-resolved fluoroimmunoassay. Plasma IGF-1 levels in chum salmon in the Bering Sea in summer were ranging from 80 to 220 ng/ml, being relatively higher than those of juveniles on the Hokkaido coast in spring (10–120 ng/ml). There was a spatial variation in plasma IGF-1 levels in fish in the Bering Sea although its link to STT was not clear. Plasma IGF-1 levels exhibited a larger variation in fish in the Gulf of Alaska in winter, ranging from 50 ng/ml to 400 ng/ml, possibly due to a mixture of different ages, nutritional status or/and maturation stages. With some exceptions, plasma IGF-1 levels in fish in cold area were rather high. The reason for this is not known at preset but we suspect that the high IGF-1 levels might be due to reduced binding to the receptor in poor growing fish in cold seawater. We are currently re-establishing immunoassays for IGF-binding proteins (IGFBPs) which respond to metabolic conditions, and negatively or positively affect the availability of circulating IGF-1 to the receptor. The ratio of IGF-1 to these IGFBPs should inform us catabolic and anabolic status of the fish more precisely and reveal relationships among IGF-1, fish condition and environmental variables.

All correspondence should be addressed to Munetaka Shimizu.
email: mune@fish.hokudai.ac.jp

Exploring the Winter Salmosphere in the Open Ocean with Genomic Tools

Christoph M. Deeg[1,2], Andrew W. Bateman[2], and **Kristina M. Miller[1,3]**

[1]*Department of Forest & Conservation Science, University of British Columbia, Vancouver, BC V6T 1Z4, Canada*

[2]*Pacific Salmon Foundation, Vancouver, BC V6J 4S6, Canada*

[3]*Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC V9T 6N7, Canada*

Exploration of the winter salmosphere, the open ocean environment salmon experience during the winter months, is a key objective of the International Year of the Salmon (IYS) as winter is thought to be a critical period for survival at sea. Here we present our research into the winter salmonsphere utilizing genomic tools during the 2019 and 2020 Gulf of Alaska expeditions as well as the 2022 Pan-Pacific expedition. To illuminate the role of infection we deployed high throughput qPCR screens of all salmon species for 48 infectious agents and identified several key pathogens showing open ocean transmission, specifically via trophic acquisition. Discrepancies in infectious agent prevalence in the open ocean compared to coastal British Columbia highlight agents possibly associated with mortality during the early marine phase. Studying the gene expression patterns of salmon at sea using Fit-Chips allows us to pinpoint stressors arising from disease and environmental factors as well as their cumulative effects. Initial results indicate that salmon are primarily experiencing stress associated with prey availability and oceanographic variables such as temperature, highlighting the spatiotemporally dynamic nature of open-ocean seascapes. Environmental DNA (eDNA) utilizes the detection of traces of genetic material shed by organisms in the environment to analyze ecosystem composition in a non-invasive manner that circumvents the bias associated with many conventional sampling strategies. Our eDNA detections during the 2019 and 2020 Gulf of Alaska expeditions coincided with observations on salmon distribution made in trawl surveys and were able to expand salmon distribution in some notable cases such as pink salmon (*O. gorbuscha)* that were caught at lower density than expected. Further, eDNA provided novel insights into the distribution of large and mobile species such as salmon sharks that are thought to be key predators of salmon but are only rarely observed. Similarly, eDNA was able to detect diurnal vertical migrators such as squid and lantern fish (myctophids) independent sampling time, adding important information on the distribution and relative abundance of key competitors of salmon. Building on the Gulf of Alaska surveys, we collected eDNA samples covering the entire survey area during the 2022 Pan-Pacific expedition at multiple depths while also adding continuous sampling between stations during transit providing unprecedented spatiotemporal coverage and resolution. Together our genomic surveys provide additional tools to improve our understanding of the changing open-ocean seascape and how salmon navigate it.

All correspondence should be addressed to Christopher Deeg.
email: chrdeeg@gmail.com

Entering the Next Dimension: Combining Continuous eDNA, Hydroacoustic, and Oceanographic Sampling to Deciphering Open Ocean Ecosystem Structure

Christoph M. Deeg[1,2], Brian K. Wells[3], Abigail Wells[4,5], Robert Saunders[6], Brandon E. Chasco[3], Jarrod A. Santora[3], Brian R. Dykeman[7], Andrew W. Bateman[2], and **Kristina M. Miller[1,8]**

[1]Department of Forest & Conservation Science, University of British Columbia, Vancouver, BC, Canada

[2]Pacific Salmon Foundation, Vancouver, BC, Canada

[3]NOAA Fisheries, SWFSC, Fisheries Ecology Division, Newport, OR, USA

[4]NOAA Fisheries, NWFSC, Seattle, WA, USA

[5]Lynker Technologies, Seattle, WA, USA

[6]RKS Laboratories, Qualicum Beach, BC, Canada

[7]NOAA Ship Bell M. Shimada

[8]Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada

Open-ocean seascapes are spatiotemporally complicated, which results in variable ocean survival of salmonids due to the availability of forage to salmon and their interactions with competitors and predators. The hostile environment in the open ocean, specifically in the winter, has historically been poorly studied. Thus far, the International Year of the Salmon (IYS) winter surveys to the Gulf of Alaska have demonstrated that the distribution of salmon, prey, and predators can be highly patchy, suggesting that alternative data streams at both a finer resolution and greater spatial scale are likely needed to diagnose seascape structure and processes. Recent advances in sampling technologies have allowed us to collect continuous and synchronous environmental DNA (eDNA), hydroacoustic (i.e., forage), and oceanographic data in a semi-automated manner during the 2022 IYS Pan-Pacific expedition. We deploy eDNA metabarcoding to identify taxa of relevant trophic levels including zooplankton, teleosts, salmonids, and predators (e.g., salmon shark) at a 20 km resolution representing a total of 6000 kms across the Gulf of Alaska from the continental shelf near the Juan de Fuca Straight to Kodiak Island and back. Synoptically collected hydroacoustic data provides a spatially explicit indication of the relative abundance of krill and forage fishes with which salmon and predators are interacting. Physical and biological oceanographic data continuously collected during the voyage (i.e., flowthrough) and remotely sensed measurements provide the additional layer describing the meso- and larger-scale environmental structure potentially mediating trophic interactions. Together, this study provides insights into the ecosystem structure of the Gulf of Alaska during the winter at unprecedented spatial resolution (i.e., improved by an order of magnitude) and will allow us to identify hotspots of biological activity as well as the associated biophysical factors. By improving our understanding of ecosystem functionality, we aim to facilitate the recognition of factors regulating ocean survival for salmonids.

All correspondence should be addressed to Christopher Deeg.
email: chrdeeg@gmail.com

Downstream Migration of Released Salmon Juveniles Estimated with Environmental DNA

Kazuya Fujii[1,2], Takashi Kanbe[3], Shouko Inoue[3], and Hitoshi Araki[3]

[1]*Laboratory of Animal Ecology, Graduate School of Agriculture, Hokkaido University, Kita-9, Nishi-9, Kita-ku, Sapporo, Hokkaido, 060-8589, Japan*

[2]*Fukuda Hydrologic Center Co., Ltd., Kita-24, Nishi-19, Kita-ku, Sapporo, Hokkaido, 001-0024, Japan*

[3]*Laboratory of Animal Ecology, Research Faculty of Agriculture, Hokkaido University, Kita-9, Nishi-9, Kita-ku, Sapporo, Hokkaido, 060-8589, Japan*

Knowledge of the downstream migration of salmon juveniles is limited, and even less is known about their behaviors immediately after release. To elucidate the downstream migration of 27000 juveniles of chum salmon released into the Makomanai River, a tributary of the Toyohira River in Hokkaido, Japan, water samples were collected multiple times at multiple points for three days after the release of the salmon juveniles for an environmental DNA (eDNA) survey. Using a semi-quantitative eDNA detection method, we estimated the concentration of salmon-derived eDNA, and clarify the spatiotemporal distribution of salmon juveniles after release.

As a result of the analysis, eDNA presumably derived from released salmon juveniles was detected. Peak of the salmon eDNA concentration was detected on the first day of release and shifted downstream over time. Our results suggest that it is possible to estimate the downstream migration of released salmon juveniles using eDNA, at least for a day or two within c.a. 10 km below the release point in the river.

All correspondence should be addressed to Kazuya Fujii.
email: k-fujii@f-suimon.co.jp

Does Hatchery Program in Hokkaido Affect the DNA Methylation of Chum Salmon?

Yuya kogame[1], Hirokazu Urabe[1], and **Takafumi Fujimoto[2]**

[1]Salmon and Freshwater Fisheries Research Institute, Hokkaido Research Organization, 3-373 Kitakashiwagi, Eniwa, Hokkaido 061-1433, Japan

[2]Faculty of Fisheries Sciences, Hokkaido University, 3-1-1, Minato, Hakodate, Hokkaido 041-8611, Japan

Hatchery-reared fish differ from wild fish in phenotypic traits that are related to fitness. This is thought to be related to changes in DNA methylation due to rearing in hatcheries. DNA methylation is a mechanism that regulates gene expression, tends to occur during early life, and is persistent. Therefore, the DNA methylation that occurs during adaptation to hatchery environment may adversely affect the adaptation of juveniles to wild environment after release. In the chum salmon hatchery program in Hokkaido, juveniles are reared in hatchery environment until they attain release size (1 g), and it is possible that their DNA methylation may differ from that of wild fish. In this study, we compared hatchery-reared and wild adults to investigate whether hatchery environment affects DNA methylation of fish.

Hatchery-reared adults (n = 8) were caught from the Chitose River and wild adults (n = 10) were caught from the Izari River. Liver tissue and sperm samples were collected from the fish. DNA was extracted from each sample, and the percentage of methylated DNA was measured. Otoliths were checked to determine whether the fish originated from a hatchery or the wild.

No significant difference was observed between hatchery and wild fish ($p = 0.41$); the mean percentage of methylated DNA in the liver of hatchery fish and wild fish was $0.92 \pm 0.05\%$ and $0.86 \pm 0.28\%$ (mean $\pm$ SDs), respectively. The mean percentage of methylated DNA of sperm was $0.45 \pm 0.08\%$ for hatchery fish and $0.46 \pm 0.07\%$ for wild fish, with no significant difference between them ($p = 0.70$). There was no difference between the mean percentage of methylated DNA of hatchery and wild fish for both liver and sperm; however, variations in the methylated DNA of liver of wild fish (0.35‑1.35%) was greater than that of hatchery fish (0.90‑1.03%).

All correspondence should be addressed to Yuya Kogame.
email: kogame-yuuya@hro.or.jp

Investigations into the Emergence of Widespread Thiamine Deficiency in California Salmon

Nate Mantua[1], Rachel Johnson[1], John Field[1], Steve Lindley[1], Tommy Williams[1], Jeff Harding[1], Anne Todgham[2], Nann Fangue[2], Carson Jeffres[2], Heather Bell[2], Abigail Ward[2], Dennis Cocherell[2], Jacques Rinchard[3], Donald Tillitt[4], Dale Honeyfield[5], Taylor Lipscomb[6], Scott Foott[6], Kevin Kwak[7], Mark Adkison[7], Brett Kormos[7], Frederick Colwell[8], and **Christopher Suffridge[8]**

[1]NOAA/NMFS Southwest Fisheries Science Center, Fish Ecology Division, 110 McAllister Way, Santa Cruz, CA, USA

[2]University of California, Davis

[3]State University of New York, Brockport

[4]U.S. Geological Survey, Columbia Environmental Research Center

[5]Retired United States Geological Survey, Northern Appalachian Research Branch

[6]US Fish and Wildlife Service

[7]California Department of Fish and Wildlife

[8]Oregon State University, Department of Microbiology, Corvallis, OR, USA

Thiamine (vitamin B1) deficiency in marine systems is recognized as a globally-significant emerging threat to marine life. Thiamine Deficiency Complex (TDC, a nutritional deficiency of thiamine) was first linked with high mortality of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley (CCV) hatcheries in 2020. We subsequently launched investigations into the extent and impacts of TDC, and mitigation strategies and causes for TDC in California's salmon. We established an egg surveillance effort that found widespread thiamine deficiency in CCV Chinook salmon in 2020 and 2021, and emerging TDC in Klamath and Trinity River Coho salmon in 2021. We demonstrated effective methods to prevent mortality of young salmon at three life stages: thiamine injection of pre-spawn females, and thiamine baths at egg fertilization and at the post-hatch juvenile stage. We investigated natural sources of thiamine by measuring dissolved thiamine and microbial community composition across spatial and temporal gradients in the water column and sediments of marine and freshwater systems. We developed a model for predicting population-level fry mortality rates from egg thiamine samples. We analyzed five common salmon prey items and found that northern anchovy had the highest lipid content and the highest thiaminase activity levels. Our gut content analysis found that northern anchovy were the dominant prey item for Chinook salmon captured in California's ocean fisheries in 2020 and 2021. Previous research showed that diets dominated by lipid-rich or thiaminase-carrying clupeids can result in consumers with thiamine-deficient eggs and TDC in their offspring. Our research suggests that California's salmonids are likely to remain at risk of TDC as long as their forage-base is dominated by northern anchovy, thereby adding a new stressor to highly-valued, but already highly-stressed, populations.

All correspondence should be addressed to Nate Mantua.
email: nate.mantua@noaa.gov

Integrating 'omics Approaches for a Deeper Understanding of Atlantic Salmon Life History Variation

Jukka-Pekka Verta[1,2], Craig Primmer[1,2] and **the Evolution, Genomics and Conservation Research Group**

[1] *Organismal and Evolutionary Biology Research Programme, University of Helsinki, Finland*

[2] *Institute of Biotechnology, University of Helsinki, Finland*

Age at maturity is a key life-history trait that is evolving under a trade-off between fecundity and survival. Atlantic salmon is among the most variable vertebrates on Earth in terms of age at maturity, which is thought to promote population adaptability and resilience in a variable environment. Recent research has shown considerable changes and contemporary evolution in the age structure of Atlantic salmon populations, which underlines the importance of understanding the biological processes behind age at maturity variation for better conservation and management. Age at maturity in Northern European Atlantic salmon is largely determined by genetic variation in a single genome region containing the transcription co-factor gene *vestigial-like 3* (*vgll3*). Research at the Evolution, Conservation & Genomics Group strives for a detailed understanding of the molecular bases of variation in salmon maturity onset. By using complementary 'omics approaches, historical samples, and common-garden experiments, we are revealing the molecular mechanisms behind the genotype-phenotype association in *vgll3* and other life-history genes, as well as their evolutionary trajectories. Here, we will summarize our most recent results that shed light on the molecular machinery behind variation in age at maturity and its evolutionary responses to ecological shifts. Such in-depth knowledge of the genetics and ecology of life-history determination not only informs us about salmon biology, but is also key to intelligent salmon breeding, conservation, and management.

All correspondence should be addressed to Jukka-Pekka Verta.
email: jukka-pekka.verta@helsinki.fi

Non-Lethal Novel Approach to Measure Persistent Contaminants in Salmonids

Marta Assunção, Mark Ives, Phil Davison, and **Jonathan Barber**

Centre for Environment, Fisheries and Aquaculture Science, Pakefield Road, Lowestoft NR33 0HT, UK

We report on a novel approach to measure concentrations of legacy contaminants using the adipose fin of adult Atlantic salmon (Salmo salar) and sea trout (Salmo trutta). Legacy contaminants such as polybrominated diphenylethers (PBDEs), polychlorinated biphenyls (PCBs), dichlorodiphenyldichloroethylene (p,p′-DDE) and hexachlorobenzene (HCB) have low water solubility and high affinity to particulate matter, therefore tend to accumulate via the food web. We measured these compounds in adipose fins collected from migrating salmonids returning to the river Tees (Northeast of England). Higher concentrations of PBDEs and PCBs were found in sea trout samples, where the detected congeners reflected the widely used commercial formulations, in particular the penta formulation for PBDEs. Overall, the range of concentrations we measured where within or above the ranges previously reported for both species (muscle and body homogenates) originating from North Sea, North Atlantic and Baltic Sea. Our results indicate that these fish could be bioaccumulating persistent organic pollutants via diet during their migratory routes (North Sea and the Norwegian Sea). The evidence gathered from monitored rivers around the North Atlantic indicates that the survival of salmon during the marine phase of their life cycle has declined in recent decades. Furthermore, the North East Coast Net Fishery captures salmonids for human consumption. The development of non-lethal approaches could allow for a more regular assessment of wild populations showing declining trends, and to ascertain persistent contaminant burdens in fish destined to the table. Validation work is being carried on the use of adipose fin by assessing persistent contaminants in fin and muscle samples on individual fish from two distinct locations (1) Atlantic salmon and sea trout returning to English South West rivers and (2) Atlantic salmon migrating to the West coast of Greenland. The use of adipose fin has the potential to be further developed as a non-lethal approach to assess whether persistent contaminants are being accumulated during the salmonids juvenile to adult phase (marine phase).

All correspondence should be addressed to Marta Assuncao.
email: marta.assuncao@cefas.co.uk

Behaviours and Movement Patterns of Return Migrating Adult Chinook Salmon Throughout the Salish Sea

Brian J. Hendriks[1], Stephen D. Johnston[1], Joe Watson[2], Andrew W. Trites [3,4], Brian P.V. Hunt[4], David W. Welch[5], Erin L. Rechisky[5,6], Aswea D. Porter[5,6], and **Scott G. Hinch[1]**

[1]*Pacific Salmon Ecology and Conservation Laboratory, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada*

[2]*Department of Statistics, University of British Columbia*

[3]*Marine Mammal Research Unit, University of British Columbia*

[4]*Institute for the Oceans and Fisheries, University of British Columbia*

[5]*Kintama Research Services Ltd., Nanaimo British Columbia*

[6]*Fisheries and Oceans Canada, Nanaimo, British Columbia*

The homing migrations of adult Chinook salmon in the Salish Sea is an important event for anglers and a key predator, Southern Resident Killer Whales. However, the productivity of Chinook populations in southern British Columbia is in rapid decline and several stocks are designated as threatened or endangered. Unfortunately, better knowledge about spatiotemporal distributions in this area is limited. Prior to entry into the Salish Sea, we angled and released ~150 adult Chinook salmon equipped with acoustic tags during the onset of their adult return migration in the waters nearshore to Port Renfrew, British Columbia. Each tag had a pressure sensor for tracking depth of individuals, and tissue samples allowed genetic stock identification which enables us to determine the natal rivers tagged fish were heading. We utilized a vast underwater acoustic telemetry array system to track fish which had to cross several acoustic 'curtains' in the Salish Sea in order to get to natal areas. Acoustic data captured movements up to 50 days after release and covered distances upwards of 750 km. Detections were highest along receivers closet to shore. Assuming shortest distances within waters, individuals bound for the Fraser River migrated at an average rate of 0.74 km/h [0.32–1.50 km/h], with slower migration rates observed as individuals neared natal systems. Fish frequented the upper water column, migrating at depths of 25.4 m [0–131.4 m] in the Strait of Juan de Fuca, 28.7 m [0.5–89.3 m] in Haro Strait, and 21.8 m [4.9–41.2 m] in Puget Sound. The acoustic data also showed diel patterns with fish occurring at greater depths during the day. This information shared provides insight at a finer scale then previously available, including some of the first information about vertical distributions.

All correspondence should be addressed to Brian Hendriks.
email: b.hendriks@oceans.ubc.ca

The Composition of Microelements of Pink Salmon Going to Spawn in the Rivers of the Sakhalin-Kuril Basin and the European North of Russia

N.K. Khristoforova[1,2], A.V. Litvinenko[1], M.Yu. Alekseev, and **V.Yu. Tsygankov[1]**

[1]*Far Eastern Federal University, Mordovtseva 12, 690922, Vladivostok, Russia*

[2]*Pacific Institute of Geography of the Far Eastern Branch of RAS, Radio 7, 690041, Vladivostok, Russia*

[3]*Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, 183038, Russia*

The trace element composition of salmon (*Salmo salar* L.), as the most valuable salmon grown in the cages of North European sea waters, as well as whitefish (*Coregonus lavaretus* L.) inhabiting fresh water bodies of the Kola Peninsula, has been studied relatively well. However, the content of trace elements in pink salmon (*Oncorhynchus gorbuscha* W.), introduced from the Russian Far East to the Euro-Arctic region in the second half of the last century by the Soviet Union, has remained unexplored to date, despite its significant spawning approaches in the last decade.

In this study, the content of essential and nonessential trace elements Pb, Cd, Ni, Cu, Zn and Fe was evaluated in the organs and tissues of pink salmon that came to spawn in July 2019 in the watercourses of the Kola Peninsula—the Kola and Tuloma rivers flowing into the Barents Sea and pink salmon within the natural range, previously selected in two Sakhalin-Kuril region rivers—Firsovka and Reidovaya. Pink salmon, going out to feed within the natural range in the Pacific Ocean and returning back to spawn, passes a highly nourished and at the same time geochemically impacted natural zone formed in the Kuril Islands area by high volcanic activity, supplying a variety of chemical elements to surface waters due to upwelling and hydrodynamic processes. For Sakhalin-Kuril pink salmon, the concentration of Pb in organs and tissues is most noticeably increased. The sea waters of the extreme north-west of Russia are experiencing a powerful anthropogenic and technogenic impact formed by the Gulf Stream collecting household and industrial effluents of the American coast and Northern European countries and unloading in the form of the North Atlantic Current in the Barents Sea. In addition, surface runoff and aerotechnogenic transfers from the industrially saturated Kola Peninsula, which is determined by the extraction, processing and smelting of a number of metals, primarily Ni and Cu, as well as Zn and Fe, "enrich" the marine environment and affect the trace element composition of introduced pink salmon.

All correspondence should be addressed to N.K. Khristoforova.
email: vesna271@rambler.ru

Investigating Post-Release Mortality of Coho Salmon in a Marine Recreational Fishery

Emma Lunzmann-Cooke[1], Stephen Johnston[1], Brian Hendriks[1], Aswea Porter[2], David Welch[2], Erin Rechisky[2], and **Scott Hinch[1]**

[1] *Pacific Salmon Ecology and Conservation Laboratory, Department of Forest and Conservation Sciences, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada*

[2] *Kintama Research Services, 4737 Vista View Crescent, Nanaimo, BC V9V 1N8, Canada*

Although many recreationally caught Pacific salmon are harvested in British Columbia, a substantial number of fish are released after capture. Released fish are often assumed to survive; however, actual catch-and-release mortality rates are largely unknown for Pacific salmon. This study examines the factors influencing post-release mortality of coho salmon (*Oncorhynchus kisutch*) in a marine recreational fishery in British Columbia. Coho were angled in the marine environment, affixed with acoustic transmitters, and tracked using an existing network of acoustic receivers located at multiple locations frequented by coho including the Salish Sea, Puget Sound, and the Fraser River. We found survival to the first point of detection was 61%, and survival was lower among coho with injuries such as scale loss, eye damage, and bleeding. Quantifying post-release survival rates and understanding how capture and handling factors influence behaviour and survival will provide information vital to developing management tools and fishing best practices to increase survival of wild fish.

All correspondence should be addressed to Emma Lunzmann-Cooke.
email: emmallcooke@gmail.com

Microchemical Techniques to Evaluate Priority Contaminant Sources Along the Migration Routes of Chinook (*Oncorhynchus tshawytscha*) and Coho Salmon (*Oncorhynchus kisutch*)

Micah J. Quindazzi and **Francis Juanes**

University of Victoria, Victoria, BC, Canada

During their marine life stage, Chinook (*Oncorhynchus tshawytscha*) and Coho Salmon (*Oncorhynchus kisutch*) from watersheds connected to the Salish Sea display two distinct migration phenotypes; Salish Sea resident and out-migrant. Knowledge of Chinook and Coho marine migrations has been limited to tagged individuals caught by anglers and researchers. It is unclear how fishing effort and angler compliance, as well as other factors influence the proposed migration pathways undertaken by different stocks. Amongst the migrant phenotype, these salmon may only move as far as the continental shelf just off the coast of Washington and Vancouver Island, or they may migrate offshore into the Gulf of Alaska. It is unknown how environmental and genetic factors cause some salmon to remain resident in the Salish Sea and others to out-migrate. These different migration pathways influence contaminant burden of these salmon and the degree to which they are exposed to local versus global sources. It is currently unknown which migration paths would lead to increased contaminant burdens as it has not been feasible to track the individual movement of salmon. Microchemical techniques, specifically trace element and stable isotope analyses, can be used to identify the marine migration life history of Chinook and Coho that return to their natal watersheds. Initial results on 2018 Coho samples indicate that otolith trace elements can be used to determine differences between marine regions with a 100% classification success rate. ~40% of Coho from a few Southern BC river systems remained as residents within the Salish Sea, which is consistent with other models. Contaminants of concern, such as mercury (Hg) and polychlorinated biphenyls (PCBs) as well as dietary tracers (stable isotopes of C, N, S) are assessed in conjunction with marine migration information to determine differences in contamination between marine regions across the Northeast Pacific.

All correspondence should be addressed to Micah Quindazzi.
email: m.j.quindazzi@gmail.com

Effects of Angling Approaches and Riverine Water Temperature on Survival to Spawning Grounds of Marine Captured and Released Chinook Salmon

Kaitlyn Zinn, Scott Hinch, Stephen Johnston, and **Emma Cooke**

Pacific Salmon Ecology and Conservation Laboratory, Department of Forest and Conservation Sciences, University of British Columbia, Vancouver, BC V6T 1Z4, Canada

In 2021, we used acoustic telemetry, PIT tagging and temperature loggers to link the thermal experience of 283 angled and released adult Chinook salmon in Barkley Sound British Columbia to their migration rates and survival to spawning grounds. Fight time, reflex, blood loss, wound, eye damage, fin condition, and scale loss assessments were performed following various air exposure treatments once fish were captured. Of 85 Chinook tagged with acoustic transmitters, 65% were detected in Alberni inlet, 38% made it from the inlet to the lower Somass river, and 12% made it to spawning grounds. Most fish are likely from one population, but survival rates are conservative as DNA stock ID is still not complete. Fish that made it to the inlet had low levels to moderate hook-related eye damage (2%). Salmon frequently encountered >21 °C in the riverine migration, and high thermal exposure likely contributed to poor survival to spawning grounds.

All correspondence should be addressed to Kaitlyn Zinn.
email: zinn@zoology.ubc.ca

Theme 5: Human Dimensions

Cryopreservation in The Norwegian Gene Bank for Atlantic Salmon as a Means to Preserve Genetic Diversity in a Changing Environment

Kristin Bøe[1], Bjørn Bjøru[1], Steffen Wolla[2], and **Arne Sivertsen[3]**

[1]*Department of Fish Health and Fish Welfare, Norwegian Veterinary Institute, Trondheim, Norway*

[2]*Cryogenetics AS, Hamar, Norway*

[3]*Norwegian Environmental Agency, Trondheim, Norway*

Atlantic salmon populations in Norway are facing a gradual deterioration in genetic diversity due to population losses and declines, as well as introgression by farmed Atlantic salmon. In order to ensure that Atlantic salmon populations have the best chances of adapting to a changing environment, preserving genetic diversity in the wild is imperative. Cryopreservation of Atlantic salmon sperm is a method that allows for a long-term repository of important genetic material, and is a valuable tool in preserving the genetic resources of wild salmonid populations. When used in combination with live brood-stock, cryopreserved sperm may enable the restoration of genetic diversity lost in the wild. The current presentation describes The Norwegian Gene Bank program for Atlantic salmon, which involves live gene bank facilities as well as a 'frozen gene bank' where paternal germplasm from 180 Norwegian Atlantic salmon populations have been stored. Although *in situ* conservation efforts should always be the preferred means to conserve biodiversity, *ex situ* measures such as cryopreservation may act as an important 'failsafe' or as a complementary measure.

All correspondence should be addressed to Kristin Bøe.
email: kristin.boe@vetinst.no

Influence of Catch-and-Release and Temperature at Release on the Reproductive Success of Atlantic Salmon (*Salmo salar L.*)

Raphaël Bouchard[1,2], Kyle Wellband[2], Laurie Lecomte[1,2], Louis Bernatchez[1,2], and **Julien April[3]**

[1]*Département de Biologie, Université Laval, Québec, Canada*

[2]*Institut de Biologie Intégrative et des Systèmes (IBIS), Université Laval, Québec, Canada*

[3]*Direction de l'expertise sur la faune aquatique, Ministère des Forêts, de la Faune et des Parcs du Québec, Québec, Canada*

Catch-and-release fishing is among the most adopted conservation practices in recreational fisheries. However, its success as a management tool relies on the ability of the released fish to survive and reproduce. In the case of Atlantic Salmon, only one study specifically measured the reproductive success of caught-and-released Atlantic salmon in natural settings, and no study to date evaluated if released salmon can reproduce when released at temperatures warmer 20°C which are known to increase post-release mortality. This lack of knowledge becomes increasingly important to tackle as climate change exerts additional pressure on fisheries. Here, we evaluate the relative reproductive success of caught-and-released compared to non-caught salmon and the effect of temperature at release on their reproductive success. To do so, we use high-throughput microsatellite sequencing of 38 loci to accurately assign 2500 offspring to a comprehensive set of possible parents from a supplemented Atlantic salmon population in Québec, Canada. Our results showed that at least 83% of caught-and-released salmon that moved upstream of the dam did successfully reproduce, including fish that have been released in water above 20°C. Nevertheless, caught-and-released female salmon have a reduced reproductive success, averaging 73% of the reproductive output of non-caught salmon. Moreover, our results suggest that increasing temperature did not affect the reproductive output of released fish. However, these results must be interpreted cautiously given our small sample size. This study should help refining managers' ability to analyze the risks and benefits associated with catch-and-release, and thus, optimize conservation practices used for the preservation of Atlantic salmon populations.

All correspondence should be addressed to Raphaël Bouchard.
email: raphael.bouchard.3@ulaval.ca

A Dynamic Decision Support Framework for Managing Water Temperatures for Salmon

Eric Danner, Miles Daniels, and **James Gilbert**

NOAA Fisheries, Southwest Fisheries Science Center; 110 McAllister Way, Santa Cruz, CA 95060, USA

University of California, Santa Cruz, Institute of Marine Sciences, Fisheries Collaborative Program; 110 McAllister Way, Santa Cruz, CA 95060, USA

Water in California's Central Valley is highly regulated by state and federal water projects, and salmonid freshwater habitats are highly impacted by how the system is managed. Water temperatures are a key factor, as these habitats are at the southern end of the range for Chinook salmon. We developed a temperature dependent mortality model to quantify the impacts of water management scenarios on developing salmon eggs. We then linked a comprehensive suite of models to forecast how operations interact with key inputs, including reservoir inflow, agricultural demand, valley floor hydrology, meteorology, reservoir and conveyance facility operations, and salmon spawning distributions. The resulting decision support tool has a number of properties that make it highly applicable to salmon management. (1) The framework has the capacity efficiently to evaluate thousands of combinations of inputs (hydrology, meteorology, operations, etc.). As a result, instead of evaluating a limited number of operational scenarios (which are highly dependent on the dynamic hydrological and meteorological conditions), this tool can be used to explore the sample space and determine if there are efficiencies that would otherwise be unknown. (2) The framework can incorporate a wide range of objectives, including environmental (other managed species), and economic (costs associated with altering water deliveries). (3) The framework is linked to a full life cycle model of endangered Sacramento winter-run Chinook salmon, which allows for the evaluation of long-term population dynamics associated with all of the above factors, including climate change.

All correspondence should be addressed to Eric Danner.
email: eric.danner@noaa.gov

Atlantic Salmon Fisheries Harvest Reference Points Need Not Compromise Conservation-Based Limit Reference Points Under Non-Stationarity Productivity Conditions

Guillaume Dauphin[1], Julien April[2], Suncica Avlijas[1], Cindy Breau[1], and **Gérald Chaput[1]**

[1] *Fisheries and Oceans Canada, 343 University Avenue, Moncton (NB), Canada*

[2]*Ministère des Forêts, de la Faune et des, 880 chemin Sainte-Foy, Québec (QC), Canada*

Canada's Wild Atlantic Salmon Conservation policy identified the implementation of the Precautionary Approach (PA) as a priority action for the conservation of Atlantic Salmon in Eastern Canada. River-specific Limit Reference Points (LRPs) were defined for the Atlantic Salmon (*Salmo salar*) rivers of Fisheries and Oceans Canada Gulf Region as the total eggs in spawners of all sea-age / size groups that result in less than 25% chance of the recruitment at the smolt stage being less than 50% of maximum recruitment.

Variations in survival at sea have important consequences on reference values derived from adult to adult relationships. There is substantial evidence of non-stationarity in the North Atlantic Ocean conditions affecting anadromous Atlantic Salmon productivity. Considering the association between reference points and sea survival, and that the LRPs for salmon have been defined using data from the freshwater phase of the life cycle, defining Upper Stock Reference (USR) and Target Reference (TR) points directly from adult to adult relationships was not considered appropriate. Rather, ratios that characterize the expected spread between the LRP and the upper reference points are used to define the river-specific USR and TR reference points.

Adult to adult stock and recruitment reconstructions from ten rivers of Eastern Canada were analysed with a Bayesian hierarchical Ricker stock and recruitment model. The estimates of recruitment at maximum sustainable yield (Rmsy) for the 10 rivers ranged from 146 to 667 eggs per 100 m² of wetted fluvial area, a factor of 4.6. In contrast, the ratios of 80%Rmsy (USR) to LRP ranged from 3.1 to 4.3 and the ratios of Rmsy (TR) to LRP ranged from 3.8 to 5.4, factors of 1.4 for each.

Using the ratios of USR or TR to LRP derived from adult to adult stock and recruitment data does not resolve the problem of reference values being associated with sea survival. As the perceived trend in productivity is from a high state to a low state, and the factors driving the reduced productivity of salmon are considered to be acting at sea and reversible, the derived reference values are higher than those based only on the recent time period of low productivity. The use of a longer time series is consistent with reviews and conclusions that reference points should not be changed due to changes in productivity but rather to adapt robust control rules for the changed conditions.

All correspondence should be addressed to Guillaume Dauphin.
email: Guillaume.Dauphin@dfo-mpo.gc.ca

Managing the Large Atlantic Salmon Population Complex of the River Teno/Tana: Sub-Population-Specific Monitoring, Targets, Assessment and Advice

Jaakko Erkinaro[1], Morten Falkegård[2], Panu Orell[1], Anders Foldvik[3]

[1]*Natural Resources Institute Finland (Luke), Oulu, Finland*

[2]*Norwegian Institute for Nature Research, Tromsø, Norway*

[3]*Norwegian Institute for Nature Research, Trondheim, Norway*

The River Teno (Tana in Norwegian, Deatnu in Sami) is a border river system between northernmost Finland and Norway that supports a large population complex of Atlantic salmon. Fisheries are managed by a bilateral agreement between Finland and Norway and salmon are exploited in mixed-stock fisheries in the Teno main stem and various tributaries.

A recent (2017) bilateral agreement on the Teno fisheries has implemented an adaptive knowledge-based stock-specific management regime based on principles of the North Atlantic Salmon Conservation Organization (NASCO). Stock-specific status assessments and mixed-stock fisheries evaluations are carried out annually by the joint Teno Monitoring and Research Group, consisting of four scientists from Norway and Finland.

Spawning targets (=conservation limits) have recently been established for most populations in tributaries and the main stem of the river. Target attainment is estimated based on a combination of a spatially designed monitoring program which counts ascending salmon (video, sonar) and spawners (snorkeling) in various parts of the river and detailed catch statistics. Poor target attainment (>40% probability of reaching the spawning target over the last 4 years) should trigger the implementation of stock-specific recovery plans with specific management actions reducing the stock-specific exploitation down to a level specified in the plan.

In order to evaluate the stock-specific effects of the mixed-stock fishery, the composition of the mixed-stock catch in the main stem of the river has been analyzed by genetic methods for stock assignment. ~30 genetically distinct populations were defined as a baseline. Based on catch statistics, stock-identified catch samples, population-specific exploitation in the main stem can be estimated in time and space, for different fishing gears and user groups and for different life histories (sea-ages, previous spawners). Thus, stock-specific regulatory measures can be selected as part of the recovery plans in order to restore the weakest populations while allowing for the continuation of a diverse salmon fishery.

All correspondence should be addressed to Jaakko Erkinaro.
email: jaakko.erkinaro@luke.fi

Freshwater Decision Triggers That Increase Ocean Survival: An Assessment of Seasonal and Biological Indices of Juvenile Chinook Salmon

Jennifer L. Gosselin[1,2], James J. Anderson[1], Beth L. Sanderson[2], Mollie A. Middleton[1,2], Benjamin P. Sandford[3], and **Laurie A. Weitkamp[4]**

[1]*School of Aquatic and Fishery Sciences, University of Washington, 1122 Northeast Boat Street, Seattle, Washington 98105, USA*

[2]*Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, Washington 98112, USA*

[3]*Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 3305 East Commerce Street, Pasco, Washington 99301, USA*

[4]*Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2032 Southeast OSU Drive, Newport, Oregon 97365, USA*

Decision triggers are used in adaptive management frameworks to decide when a specific management action will be implemented and they are often informed by monitoring data. With decision triggers and real-time data, the need for guess work and any inaction due to uncertainty can both be minimized. However, triggers based solely on historically observed environmental patterns may become unreliable under a changing climate, habitat modifications, and alternative hydrosystem operations. In a recent study, we examined the identification and application of biologically-based decision triggers for endangered fish migrating through regulated rivers. The main goal was to determine whether seasonal patterns of behavioral, physical, and physiological indices of smolts were related to subsequent smolt-to-adult return (SAR) survival. If so, we would also determine whether these indices could be used to guide decisions related to the mitigation strategy of the juvenile fish transportation program in the Federal Columbia River Power System (Pacific Northwest, USA). Hatchery yearling Chinook Salmon (*Oncorhynchus tshawytscha*) were collected over the migration season at three dams in the hydrosystem and measured for fork length, wet mass, Fulton's *K* (or condition factor), Na^+/K^+-ATPase (NKA) activity (or smoltification index), and % dry mass (or index of energetic reserves and smoltification). We estimated SAR survival from passive integrated transponder-tagged fish representative of our field samples and assessed its relationship to our fish indices, distance of sampling site to ocean, and indices of transported vs run-of-river passage. SAR survival was associated to interaction effects between juvenile fish transportation and % dry mass or NKA activity. Transported hatchery Chinook Salmon with dry mass <23% of whole fish wet mass and NKA activity >7 μmol ADP mg protein^{-1} h^{-1} showed greater SAR survival than their run-of-river counterparts. Fish with the highest predicted SAR survival had been transported and had fish indices consistent with smolts that were more developed (i.e., lower % dry mass and higher NKA activity). Furthermore, our results on % dry mass provided support for the hypothesis that greater lipid content increases fish buoyancy leading to greater susceptibility to predation. The buoyancy effect is expected to be greatest in hatchery fish. Overall, this study shows that decision triggers based on biological indices of migrating fish are potentially useful tools for in-season management. In our presentation, we will suggest and seek ways decision triggers may be applied in other life stages and mitigation strategies.

All correspondence should be addressed to Jennifer Gosselin.
email: gosselin@uw.edu

Survival and Fitness of Pacific Salmon Released from Fisheries Capture: A Growing Concern as Stocks Decline and Climates Change

Scott G. Hinch[1], Steve Cooke[2], and David Patterson[3]

[1]Pacific Salmon Ecology and Conservation Laboratory, Department of Forest and Conservation Sciences, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada

[2]Department of Biology, Nesbitt Building Room 209, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada

[3]Fisheries and Oceans Canada, Cooperative Resource Management Institute, Simon Fraser University 8888 University Drive, Burnaby, BC V5A 1S6, Canada

Bycatch makes up large levels of global commercial fish harvest and these non-targeted fish are usually released, often injured or dead, or at least to an uncertain fate. Large segments of recreational harvest are also released because of conservation or regulatory reasons. What is the fate of fish that we capture and set free? These issues have proven to be difficult for fisheries managers to resolve and they can have large impacts on recruitment and spawning escapement estimates, as well as having large impacts on stocks of conservation concern. Over the past two decades, we have been exploring these issues in adult Pacific salmon from physiological, behavioural, survival and fitness perspectives, using an individual based approach involving telemetry tracking and field experiments, and tissue biopsy to understand underlying mechanisms. We have worked directly with commercial and recreational fisheries, and different Pacific salmon species, in both fresh and saltwater. This presentation will overview some of our key findings that involve: approaches for predicting fate of released fish in both commercial and recreational fisheries, and, recommendations for how management systems can minimize mortality of released fish, in particular in an era of warming aquatic environments.

All correspondence should be addressed to Scott Hinch.
email: scott.hinch@ubc.ca

Assessing and Managing Biodiversity of Pacific Salmon: Methods for Setting Limit Reference Points

Carrie Holt[1], Kendra Holt[2], Luke Warkentin[3], and **Catarina Wor[1]**

[1]Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Rd, Nanaimo, BC V9T 6N7, Canada

[2] Institute for Oceans Sciences, Sidney, BC, Canada

[3]DFO North Coast Office, Terrace, BC, Canada

Biodiversity of salmon populations contributes to long-term sustainability by buffering against environmental variability and climate change. Population aggregates can produce temporally stable recruitment through independent dynamics among component populations. In Canada, "conservation units", defined as groups of wild salmon that if lost are unlikely to recolonize within an acceptable timeframe, are the biological basis of assessments. However, managers are often asked to provide reference points at scales that aggregate across multiple conservation units. We propose a new method to develop limit reference points that accounts for biodiversity within stock aggregates. Our results highlight that when productivity decreases in component CUs, higher aggregate abundances are required to support biodiversity objectives. The interaction between climate-driven changes in productivity and stock structure is an important area for future research, and our results inform how conservation and management targets can be adjusted to help maintain biodiversity under climate change.

All correspondence should be addressed to Carrie Holt.
email: carrie.holt@dfo-mpo.gc.ca

The "Iron Triangle" of Fisheries Management and a Case Study in Overcoming Its Challenges

Brittany Jenewein and **Mike Hawkshaw**

Fisheries and Oceans Canada, 3-100 Annacis Parkway, Delta, BC, Canada

Meeting the needs of a rapidly changing salmosphere requires a clear plan and collaborative efforts across communities and jurisdictions to implement, assess, and adapt. The "iron triangle" model provides a visualization of competing constraints to this process. It is often represented as a trade-off where only two aspects of the three points of the triangle can be optimized—for example, choosing whether a project is done well, quickly, or cheaply. We propose a similar conceptual model of three pillars that influence the quality of fisheries management: Knowledge, Strategy, and Decision. Trading off among these three pillars most directly affects fisheries management outcomes, but there are shared factors that shift the balance of each, including cost, capacity, collaboration, time, and communication.

The challenges each of these factors present have been documented in fisheries management for decades, but improvements in managements systems to gather the right information, lower the risk of decisions, and resolve conflicting objectives have been somewhat limited and slowly implemented. Recent research in project management suggests it is possible to balance all aspects of the iron triangle with new approaches and efficiencies (e.g. lean, agile, Scrum, Kanban), and we argue that can also be the case in fisheries management. Effective fisheries management plays a critical role in ensuring fish recovery and survival, especially in light of unknown effects of environmental change, and can be achieved by understanding how the pillars interact and optimizing them simultaneously. One example of an effective management system that optimizes each of the three pillars comes out of the Pacific Salmon Treaty's Chum Technical Committee: In 2012 they developed a Strategic Plan to identify priorities and gaps in information needed to support the requirements of the Pacific Salmon Treaty (Knowledge), the Treaty language was not prescriptive in how these requirements should be achieved (Strategy), and they directed efforts into these priority research areas and into developing a multi-component model to incorporate this information into management (Decision). This work has led to significant improvements in the understanding of and ability to effectively manage Chum Salmon in the South Coast of British Columbia and Puget Sound. There is still work required to determine whether Chum Salmon will be positively or negatively affected as changes continue in their environment, but this approach of building up each pillar simultaneously is putting the tools in place to ensure management can adaptively respond to either scenario.

All correspondence should be addressed to Brittany Jenewein.
email: Brittany.Jenewein@dfo-mpo.gc.ca

Reel Impacts: Post-Release Mortality of Capture-and-Released Chinook Salmon in Marine Recreational Fisheries

Stephen D. Johnston[1], Brian J.L. Hendriks[1], Emma L. Cooke[1], Kaitlyn R. Zinn[1], Aswea D. Porter[2,3], Erin L. Rechisky[2,3], David W. Welch[3], and **Scott G. Hinch[1]**

[1]Pacific Salmon Ecology and Conservation Lab, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada

[2]South Coast Stock Assessment, Fisheries and Oceans Canada, 3225 Stephenson Point Rd, Nanaimo, BC V9T 1K3, Canada

[3]Kintama Research Services, Ltd., 4737 Vista View Crescent, Nanaimo, BC V9V 1N8, Canada

Chinook salmon (*Oncorhynchus tshawytscha*) population productivity has generally declined coast-wide, and one approach that has been adopted to help conserve populations is an increased reliance on catch-and-release regulations. Fisheries managers have employed these regulations that aim to maintain the socioeconomic benefits of these fisheries and reduce the exploitation on stocks of concern. Incidental mortality of these discard events remains largely unquantified and may be relatively large, thus, undermining the conservation goals. Using acoustic telemetry and a large-scale receiver network we have tracked the fate of 379 Chinook post-release within the Salish Sea in 2020 and 2021. We have found eye injuries and notable bleeds sustained during fishery interactions caused decreases in survival probability in successful migration through the Discovery Islands and northern Strait of Georgia by 20% and 14%, respectively. Chinook that were captured with relatively larger, "Commercial" style hooks were 4.9 times more likely to sustain an eye injury and 2.2 times more likely have notable blood loss. Further, presence of scale loss was associated with a 15% reduction in survival probability and was 3.7 times more likely when fish were netted, and 14 times more likely if fish were netted and placed on the deck of the boat. The use of in-line attractors, or "flashers", were shown to reduce immediate survival from 98% to 85%, suggesting that escape behaviours associated with this gear type may elicit a more acute anaerobic response. We provide evidence that specific injuries and angler gear choice and handling behaviour alter survival outcomes for Chinook salmon post-release.

All correspondence should be addressed to Stephen Johnston.
email: stephen.johnston@ubc.ca

Renovating the Regulation of the Exploitation of Atlantic Salmon by the Angling Fishery in Brittany (France)

Etienne Prévost[1], Clément Lebot[1], Marie-Andrée Arago[2], Laurent Beaulaton[3,4], Gaëlle Germis[5], Marie Nevoux[4,6], and **Etienne Rivot[4,6]**

[1] *Université de Pau et des Pays de l'Adour, e2s UPPA, INRAE, OFB, Institut Agro, ECOBIOP, Management of Diadromous Fish in their Environment, Saint-Pée-sur-Nivelle, France*

[2] *DIR Bretagne-Pays de la Loire, OFB, Rennes, France*

[3] *Direction de la Recherche et de l'Appui Scientifique, OFB, Rennes, France*

[4] *Management of Diadromous Fish in their Environment, OFB, INRAE, Institut Agro, Université de Pau et des Pays de l'Adour, Rennes, France*

[5] *Bretagne Grands Migrateurs, Rennes, France*

[6] *UMR DECOD (Ecosystem Dynamics and Sustainability), Institut Agro, INRAE, Ifremer, Rennes, France*

Over the last 6 years (2016–2022), we carried out an inclusive and management-oriented research project in close interaction with stakeholders (government agencies, angling associations, NGO's). Its ultimate goal was to provide them with the relevant information that should facilitate the renovation of the regulation of the angling exploitation of Atlantic salmon in Brittany (France). This exercise is unprecedented in France given the breadth of the achievements, the amount of data analysed and the consideration of international recommendations from NASCO.

The project produced new knowledge for the 18 main salmon rivers of Brittany regarding (i) the abundance of the adult returns and of the YOY recruitment, (ii) the exploitation regime of A. salmon by the angling fishery, and (iii) the generation renewal process of the populations studied. This new knowledge covers more than 3 decades (1987–2020) and is the foundation for the establishment of new conservation limits for each of the population studied, followed by a comparative analysis of the performances of a large set of regulation scenarios (~200). A new operational definition of conservation was agreed by the stakeholders. It is based on two criteria relative to the control of both the risk of low recruitment and of the selectivity of exploitation regarding sea-age. This departs from, and in our view improves over, the current default standard promoted by NASCO which defines conservation limits as the stock producing MSY. New modelling tools have also been produced and shall allow the update and the extension in the future of the work already accomplished.

The ultimate comparative analysis of regulation scenarios revealed that (i) 4 populations were not meeting the first conservation criteria (i.e. risk of low recruitment) even in the absence of any fishing, (ii) for the 14 other rivers, under the current regime of exploitation, there would be no need to constrain fishing of the one-sea-winter fish beyond the fishing dates presently in use, (iii) depending on the river, stricter constrains should be set on the exploitation of the multi-sea-winter fish in order to satisfy the second conservation criteria (i.e. non-selectivity of exploitation), (iv) whether the variability of the catches is considered to be relevant or not as a performance criteria for the exploitation, the preferred scenarios for this stricter regulation should rely solely on fixed catch quotas or could include a control by means of a narrower fishing season for the multi-sea-winter fish.

All correspondence should be addressed to Etienne Prévost.
email: etienne.prevost@inrae.fr

Does Protection of Female Salmon Affect the Accuracy of Gender-Specific Catch Reports?

Grethe Robertsen[1], Ola Ugedal[1], Eva Marita Ulvan[1], Peder Fiske[1], Sten Karlsson[1], Bjørn Florø-Larsen[2], Merethe Hagen Spets[1], and **Øyvind Solem[1]**

[1]*Norwegian Institute for Nature Research, Høgskoleringen 9, NO-7034 Trondheim, Norway*

[2] *Veterinærinstituttet, Postboks 4024 Angelltrøa, NO-7457 Trondheim, Norway*

To ensure recruitment levels that are sufficient to maintain Atlantic salmon populations over time, spawning targets are set for many Norwegian rivers. Spawning targets includes calculating a desired minimum biomass of spawning females in individual rivers. One measure to increase the probability that spawning targets are reached is to protect female salmon from being harvested in sports fisheries by setting rules that they should be released if caught. For this measure to be effective the fishermen have to respect the rules and be able to recognize females based on morphological appearance. We do an assessment of this by comparing the gender of salmon caught and reported by sportfishermen with the gender determined genetically from scales that the fishermen collect and submit together with each catch report. In analyses of salmon that were caught and reported by sport fishermen in one river with no female protection (River Namsen) and three rivers with female protection (River Surna, River Orkla and River Gaula), we find that females are generally reported as males (25–45%) more frequently than males are reported as females (10–17%). Furthermore, the proportion of females that are reported with the wrong gender was lowest in the river where there were no specific protection of female salmon. Finally, the probability that a caught fish is reported with the correct gender increases with body size for females and decreases with body size for males.

All correspondence should be addressed to Grethe Robertsen.
email: grethe.robertsen@nina.no

Rivers and Roads: Effectiveness Monitoring for Culvert Remediations to Improve Salmon Migrations

Zachary Sherker, Patrick Zubick, Nicholas Lapointe, Pat Matthew, David Maloney, and **Scott Hinch**

Pacific Salmon Ecology and Conservation Lab, Department of Forest and Conservation Sciences, The University of British Columbia

Pacific salmon cannot access thousands of kilometers of spawning and rearing habitat in B.C. because of culvert barriers. Tens of millions of dollars have been spent to remediate these barriers by either retrofitting culverts with baffles and weirs, or replacing them with bridges. Very little monitoring has been done to assess the effectiveness and longevity of these remediations. We are assessing fish passage at 20 bridge replacement and 20 culvert retrofit sites (aged 10–15 years) by comparing fish community structure and abundance upstream and downstream of remediated sites. We collected data for 14 retrofit sites in 2021, and found that over a third of these had no anadromous salmonids upstream, and two thirds had lower species richness above the culvert, suggesting that these sites were again barriers. Structural assessments of the remediated culverts indicated that failed rock weirs and unresolved stream constriction issues were the biggest inhibitors to fish passage.

All correspondence should be addressed to Zachary Sherker.
email: sherkerz@mac.com

The French National Action Plan for Migratory Fish Species

Bénédicte Valadou[1], Marine Porteneuve[2], Maud Charles[2], Laurent Beaulaton[2], Vincent Toison[3], Matthieu Chanseau[4], and **Nicolas Ampen[5]**

[1]OFB, Immeuble Tabella - ZAC de l'aéroport, 125 impasse Adam Smith, 34470 Pérols, France

[2]OFB, pôle OFB-INRAE-Institut Agro-UPPA MIAME -Management of Diadromous Fish in their Environment, U3E, F-35042, Rennes, France

[3] OFB, 16 quai de la Douane, CS42932, 29229 Brest Cedex 2, France

[4]OFB, Direction régionale Nouvelle-Aquitaine, 207 cours du Médoc, 33073 Bordeaux Cedex, France

[5]OFB, Direction régionale Normandie, 3 rue du Presbytère - Saint-Georges-d'Aunay, 14260 Seulline, France

With Atlantic salmon as a flagship species, the French national action plan for migratory fish species, has as aim to work towards solutions that overcome the challenges salmon and other migratory fish face. National action plans (NAPs) are strategic operational tools aimed at ensuring the conservation or restoration in a favorable conservation status of a set of threatened species or of special interest species. A NAP is mobilized when other environmental and sectoral public policies including regulatory tools for nature protection are considered insufficient.

It is relating to the requirements of the European Union directives 2009/147/EC (the Birds Directive) and 92/43/EEC (the Habitats Directive). These Directives recognize that habitat loss and degradation are the most serious threats to the conservation of wild species.

The Habitats Directive seeks to ensure the survival of Europe's most endangered and vulnerable species by the conservation of natural habitats and wild fauna and flora. Together with the Birds Directive, it sets the standard for nature conservation across the EU and enables all Member States to work together within the same legislative framework to protect the most vulnerable species and habitat types across their entire natural range within the EU. The Habitats Directive protects around 1200 European species including fish. Under Annex II[1] and Annex V[2] of the Habitat Directive *Salmo salar* is a protected species in fresh water.

The implementation of the NAP provides the opportunity to support conservation of Atlantic salmon and other migratory fish species and their environments and enable collaboration among organizations and researchers in France. Salmon would be the emblematic species of the implementation phase. In order to keep the conservation actions going, time will be dedicated to identify and mobilizing potential financers at various action levels (including EU programs such as LIFE).

All correspondence should be addressed to Bénédicte Valadou.
email: benedicte.valadou@ofb.gouv.fr

Indigenizing Salmon Science & Management: What Can We Learn from Yup'ik and Athabascan Perspectives and Experiences?

Janessa Esquible

University of Alaska Fairbanks, College of Fisheries & Ocean Sciences, PO Box 188, Glennallen, AK 99588, USA

The Indigenizing Salmon Science and Management project is centered on Indigenous cosmologies and methodologies to better understand the historical and contemporary ways in which Alaska Native people stewarded salmon, incorporating values and providing ideas to improve current management practices and systems. Indigenous people have stewarded Alaska lands and waters for thousands of years, yet have been largely excluded from science and management systems that fail to advance Indigenous self-governance initiatives. This has resulted in devastating impacts to Alaska Native fishing communities. This project also documents the inequities embedded in the current salmon management system. Project methodology utilizes Indigenous and participatory methodological approaches through spending time in "place" with participants, facilitating circle dialogues, conversations, semi-directed interviews with individuals and multigenerational fishing families. Respect, reciprocity, responsibility, and relational accountability are used as some of the many guiding principles in this work.

This talk will focus on research conducted along the Kuskokwim River, with the guidance of local Tribal and Indigenous community members. Results from 21 fishing family interviews of coastal, lower, middle and headwater river Alaska Native communities will be shared. Yup'ik and Athabascan values, knowledge, management and Indigenous stewardship practices are documented. Core values and principles in caring for salmon are centered around respect, sharing and spirituality. Barriers for bringing Alaska Native peoples and knowledge systems into fisheries management include: power disparities embedded in current management systems, lack of meaningful inclusion of Alaska Native peoples and epistemologies in fisheries management systems, failure of management to include space for spirituality, and prioritization of commercial fishing interests and Eurocentric values over Alaska Native values and subsistence priorities. This research identified a clear need for relationship building between management agencies and communities. Several strengths and weaknesses of the salmon management system are documented from the perspectives and experiences of Yup'ik and Athabascan fishers. Alaska Native youth, adults and elders call for an improved, more inclusive and holistic approach to fisheries management that better reflects their knowledge, value and governance systems. These changes are critical for sustainable salmon and people systems in Alaska and beyond.

All correspondence should be addressed to Janessa Esquible.
email: jaesquible@alaska.edu

Management of Atlantic Salmon — from Indigenous Communities Perspective

George Russell[1], Donna Carroll[1], and **Kristen Milbury[1]**

[1] Department of Environment and Natural Resources, NunatuKavut Community Council Inc., PO Box 460 Stn. B, 200 Kelland Drive, Happy Valley-Goose Bay, NL, Canada

The NunatuKavut Community Council (NCC) represents ~6,000 Inuit who reside primarily in coastal communities of central and southern Labrador. The NCC Department of Environment and Natural Resources (ENR) works to conserve, protect, and preserve our lands, ice, and waters. ENR works collaboratively with federal and other agencies on natural resource management. Our work includes scientific and technical activities geared towards conservation and sustainable use of aquatic resources. Within ENR, opportunities exist for improvement in ways that resources are governed, and the manner in which Inuit values and knowledge are integrated.

Indigenous communities in NunatuKavut territory have a deep-rooted cultural connection to Atlantic salmon. As humans' anthropogenic encroachment on Atlantic salmon's population and habitat intensifies as non-renewable resources are explored and exploited and ongoing community economic pressures, it's critical for Atlantic salmon that management of the population is highly scrutinized and micro-managed. Management of Atlantic salmon is to ensure species population growth longevity in the territory. In addition to management efforts, it's to ensure Atlantic salmon population health continues for the fish, their habitat availability reliability is sustained through monitoring and protection, and for continued cultural teachings and connections for indigenous whom have the profound connection to the species.

While NunatuKavut's Atlantic salmon management style is not only localized to NunatuKavut territory and its people, the directions feeds into a collaborative effort with local stakeholders, and provincial and federal departments to ensure:

- The development of a co-management approach to aquatic resources and Atlantic salmon that is wholistic, streamlined, efficient, and effective,
- Invest in the continuous growth of capacity of Inuit and NunatuKavut communities,
- Increases the involvement of community members and resource users in management,
- Incorporates Indigenous Knowledge into all activities and decision-making, and
- Become the driver of research related to Atlantic salmon management in NunatuKavut while continuing NCC Research Priorities related to Atlantic salmon management and ensure that all research activities support these priorities.

All correspondence should be addressed to George Russell.
email: grussell@nunatukavut.ca

Our River, Our People, Our Fish: The Kuskokwim River Inter-Tribal Fish Commission as a Model for Indigenous Salmon Stewardship & Management

Jonathan Samuelson[1] and **Terese Schomogyi**[1]

[1]*Kuskokwim River Inter-Tribal Fish Commission, P.O. Box 190, Bethel, AK 99559, United States*

For generations, Yupik and Athabaskan families have stewarded and depended on the salmon fisheries of the 700-mile-long Kuskokwim River, located in rural western Alaska. Despite the presence of outside Western agencies in fisheries management on the Kuskokwim, local Indigenous fishermen are heavily involved in the conservation and harvest of salmon. This presentation examines how the Kuskokwim River Inter-Tribal Fish Commission (KRITFC)—rooted in Yupik and Athabaskan values, wisdom, and knowledge, and guided by both Indigenous Knowledge and the best available Western science—has emerged as a model for Indigenous-led salmon management and stewardship.

Composed of the 33 federally recognized Tribes of the Kuskokwim drainage, KRITFC collaboratively manages the salmon fisheries of the Kuskokwim River with U.S. Fish and Wildlife Service at Yukon Delta National Wildlife Refuge. Through this partnership, KRITFC's five In-Season Managers and two Elder Advisors, elected from and by Tribes stretching from the Kuskokwim's headwaters to its mouth, provide Indigenous Knowledge to consider alongside Western scientific data when they and Yukon Delta make salmon management decisions. The Indigenous Knowledge of our In-Season Managers—fishermen themselves who depend on the salmon and other fish of the Kuskokwim for physical, spiritual, and cultural vitality—has painted more accurate portraits of salmon run timing and abundance than available Western scientific models. Such accuracy has led KRITFC to both achieve adequate escapements of Chinook salmon as well as provide Kuskokwim fishermen with some subsistence harvest. This is especially critical in a time when Chinook and chum salmon populations are in steep decline throughout western Alaska, including on the Kuskokwim, yet when Indigenous fishermen's need for fish has not decreased. The observations and Indigenous Knowledge that KRITFC brings to fisheries management, as well as the formalized federal partnership through which its management takes place, models how Indigenous Knowledge can and should be used alongside Western science to carefully balance conservation and harvest of salmon.

All correspondence should be addressed to Terese Schomogyi.
email: terese@kritfc.org

Ecosystem Services of Salmon Using Western and Indigenous Frameworks

Katharine N. Shelledy[1,2], and **Ken Currens[2]**

[1]*Washington Sea Grant, 3710 Brooklyn Ave NE, Seattle, WA 98105, USA*

[2]*Northwest Indian Fisheries Commission, 6730 Martin Way E, Olympia, WA 98516, USA*

This presentation characterizes the ecosystem services of salmon and salmon hatcheries, as described in published literature, for socio- and eco- logical systems. Hatcheries produce over 80% of salmon in Washington. Ecosystem services provided by salmon and by extension salmon hatcheries have yet to be described in a way that considers both Western and Indigenous frameworks. We relied on two existing frameworks 1) Common International Classification of Ecosystem Services (CICES) and 2) Earth Economics' Sociocultural Framework on the Significance of Salmon for Tribes and First Nations to organize ecosystem services of a) salmon in general and b) salmon specified as originating from hatcheries. We identified 159 papers that met our criteria based on a rigorous, systematic review of 685 published papers found through Web of Science. Authors frequently described how salmon provide nutrients and energy to various systems and organisms, provision profit (especially to fisheries), regulate freshwater chemistry, and have significance for culture or heritage, all falling within the CICES framework. Some of these same services were applicable to Earth Economics' Sociocultural Framework, although far fewer services could be mapped onto this framework compared to CICES. The importance of salmon as food was most frequently described, followed by the significance of salmon for indigenous management systems. Notably, the majority of services described overall were ecological rather than sociocultural, and authors focused on services of naturally produced salmon and not hatchery salmon. These results reflect a research emphasis on the ecological effects of 'wild' salmon; we recommend broadening research scope in the future to reflect the influence of the total salmon production system—hatcheries included—on local ecosystems, tribes, and communities.

All correspondence should be addressed to Katherine Shelledy.
email: shellkn1@uw.edu

The Six Rivers Project: Conservation of the North Atlantic Salmon in North East Iceland

Gísli Ásgeirsson[1], Sveinn Björnsson[1], Stefán Hrafnsson[1], Peter Williams[1], Olivia Morris[2], James Rosindell[2], Guy Woodward[2], Hlynur Bárðarson[3], Guðni Guðbergsson[3], and **Sammi Lai[3]**

[1]The Six Rivers Project

[2]Imperial College London

[3]The Marine & Freshwater Institute, Iceland

This paper will provide some initial findings from The Six Rivers Project, which has been set up to help sustain and support the North Atlantic Salmon population in key rivers in North East Iceland, including the Vesturdalsa and the Sela.

Although Iceland stocks have not experienced the substantial declines seen elsewhere the number of salmon returning has recently reduced to a new low and the number of 2SW salmon has declined. The Six Rivers Project aims to understand better the underlying causes of this decline and identify and implement conservation measures to support the salmon population.

The Project brings together the extensive knowledge and science base of the Marine and Freshwater Research Institute in Iceland with the expertise in river ecology and population modelling from Imperial College London. This is supplemented by a Six Rivers team carrying out fieldwork based in East Iceland in cooperation with the local river associations. Although there has been an initial substantial injection of funds to start the project, the intention in the longer term is that the work is funded from income from sports fishing on the river. In this way, it is expected that the project will become self-sustaining, creating longer term benefit to the environment, the salmon population, and to the local community.

The project is long term and holistic.

- Resources within the rivers are quantified and food web models are built to further our understanding how food availability is a driver of population dynamics for juvenile Atlantic salmon. In addition, the long-term reforestation programme could create a higher diversity within the riverine food web and thus diversify the types of food consumed by juvenile salmon.
- In the rivers, parr and smolt cohorts are being studied through the life cycle on the Vesturdalsa through PIT tagging and introduction of detection antenna at three positions in the river. This is already providing important additional information on population movements and survival rates.
- The number of adult salmon ascending river Vesturdalsa are counted with a video counter giving information on the size of the run, sea survival, sea age composition and spawning stock size.
- New areas of the river are being opened up by construction of salmon ladders in waterfalls, by relocation of adult spawning pairs, and in the interim by egg-planting. Radio tagging of adult pairs is being done to determine spawning areas and estimate the number of repeat spawners.
- Historical and new data on population demographics as well as environmental factors such as temperature are being used in the construction of a mechanistic population model.
- Rod fishery is the only fishing method with limited number of rods set by a harvest plan that needs to be accepted by the Directorate of Fisheries. Fishing pressure on the rivers is being reduced by catch and release only and further reducing the number of rods on each river and ensuring that certain river areas are not fished.
- Links are being created with other salmon conservation and research groups via knowledge sharing and an annual conference and to ensure that resources are not wasted by needlessly repeating work done elsewhere.

All correspondence should be addressed to Peter Williams.
email: peter.williams@ineos.com

- To maximize and sustain funding for the research and conservation work, river infrastructure is being improved in parallel through construction of new lodges. In this way, we hope to combine responsible world class fishing with internationally important research and conservation work

Salmon Sanctuaries—Engaging Human Communities in Salmon Conservation

Mark Boyden[1], Michael Furniss[2], and Rauri Maguire[3]

[1] *StreamScapes Project Director, Coomhola Salmon Trust, Bantry, County Cork, P75 TY47, Ireland*

[2] *Adjunct Professor, Department of Forestry & Wildland Resources, California Polytechnic University, Humboldt*

[3] *Manager, 'The StreamSchool,' Coomhola Salmon Trust, Bantry, Co. Cork, Ireland*

Creative and compelling Lay Environmental Education in local communities has the capacity to play a major role in assisting long-term recovery and conservation of salmon populations. Utilising local schools as a vector into promoting enhanced wider community awareness, a programme focus upon salmon and their habitats is an ideal substrate for fostering an understanding and appreciation for land and water issues, invoking the wonders which high-status waters support as well as equipping citizens with the 'best-practices' which must be achieved in the pursuit of livelihood, recreation, and domestic management to conserve these wonders. The StreamScapes program in Ireland has been engaged in Atlantic Salmon-focused environmental education for decades, most recently producing, with NASCO and other parties, the 'Salmon Sanctuaries' project as part of the wide International Year of the Salmon initiative. This poster will examine StreamScapes ethos & methodology and how these elements manifest in the development and delivery of the 'Salmon Sanctuaries' resource.

All correspondence should be addressed to Mark Boyden.
email: streamscapes1@gmail.com

The Pacific Salmon Explorer: An Online Tool to Communicate Salmon Population and Habitat Status Across BC

Katrina Connors, Eric Hertz, and **Katy Kellock**

Salmon Watersheds Program, Pacific Salmon Foundation, 300 - 1682 West 7th Ave, Vancouver, BC V6J 4S6, Canada

Salmon play a key role in the culture, ecology and economy of British Columbia. However, the lack of centralized, standardized, and easily accessible data on the state of Pacific salmon, and threats to them, impedes efforts to make evidence-based management decisions. In an effort to create broader public understanding of salmon status and trends in British Columbia, the Pacific Salmon Foundation is leading a major initiative to synthesize, and make openly accessible, the best available information on salmon and their freshwater habitats in British Columbia. We have developed an interactive data visualization platform, the Pacific Salmon Explorer (www.salmonexplorer.ca), to provide standardized, reproducible, and open-access information on a suite of indicators of salmon population condition. This biological information is coupled with habitat assessments that quantify pressures on freshwater salmon habitats. Our novel approach provides a synoptic overview of the current status of salmon populations and their habitats in British Columbia, while highlighting areas where data gaps exist and where more research is needed. The Pacific Salmon Explorer provides a relevant example for demonstrating how the synthesis, analysis, and communication of decision-relevant information can be brought to managers, scientists and the general public on complex environmental problems.

All correspondence should be addressed to Eric Hertz.
email: ehertz@psf.ca

Applications of PSF Citizen Science Monitoring in Salmon Research

Svetlana Esenkulova, Nicole Frederickson, and **Isobel Pearsall**

Pacific Salmon Foundation, 1682 W 7th Ave, Vancouver, BC V6J 4S6, Canada

Citizen Science Oceanography Program in the Strait of Georgia has been operated since 2015 by the Pacific Salmon Foundation with assistance from Fisheries and Oceans Canada (DFO) and Ocean Networks Canada (ONC). The purpose of the program is to obtain high-resolution (50 sites sampled 20 times a year) data on oceanographic conditions and lower trophic levels. Each year thousands of CTD casts, secchi measurements, nutrients and phytoplankton samples are collected. Analyzed data are archived at ONC and the Strait of Georgia Data Centre as open access datasets. The scope and resolution of collected data is unprecedented and can be used to assess conditions relevant to juvenile salmon survival in the Salish Sea.

All correspondence should be addressed to Svetlana Esenkulova.
email: sesenkulova@psf.ca

Perspectives on Pacific Salmon Expanding Across the Western Canadian Arctic

Jody Illisiak[1], Michelle Gruben[2], and **Karen Dunmall[3]**

[1] *Paulatuk Hunters and Trappers Committee*

[2] *Aklavik Hunters and Trappers Committee*

[3] *Freshwater Institute, Fisheries and Oceans Canada, 501 University Cr, Winnipeg, MB R3T2N6, Canada*

Pacific salmon are increasingly being harvested as bycatch in subsistence fisheries targeting other species across the Canadian Arctic. Together, we will discuss the different histories of salmon harvests in Aklavik and in Paulatuk, Northwest Territories, as well as provide a Canadian Arctic-wide overview of recent harvests. We will describe how harvesters and researchers have been working together for 20 years to monitor changing harvests and track where salmon are being caught across the Canadian Arctic. We will discuss research that community members complete collaboratively with researchers in order to address community-driven questions related to increasing salmon. We will then reflect on what increasing salmon means to our communities in the broader context of climate change.

All correspondence should be addressed to Karen Dunmall.
email: Karen.Dunmall@dfo-mpo.gc.ca

Leveraging the 2022 Pan-Pacific Winter High Seas Expedition for Integration into an Alaskan Salmon Curriculum

Kate Morse[1] and **Tommy Sheridan**[2]

[1] *Copper River Watershed Project, PO Box 1560, Cordova, AK 99574, USA*

[2] *Sheridan Consulting, LLC, PO Box 375, Cordova, AK 99574, USA*

Building off the success of the International Year of the Salmon's 2022 Pan-Pacific Winter High Seas Expedition, this presentation seeks to highlight the integration of the Expedition's outreach program(s) into Copper River Watershed Project's (CRWP) salmon-themed education programs. Since 2010, the CRWP and the Prince William Sound Science Center have partnered together to help Cordova's elementary-aged students raise salmon from eggs to fry in a tank in their school as part of a broader salmon-centric curriculum. In 2019 this program expanded to include the five additional schools in the Copper River Watershed. The overall goals of these education programs are to help students learn about and connect with salmon, the natural resource at the core of their cultures, communities, and way of life. Tying learning to real-world experiences brings classroom lessons to life, and students learn about local jobs and salmon economics through field trips and connecting with salmon scientists, harvesters, and resource managers. As part of the 2022 International Year of the Salmon research expedition, North Pacific Anadromous Fish Commission Commissioner Tommy Sheridan crewed the F/V *Northwest Explorer* as part of the Expedition's broad ecosystem survey, pelagic trawling, and detailed sampling of marine life in the upper ocean. Throughout the *Northwest Explorer*'s 20 days at sea, expedition scientists, including Sheridan, were able to provide frequent updates to the public via the Expedition website, including journal entries, and occasional videos as bandwidth allowed. As Program Director for Copper River Watershed Project, Morse led shoreside lessons with her team of collaborators as students tracked the expedition and expanded their understandings of the Salmonsphere to include open ocean research. This presentation will provide examples of innovative ways to connect salmon scientists and salmon science to youth so they grow to become inspired, informed salmon advocates.

All correspondence should be addressed to Kate Morse.
email: kate@copperriver.org

Synthesis Papers

Fishous Rumours: A Synthesis of What We (Don't) Know About Captive Rearing Programs in a Pacific and Atlantic Basin Context

Hannah L. Harrison[1], Øystein Aas[2], Valerie Berseth[3], Tom Chance[4], Shelley Denny[5], Lian Kwong[6], Tommi Linnansaari[7], Adrian Spidle[8], Alan Walker[9], Kyle Wellband[10], Lorna Wilson[11], and Kurt M. Samways[12]

[1]Dalhousie University, Canada

[2]Norwegian University of Life Sciences (NMBU), Norway

[3]University of British Columbia, Vancouver, BC, Canada

[4]Lummi Natural Resources Department

[5]Unama'ki Institute of Natural Resources

[6]Salmonid Enhancement Program, Fisheries and Oceans Canada, Vancouver, BC, Canada

[7]University of New Brunswick, Canada

[8]Northwest Indian Fisheries Commission

[9]CEFAS, UK

[10]Fisheries and Oceans Canada, Canada

[11]Alaska Department of Fish and Game, Alaska, USA

[12]Parks Canada Research, Canada

Populations of salmon around the globe have undergone precipitous declines due to a variety of factors including, but not limited to, climate change, damming of rivers, overfishing, habitat loss/change, diseases and parasites, losses of biodiversity and productivity, and impacts from aquaculture. For over a century, programs to captively rear and release salmon have been used in a wide variety of life-stages, scales, and contexts in the Pacific and Atlantic basins to both supplement wild populations and mitigate loss. Over time, these programs have been found to have mixed results (with examples of positive, neutral, and negative outcomes) in meeting their various objectives (i.e., loss mitigation, reintroduction, catch enhancement). For many years, public policies have supported and financed these practices, with policy trends diverging across different captive rearing captive rearing contexts. While the natural science peer-reviewed literature on this topic is robust, the field has expanded in the last decade, warranting a review of the state of knowledge about captive rearing as global objectives shift. Moreover, knowledge syntheses in this area have yet to consider the body of human dimensions research on salmon supplementation, or understandings of supplementation produced by knowledge systems from traditions outside of academia (e.g., Indigenous knowledge). To address these gaps, this paper synthesizes 10 years (2012–2021, inclusive) of peer-reviewed literature to elicit key ecological, biological, and social understandings of stocking/captive rearing programs for salmon in the Pacific and Atlantic basins. We frame this interdisciplinary synthesis in the context of climate change and the Anthropocene to better understand what role captive rearing could play in conserving future wild populations and/or supporting fisheries. We also explicitly attend to what topics and knowledge systems are not represented in this search, and how those exclusions may influence the scientific debate as well as on-the-ground decision-making for those involved in, and impacted by, captive-rearing efforts.

All correspondence should be addressed to Hannah Harrison.
email: hannah.harrison@dal.ca

The Early Marine Distribution of Atlantic Salmon in the North-East Atlantic: A Genetically Informed Stock-Specific Synthesis

John Gilbey[1], Kjell Utne[2], Vidar Wennevik[2], Philip McGinnity[3], and **Eric Verspoor[4]**

[1]*Marine Scotland Science Marine Scotland Science Perth, Scotland, UK*

[2]*Institute of Marine Research in Norway, Bergen, Norway*

[3]*School of Biological, Earth and Environmental Sciences, University College Cork, Ireland*

[4]*Salmonoid Genetics, University of Highlands and Islands, Scotland, UK*

The survival of Atlantic salmon (*Salmo salar)* has declined dramatically during its marine phase with presumed disproportionate impacts on the poorly understood early post-smolt period. To advance understanding of post-smolt distributional ecology in the North-east Atlantic, a comprehensive collation and analysis of existing information was undertaken. Data were synthesized from 385 marine cruises, 10,202 individual trawls, and 9,269 captured post-smolts, spanning three decades and ~4.75 million km^2 of ocean, with 3,423 individuals genetically assigned to regional phylogeographic origin. The findings confirm major migrational post-smolt aggregations on the continental shelf-edge off Ireland, Scotland and Norway, and an important marine foraging area in the Norwegian Sea. Genetic analysis shows that aggregational stock composition does not simply reflect distance to natal rivers, with northern phylogeographic stock groups significantly under-represented in sampled high-seas aggregations. It identifies a key foraging habitat for southern European post-smolts located in international waters immediately west of the Vøring Plateau escarpment, potentially exposing them to a high by-catch mortality from extra-territorial pelagic fisheries. Evidence of the differential distribution of regional stocks points to fundamental differences in their migration behaviours and may lead to inter-stock variation in responses to environmental change and marine survival. The study shows that understanding of post-smolt marine ecology, as regards to stock-specific variations in habitat utilization, biological performance and exposure to mortality factors, can be significantly advanced by data integration across studies and exploiting genetic approaches. However, the temporal and spatial account of post-smolt distributional dynamics remains incomplete and development of a fully comprehensive account presents an extremely difficult scientific challenge.

All correspondence should be addressed to John Gilbey
email: John.Gilbey@gov.scot

Indigenous and Local Involvement in Salmon Management: Examples from Norway in an International Context

Stine Rybråten[1], Camilla Brattland[2], Niklas Högstedt[2] and **Tomas Sandnes[2]**

[1]*Norwegian Institute for Nature Research, project leader for the SALCUL project*

[2]*The Arctic University of Norway, Tromsø, Norway*

The world's population of wild Atlantic salmon is in severe decline. As Norway is among the species' main living areas, Norwegian authorities have taken a particular responsibility to protect wild Atlantic salmon as a measure of biodiversity conservation in a global context. Current conservation measures are however subject to conflict. The authorities strive to balance the salmon stock situation with Norway's accession to international initiatives like UNDRIP and IPBES, calling for the inclusion of Indigenous and local knowledges (ILK) in sustainable management of biocultural diversity. Still, guidelines and practices for bringing together different knowledge types as a basis for decision-making is lacking in the Norwegian natural management system. Furthermore, the country's strong sector division limits the Norwegian Environment Agency's salmon management tool to regulating fishing rules. Locally, increasingly strict fishing restrictions make fishers call for salmon conservation solutions compatible to maintaining and developing local and indigenous fishing traditions and knowledges.

This presentation, addresses common and distinctive features of the Deatnu-Tana River in Sápmi, Northern Norway/Finland, and the Namsen River in Trøndelag, Central Norway, as well as these rivers' adjacent fjords. In both areas, salmon is highly valued, forming a central part of the communities' culture, identity, diet, economy, social relations and/or spiritual practices. Both areas furthermore experience a decline in their returning salmon stocks, causing national authorities to question the adequacy of local management measures. In 2021, for the first time in history, the salmon fisheries in Deatnu-Tana were closed by Norwegian authorities, as a measure of salmon protection. Based on participatory research, interviews, and local meetings, we present and discuss the complexities of Indigenous and local involvement in salmon management and knowledge production, intersecting local, national and international scales.

All correspondence should be addressed to Stine Rybråten
email: stine.rybraten@nina.no