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2020 Update on Canadian Research Relevant to the 2016–2020 NPAFC Science Plan

by

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ABSTRACT

This document summarises major scientific research activities in relation to the 2016–2020 NPAFC Science Plan. The report focuses on research activities planned by Fisheries and Oceans Canada scientists and colleagues during 2020/21 and results from recent studies not documented in previous Canadian research summaries.

INTRODUCTION

The Science Sub-Committee of the North Pacific Anadromous Fish Commission (NPAFC) developed a five-year Science Plan (2016–2020) (https://npafc.org/wp-content/uploads/2017/08/science_plan2016-20.pdf) with five research themes intended to help understand variations in Pacific salmon productivity in a changing climate:

1. Status of Pacific Salmon and Steelhead Trout

2. Pacific Salmon and Steelhead Trout in a Changing North Pacific Ocean

3. New Technologies

4. Management Systems

5. Integrated Information Systems

This document updates earlier summaries of Canada's scientific research activities in relation to the 2016–2020 Science Plan (e.g., Irvine et al. 2019) and complements a separate document summarising Canadian publications (Grant et al 2020). The focus is on research activities planned by Canada during 2020/210 that are relevant to the Science Plan. Recent studies not documented in earlier Canadian research summaries, including some to be reported on at the 28th e-mail Annual Meeting are also included in the report. The list is not complete but provides an overview of major activities planned or recently completed. Please refer to cited literature or contact appropriate co-author for further details on specific activities.

Activities are organised according to the five major themes (1–5*)* listed above. It should be noted that research activities often cross over several components of the science plan, due to the inherent overlap associated with these themes, but are only described under one theme.

1. Status of Pacific Salmon and Steelhead (including Biological Monitoring of Key Salmon Populations; Seasonal Migration and Distribution; Variation in Growth and Survival; Modeling the Future for Salmon)

Canadian scientists continues to monitor the status and important biological characteristics (e.g., salmon size, age composition, return timing, survival) for various key (important) salmonid populations. Time series information on catches, spawner escapements, and regional salmon production trends for hatchery and wild stocks are also obtained (Velez-Espino et al. 2020).

A central problem in understanding how salmon respond to global changes is differentiating the effects of local drivers from regional and global drivers that may be shared among many populations. Researchers in Fisheries and Oceans Canada's (DFO) Ecosystem Science Division and elsewhere examine time series observations of annual production variations for salmon populations originating from freshwater systems around the rim of the North Pacific Ocean. The goal of the State of the Salmon Program led by Sue Grant is to track and understand Canadian Pacific salmon population trends. It achieves this goal by developing tools and processes to foster collaboration among salmon-ecosystem experts. DFO's State of the Salmon Program held one annual meeting over the past year to integrate observations on salmon and ecosystem trends broadly across all Canadian Pacific Salmon. To make results broadly accessible, findings were published in a traditional format (Grant et al. 2019a) as well as an E-book (Grant et al. 2019b).

One data visualization package was completed using Shiny-R software to assist with tracking annual statuses for Pacific Salmon: Synoptic Status Evaluation Tool (SSET). Data have been integrated for three broad groups including Fraser Sockeye, Southern British Columbia Chinook and Interior Fraser Coho. Over the next year, integrated statuses will be updated using expert input and the application of this Shiny-R software tool. This tool includes a mapping interface, where specific populations can be selected based on their geographic area, and prioritized depending on their status. On-going work will be conducted to add in additional data sets.

Static data visualization code was developed within the State of the Salmon Program in Shiny-R to present salmon trends at the fisheries management unit (MU) level. Templates have been developed, and on-going work has been conducted to add in data sets as they become available.

Dr. John Reynolds group at Simon Fraser University is beginning a new project looking into the changes in distribution of Pacific Salmon over the past 100 years across the North Pacific at international, regional, and local scales, including an investigation of what drives these changes (Price et al 2019).

Continued collaboration by scientists studying data rich salmon populations throughout the North Pacific is needed. This should include sharing observations and time series data on annual production, productivity indices and biological traits. This should provide a cost effective means to facilitate the rapid identification of region-wide versus local area salmon production trends on an annual basis throughout the eastern North Pacific as a basis for improvements in timely advice to fisheries managers and stakeholders.

2. Pacific Salmon and Steelhead Trout in a Changing North Pacific Ocean (including Retrospective Salmon Studies; Linking Salmon Production, Climate and Ocean Changes)

DFO's State of the Salmon Program held a separate meeting this past year to integrate observations on salmon and ecosystem trends for one data rich group of populations, Fraser River Sockeye. This work's goal is to integrate knowledge and data across the ecosystems that Fraser Sockeye use throughout their life-stages, and to improve our understanding of factors contributing to population dynamics MacDonald et al. 2019).

This Program is also leading the development of annual Salmon Outlooks that integrate environmental observations across life-stages for the upcoming return year. This work combines observation and research from scientists working on freshwater and marine salmon ecosystems, and helps provide input into the fisheries management processes.

A second data visualization package prototype was developed to conduct spatial pattern analysis with salmon data using Shiny-R: Spatial Pattern Analysis Tool (SPAT). This enables researchers and managers the ability to quickly view, compare, and correlate trends visually across salmon data and environmental variables. The goal of this tool is to assist with hypotheses development related to improved understanding of salmon population dynamics.

Finally, this Program is leading a Salmon Ecosystem Climate Consortium Team across organizations to develop salmon vulnerability assessments related to climate change. This work will help to guide salmon management, habitat restoration, salmon recovery actions into the future. A contribution to an United Nations Food and Agricultural Fisheries Adaptation Climate meeting was produced to assist with a guidance document for future fisheries under climate change.

In July and August 2019, DFO (with support from UBC, NOAA, and Kintama Research) initiated a study to monitor adult Chinook salmon abundance and distribution near southern Vancouver Island to address questions related to prey availability for resident killer whales. Genetic sampling and acoustic tagging were used to identify stock-specific spatio-temporal distributions, behaviors, and survival rates. Additionally, genetics data collected from various fisheries are being used to generate models of stock-specific abundance across statistical areas to inform future management measures. Both project components are ongoing and will continue in 2020.

The Pacific Salmon Ecology and Conservation Laboratory at the University of British Columbia (UBC) led by Dr. Scott Hinch has a strong focus on investigating how physiology and behaviour of salmon is changing with global climate change (Banet et al. 2019, Houde et al. 2019 a, b, c). Water temperature, salinity, and food availability are changing which can directly affect salmon survival or even have intergenerational effects by altering the way females provision their eggs and offspring. The group examines these questions by monitoring survival and measuring behavioural and physiological traits at different life stages of salmon development. A swim flume (analogous to a tread mill for humans) is used to test the swimming ability of young salmon from different mothers, populations, or species. Also examined are morphological (body size, fin size), behavioural (aggression, predator avoidance, feeding), and physiological (stress hormones, metabolism) differences among offspring in relation to changing environmental features.

Dr. John Reynolds' group at SFU maintains a long-term research program on the Central Coast of BC to investigate ecological impacts of Pacific Salmon on freshwater and terrestrial habitats around spawning and rearing streams, including the impact of marine-derived nutrients on estuary plants, stream invertebrates, and riparian birds (Harding et al 2019, Walsh et al *in press (a)*.

V. Minke-Martin and M. MacDuffee at Raincoast Conservation Foundation recently reviewed the international scientific literature with respect to hatchery effects on Pacific salmon

(*Oncorhynchus spp.*) in the North Pacific Ocean; a brief summary follows. Intra- and interspecific competition among Pacific salmon have been well documented in the North Pacific Ocean where overlap in resource use occurs (*e.g.* Kaeriyama 1998, Ruggerone *et al.* 2003, Ruggerone and Nielsen 2004, Naydenko 2009), although the extent of density-dependent interactions in some regions is still not clear (*e.g.* Shuntov *et al.* 2017). Hatchery production increased rapidly since the 1970s and now account for about 40% of salmon in the North Pacific (Ruggerone and Irvine 2018). Large numbers of hatchery pink (*O. gorbuscha*) and chum (*O. keta*) salmon have been found to inhibit growth and productivity of wild sockeye (*O. nerka*, Ruggerone and Connors 2015, Ruggerone *et al.* 2016), Chinook (*O. tshawytscha*, Ruggerone *et al.* 2016, Cunningham *et al.* 2018), coho (*O. kisutch*, Shaul and Geiger 2016), pink (Amoroso *et al.* 2017), and chum (Agler *et al.* 2013) salmon. The strength of these density-dependent interactions however can shift across regions. In the south, where warmer ocean conditions are less favourable for early marine survival, intra- and interspecific competition for prey can substantially reduce salmon productivity, while in the north, sea surface temperature is positively related to growth and survival, which may temper negative effects of competition (Ruggerone and Connors 2015, Cunningham *et al.* 2018). Similarly, higher productivity and prey availability in the western Bering Sea may reduce the effects of competition, compared to the eastern Bering Sea (Davis *et al.* 2009, Batten *et al.* 2018). Relative stability of adult salmon biomass since 1993 suggests the North Pacific Ocean may have reached a carrying capacity (Ruggerone and Irvine 2018). As such, increases in hatchery output are unlikely to substantially increase adult returns (Peterman *et al.* 2012, Amoroso *et al*. 2017), and tradeoffs may occur among species (Ruggerone and Nielsen 2004, Ruggerone and Connors 2015). Additionally, hatcheries can alter life-history parameters (*e.g.* Nelson *et al*. 2019), reproductive fitness (*e.g.* Araki *et al.* 2009, Chilcote *et al.* 2011), and genetic diversity (*e.g.* Christie *et al.* 2011), which are important for salmon populations (Schindler *et al.* 2010), salmon dependent species (Hanson *et al.* 2010, Ward *et al.* 2010) and ecosystems (Bottom *et al.* 2009). There is a need for international cooperation to regulate hatchery output and reduce impacts on the diversity and abundance of wild salmon populations (Holt *et al.* 2008, Peterman *et al.* 2012, Ruggerone and Irvine 2018).

During 2020, DFO's inshore program plans to sample in the Salish Sea (encompassing the Strait of Georgia and Puget Sound) while the offshore program will sample along of the continental shelf surrounding Vancouver Island (mid-summer) and on the continental shelf in southern Queen Charlotte Sound, into Queen Charlotte Strait and through Johnstone Strait(early summer and fall). These surveys are both part of long-term research programs that were initiated in 1997–1998. In 2017 the offshore program began integrating with other pelagic research programs to develop a synoptic pelagic survey on the continental shelf off the west coast of Vancouver Island and 2020 will be the third year of this integration (Neville and King 2020).

A second Gulf of Alaska expedition took place during March–April 2020 aboard the 37 m long, Canadian commercial trawler, *Pacific Legacy* (Beamish and Riddell 2020) with scientists aboard from Canada, United States and Russia. The primary hypothesis being addressed was that fish that grow faster in the early months in the ocean (nearshore) are the ones that best survive through the first ocean winter, and largely determine the subsequent year class strength. Fish and oceanographic sampling gear used was similar to that used in the 2019 expedition (Pakhomov et al 2019) to ensure results were comparable. Results from 2020 are being interpreted and will be presented in forthcoming publications. In 2021, the intent is to use Canada's new B.C.-built offshore fisheries research vessel, the Sir John Franklin.

The Hakai Institute continues its juvenile salmon observing program in the northern Strait of Georgia, Discovery Islands and Johnstone Strait (Johnson et al 2019). The program is conducted in collaboration with researchers at UBC (Dr. Brian Hunt (project PI), Dr. Evgeny Pakhomov) and University of Toronto (Dr. Martin Krkosek). The program has been operational since 2015 and obtains samples annually during the juvenile salmon outmigration to: evaluate the oceanographic controls of prey phenology, quantity and quality for migrating juvenile salmon in the northern Strait of Georgia, Discovery Islands and Johnstone Strait; determine stock-specific migration behavior of juvenile sockeye salmon, and co-migrating salmon species, through the region; determine juvenile salmon feeding biology and measure growth and condition across a spatial-temporal gradient of prey quantity and quality; determine juvenile salmon parasite and pathogen infection dynamics across the Discovery Island / Johnstone Strait region and; estimate mortality rates of juvenile salmon during their Strait of Georgia to Queen Charlotte Strait migration (Hunt et al. 2018)). In 2019, an experimental study was conducted to test the effect of pCO2 on Pink Salmon physiology. This preliminary experimental research will be expanded on in 2020 to test the cumulative effects of pCO2, temperature and prey availability on sockeye salmon health. These experiments will be combined with quantification of RNA:DNA based growth rate measurements for routine application in field studies. Finally, further testing of the application of environmental (e)DNA to quantification of salmon migration paths and abundance estimates will conducted through a combination of field and lab studies.

The high seas phase of Pacific salmon life history remains particularly data-limited, and the potential implications of climate impacts on ocean productivity for salmon condition and reproductive success is poorly understood. UBC researchers Dr. Brian Hunt and Dr. Evgeny Pakhomov are conducting ongoing research to reconstruct high seas salmon life history. This includes using carbon and nitrogen stable isotopes (SI) from salmon scales to inform the trophic environment experienced by sockeye salmon on the high seas (*Oncorhynchus nerka*). Initial analyses focused on Rivers Inlet sockeye salmon over the last century (1915–2016) (Espinasse et al 2018), and subsequent analyses have been expanded to multiple stocks around the Pacific Rim. In parallel research, this group is developing a salmon diet database that is collating and standardizing previously published salmon diet data into a single framework (currently led by Ms. Caroline Graham).

3. New Technologies

In 2019, DFO's Salmon Genetics group at the Pacific Biological Station led by Terry Beacham applied direct DNA sequencing to genotype Chinook salmon, coho salmon, chum salmon, and sockeye salmon. For Chinook salmon, a panel of primers has been developed where approximately 600 amplicons are amplified via a highly-multiplexed single polymerase chain reaction, with at least one single nucleotide polymorphism (SNP) scored at each amplicon. For coho salmon, a panel has been developed to amplify about 480 amplicons. The SNP panel for chum salmon amplifies about 530 amplicons, and for sockeye about 550 amplicons. Species identification SNPs have been incorporated in all panels. For coho and Chinook salmon, the panels are being used in an evaluation of whether parental-based tagging is a practical alternative to the present coded-wire tag program for Chinook and Coho salmon.

In 2019, samples were collected from Chinook salmon broodstock (approximately 20,000 individuals) at hatcheries in British Columbia. Samples were also collected from coho salmon broodstock (approximately 7,500 individuals) at hatcheries where individuals are adipose fin clipped upon release. Canada genotyped these individuals using the SNP amplicon panels. Approximately 12,000 Chinook salmon were also sampled in fisheries in British Columbia in 2019, as well as about 9,000 coho salmon. Returning adults from prior hatchery releases were genotyped to identify returning Chinook and Coho salmon to specific hatchery parents sampled in 2014-2017, thereby providing a method to evaluate the accuracy parental-based identification (PBT). Standard genetic stock identification techniques (GSI) were also used to identify the origin of individuals not assigned via parental-based identification. Accurate identification of returning individuals to specific hatchery parents provided the year and location of hatchery release, thereby providing a possible alternative to the current method of coded wire tagging (CWT). Initial applications of a PBT/GSI approach to stock identification for mixed-stock coho salmon samples analyzed in 2017 and 2018 have proved very informative, and have provided additional information relative to the existing CWT program. Very high accuracy and resolution of stock composition estimates of mixed-stock samples from coho salmon fisheries conducted in British Columbia during 2017 and 2018 have been obtained. Similar results have been observed in Chinook salmon. The SNP panel for chum salmon has been applied to 2019 commercial fishery samples in British Columbia, as well as the 2019 Gulf of Alaska survey. The sockeye salmon SNP baseline is being developed, and will be applied in 2020 to fisheries in local areas in northern and central British Columbia.

In 2020, DFO will continue to apply the SNP panels for the four species previously noted, and anticipate that samples from mixed-stock fisheries will be collected for all four species. The samples will be analyzed by GSI and PBT as appropriate. Chinook and coho broodstocks at hatcheries in British Columbia are anticipated to be sampled as well.

The migration that adult Pacific salmon make from distant ocean feeding grounds to spawning streams hundreds of kilometers inland is among the most remarkable phenomena in the natural world. The Pacific Salmon Ecology and Conservation Laboratory at UBC collaborate with other researchers in carrying out extensive work to advance the basic understanding of those migrations and are doing so using novel and cutting edge technologies including tagging salmon with transmitters that track individual fish throughout their migrations and provide detailed information on muscle activity, 3D-acceleration, behavioural thermoregulation, fine-scale movements, and migration speeds. This information allows researchers to understand how salmon complete their difficult migration in fluctuating environmental conditions. Approaches include environmental monitoring to characterize migration experience, simulation models to better understand the role of ocean currents in salmon movements and laboratory studies to isolate the influences of water quality on fish behaviour and survival. A fish's experience and behaviour from telemetry or lab studies is linked with genomic traits to also investigate interactions between individual physiology and the environment. Studies have taken place in the

Fraser River watershed, as well as in the marine environment in the Strait of Georgia (Anttila et al 2019; Little et al 2019; Prystay et al 2019; Stevenson et al 2019a, b).

4. Management Systems (Cultural and Social Studies)

Given changing ocean and freshwater conditions experienced by Pacific salmon, assessment methods that account for time-varying parameters are increasing being used. Holt and Michielsens (2019) evaluated the performance of stock-recruitment models and associated reference points or benchmarks under scenarios of changing productivity in a simulation framework. They found that benchmarks tended to be less biased when time-varying parameters were accounted for. However, underlying true benchmarks based on spawner abundances at maximum sustainable yield, S_{MSY}, trend downwards when productivity declines, which may not be aligned with conservation objectives. They concluded by providing best-practices when considering model with time-varying parameters in assessments.

For data-limited sockeye salmon stocks where stock-recruitment data are not available to inform reference points or benchmarks in status assessments, Atlas et al (*in* press) developed a model to predict capacity of rearing lakes based on landscape and biophysical variables. This model can be used as a valuable starting point for developing lake-specific reference points for data-limited stocks.

Researchers at the UBC Pacific Salmon Ecology and Conservation Laboratory led by Scott Hinch conduct extensive research to understand the effects of capture-and-release and by-catch release in various fisheries on physiological recovery, behaviour, and subsequent migration success – in multiple species and populations of salmon. The most common technique employed has been biotelemetry—implanting radio or acoustic transmitters to track migration behaviour and success of individual fish after release. In field and laboratory experiments, they used heart-rate biologgers and blood hormones and developed simple animal reflex indicators to examine how quickly salmon can recover from being captured. In collaboration with Dr. Kristi Miller's group at PBS, the lab is also using new genomic techniques to understand how capture-and-release can affect pathogen development and disease in migrating salmon. Beyond simply documenting the impacts, they use these techniques to understand what handling practices are best for fish, and to test whether specially-designed recovery bags or boxes can be used to facilitate recovery and improve survival. This research has generated information that can be used for informing management of capture-and-release fisheries, both by providing accurate mortality estimates to fisheries managers and by giving fishers ways to minimize handling stress and mortality for the fish they release (Bass et al 2019, Cook et al 2019a, b, Kanigan et al 2019, Teffer et al 2019) .

This same program involves examining the effects of catch and release (CR) on adult marine Chinook and Coho salmon. In 2020, both Chinook and Coho will be captured using recreational fishing methods that employ traditional rod and reel techniques. Depending on CR location, salmon will be tracked using arrays within the Strait of Georgia, Discovery Islands, Johnstone Strait, and Queen Charlotte Sound. Along with developing an understanding of their migration ecology within the Salish Sea, individual characteristics, including physically observable condition (i.e. physical injuries, scale loss, previous capture wounds), stock of origin, and physiological genomic biomarkers (i.e. infectious agent presence, stress related gene expression) will be cataloged and compared among the various samples of fish tagged and released. These factors will help to determine the overall health condition of the individual and point to clues of subsequent mortality.

In addition, angler impacts will be studied by comparing the effects of various handling practices (i.e. net types, air exposure, fight times), gear types (i.e. hook size, flasher vs no-flasher, bait vs. artificial), and capture methodologies (i.e. hook location, downriggers vs. no downriggers, near shore vs. deep water) used by public anglers. Handling (i.e. fabric gloves, “salmon-sling”) and revival technologies (i.e. aerated revival tanks, assisted reventilating) will be tested for their effectiveness in improving the overall survival of individuals post-release. Migration and survival rates will be compared among the groups of variably handled fish to better understand the overall impact of public fishing practices and to inform the development of the most accurate estimates of post-release mortality. Holding studies will be completed to help understand the mechanisms of mortality and how injuries and sub-lethal impacts progress over time, through repeated biological sampling.

In partnership with the Sport Fishing Institute of BC, these UBC researchers will utilize the FishingBC App to collect a broad dataset pertaining to the methods employed by public fishers on the coast through voluntary submission of self-reported capture data, including fight times, air exposure times, gear types and presence of physical injuries. This will help better estimate the impacts of the fishery as a whole and to develop new questions to test as the research program develops. A large-scale PIT tagging program aimed at tagging potentially thousands of fish over the coming years will help increase the validity of our statistical analyses, where these relatively cheap tags allow for much larger samples of fish to be catalogued and compared. Surveys of public anglers, guides, and managers will develop an understanding of the perceptions and perspectives of public fishers towards catch and release fisheries and aid in developing future concepts to be tested and implemented in management.

The intended outcomes of the project are to develop: the most accurate estimates of post-release survival to be used in escapement modeling, scientifically defensible ‘best handling’ protocols intended to reduce the impact of anglers on their target species, and technologies that improve angler’s abilities to minimally impact both Chinook and Coho intended for release.

At SFU, Dr. Reynolds research group illustrated how Priority Threat Management can incorporate the perspectives and expertise of Indigenous peoples and other experts to evaluate and prioritize conservation strategies (Walsh et al *in press (b)*).

A management decision-support tool was developed to inform rebuilding plans for depleted Pacific salmon under various productivity regimes, with application to Fraser River Sockeye Salmon and Nass River Chum Salmon. This tool simulates population dynamics and evaluates impacts of various management actions under different hypothesis about climate driven changes in productivity. The implications of time-varying productivity and synchrony among stocks (Freshwater et al. 2019), as well as fishery stock-selectivity (Freshwater et al. 2020), were of particular focus.

5. Integrated Information Systems

Researchers in Scott Hinch's Pacific Salmon Ecology and Conservation Laboratory at UBC examine problems with integrating science into management practices (Brooks et al 2019, Iverson et al 2019, Nguyen et al 2019, Young et al 2019). For example, "knowledge mobilization theory" is an emerging field in the social sciences that examines how individuals and organizations respond to new information. Dr Hinch's group is investigating the processes involved in generating, transmitting, receiving, evaluating, managing, and implementing knowledge through interviewing and surveying salmon management systems (i.e., Fisheries and Oceans Canada, First Nations, ENGOs, industry and recreational fisheries groups). A major goal of this work is to identify breakdown barriers of science information flow to management systems.

Following a workshop that discussed ways to modernize data processing in the context of salmon research and management (NPAFC 2019), Jim Irvine and Scott Akenhead of DFO's Ecosystem Science Division at the Pacific Biological Station and Scott Carley of Organomics Consulting in Seattle are developing a prototype for a tool to assist with integrated decision making that uses graph database technology. The flow of information from data to management decisions is often impeded by an inability to quickly access relevant information. Unlike spreadsheets or relational databases, graph databases store information as a network of many types of nodes (e.g. people, places, activities). Nodes are connected by links that describe relationships (e.g. works for, works at, authored,, managed, etc.). A demonstration of this tool is planned to illustrate how information from a broad range of sources can be accessed to consider the ecological, social, economic, and cultural costs and benefits of changing fishery exploitation rates for Southern BC Chinook salmon. If the prototype is well-received, support will be sought to further develop the tool and apply it on a broader scale, both within and outside DFO.

The North Pacific Anadromous Fish Commission (NPAFC) is implementing a five-year International Year of the Salmon (IYS) collaborative project through 2022 to set the conditions for the resilience of salmon and people in a rapidly changing world. The NPAFC and the Hakai Institute, with support from the BC Salmon Restoration and Innovation Fund and the Tula Foundation, are reviewing approaches to data standardization to support the collection methods, storage, and analysis of data collected during the 2019 and 2020 high seas fishing expeditions, and a pan-pacific multi-vessel expedition planned for 2021. Through this review they will explore the feasibility of aligning the International Year of the Salmon collaborative project with the Global Ocean Observation System to measuring Essential Ocean Variables. The Global Ocean Observation System is a project of the United Nation's Intergovernmental Oceanographic Commission and unifies networks of scientists around the world. Adopting international standards such as the Ocean Biogeographic Information System, and FAIR (Findable, Accessible, Interoperable, Reusable) data principles that are widely recognized will ensure a multilateral approach to the standardization of salmon ocean ecology data.

The core components of the data management and communications model proposed by the Hakai Institute include: 1) a Data Catalogue that centralizes data access through a web portal; 2) Catalogue records compliant with ISO 19115 that make the datasets broadly discoverable; 3)

Open-access licensing; 4) Open Data Access Protocols, specifically ERDDAP data servers, where necessary and; 5) Controlled Vocabularies that define the variables, methods, units, and measurement types used in salmon ocean ecology adhering to 'Ocean Best Practices' maintained by the Global Ocean Observation System. Next steps include the development of a comprehensive Data Strategy, network building and engagement, and cyber-infrastructure development and integration. As such, NPAFC and Hakai (Brett Johnson) are actively seeking input into the project.

References

Agler, B.A., Ruggerone, G.T., Wilson, L.I., and F.J. Mueter. 2013. Historical growth of Bristol Bay and Yukon River, Alaska chum salmon (*Oncorhynchus keta*) in relation to climate and inter- and intraspecific competition. Deep-Sea Research II, 94, 165–177.

Anttila, K, AP Farrell, D Patterson, SG Hinch, and E Eliason. 2019. Cardiac SERCA activity in sockeye salmon populations: an adaptive response to migration conditions. Canadian Journal of Fisheries and Aquatic Sciences. 76(1): 1–5

Araki, H., Cooper, B. and M.S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biology Letters, 5, 621–624.

Amoroso, R. O., Tillotson, M. D., and R. Hilborn. 2017. Measuring the net biological impact of fisheries enhancement: pink salmon hatcheries can increase yield, but with apparent costs to wild populations. Canadian Journal of Fisheries and Aquatic Sciences, 74, 1233–1242.

Atlas, W. I., Selbie, D.T., Holt, C.A**.,** Cox-Rogers, S., Carr-Harris, C., Pitman, K.J., and Moore, J.W. In press. Landscape and biophysical controls of lake capacity to inform evaluation of sockeye salmon (*Oncorhynchus nerka*) populations in data-limited regions. Accepted 17 March, 2020. Limolology and Oceanography *in press*

Banet, AI, SJ Healy, EJ Eliason, EA Roualdes, DA Patterson, and SG Hinch. 2019. Simulated maternal stress reduces offspring aerobic swimming performance in Pacific salmon. Conservation Physiology. 7 (1), coz095, https://doi.org/10.1093/conphys/coz095

Bass, AR SG Hinch, AK Teffer, DA Patterson, and KM Miller. 2019. Fisheries capture and infectious agents are associated with travel rate and survival of Chinook salmon during spawning migration. Fisheries Research. 209:156–166

Batten, S.D., Ruggerone, G.T., and I. Ortiz. 2018. Pink Salmon induce a trophic cascade in plankton populations in the southern Bering Sea and around the Aleutian Islands. Fisheries Oceanography, 27, 548–559.

Beamish, R.J., and B.E. Riddell. 2020. Preliminary cruise plan for the second Gulf of Alaska expedition. NPAFC Doc. 1870. 9 pp.

Bottom, D. L., K. K. Jones, C. A. Simenstad, and C. L. Smith. 2009. Reconnecting social and ecological resilience in salmon ecosystems. Ecology and Society, 14(1), 5.

Brooks, JL, J Chapman, A Barkley, S Kessel, N Hussey, S. Hinch, DA Patterson, K Hedges, SJ Cooke, A Fisk, S Gruber, and VM Nguyen. 2019. Biotelemetry informing management: case studies exploring successful integration of biotelemetry data into fisheries and habitat management. Canadian Journal of Fisheries and Aquatic Sciences. 76(7): 1238–1252

Chilcote, M. W., K. W. Goodson and M. R. Falcy. 2011. Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. Canadian Journal of Fisheries and Aquatic Sciences 68(3): 511–522.

Christie, M. R., M. L. Marine, R. A. French and M. S. Blouin. 2011. Genetic adaptation to captivity can occur in a single generation. Proceedings of the National Academy of Sciences, 109, 238–242.

Cook, KV, SG Hinch, SM Drenner, GD Raby, DA Patterson, and SJ Cooke. 2019a. Dermal injuries caused by purse seine capture result in lasting physiological disturbances in coho salmon. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology. 227: 75–83.

Cook, KV, AJ Reid, DA Patterson, KA Robinson, JM Chapman, SG Hinch, and SJ Cooke. 2019b. A synthesis to understand responses to capture stressors among fish discarded from commercial fisheries and options for mitigating their severity. Fish and Fisheries. 20:25–43.

Cunningham, C. J., Westley, P. A. H., and M.D. Adkison. 2018. Signals of large scale climate drivers, hatchery enhancement, and marine factors in Yukon River Chinook salmon survival revealed with a Bayesian life history model. Global Change Biology, 24, 4399–4416.

Davis, N. D., Volkov, A. V., Efimkin, A. Y., Kuznetsova, N. A., Armstrong, J. L., and O. Sakai. 2009. Review of BASIS Salmon food habits studies. North Pacific Anadromous Fish Commission Bulletin, 5, 197–208.

Espinasse B, Hunt BPV, Doson Coll Y, Pakhomov EA (2018) Investigating high seas foraging conditions for salmon in the North Pacific: insights from a 100 year scale archive for Rivers Inlet sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences, https://doi.org/10.1139/cjfas-2018-0010.

Freshwater, C., S.C. Anderson, K.R. Holt, A.-M. Huang, and C.A Holt. 2019. Weakened portfolio effects constrain management effectiveness for population aggregates. Ecological Applications, 29:e01966. doi:10.1002/eap.1966

Freshwater, C., K.R. Holt, A.-M. Huang, and C.A Holt. 2020. Benefits and limitations of increasing the stock-selectivity of Pacific salmon fisheries. Fisheries Research, 226:105509. doi:10.1016/j.fishres.2020.105509

Grant, S.C.H, J.R. Irvine, T. Beacham, C. Freshwater, C. Holt, S.G. Hinch, A.M. Huang, B. Hunt, J. Pendray, J. Reynolds, and L.A. Vélez-Espino. 2020. Canadian bibliography of recent publications linked to the 2016–2020 NPAFC Science Plan. NPAFC Doc. 1910. 19 pp. Fisheries and Oceans Canada, University of British Columbia, and Simon Fraser University (Available at https://npafc.org)

Grant, SCH, BL MacDonald, and M Winston. 2019a. State of the Canadian Pacific salmon: Responses to changing climate and habitats. Can. Tech. Rep. Fish. Aquat. Sci. 3332. ix + 50 p. https://waves-vagues.dfo-mpo.gc.ca/Library/40807071.pdf

Grant, SCH, BL MacDonald, K Middleton, L Anderson, and L Sloan. 2019b. E-book: State of the Canadian Pacific salmon: Responses to changing climate and habitats. http://www.dfo-mpo.gc.ca/species-especes/publications/salmon-saumon/state-etat-2019/ebook/index-eng.html

Hanson, M. B., R. W. Baird, J. K. B. Ford, J. Hempelmann-Halos, D. M. Van Doornik, J. R. Candy, C. K. Emmons, G. S. Schorr, B. Gisborne, K. L. Ayres, S. K. Wasser, K. C. Balcomb, K. Balcomb-Bartok, J. G. Sneva and M. J. Ford. 2010. Species and stock identification of prey consumed by endangered southern resident killer whales in their summer range. Endangered Species Research, 11, 69–82.

Harding, J.M.S., Harding, J.N., Field, R.D., Pendray, J.E., Swain, N.R., Wagner, M.A. & Reynolds, J.D. (2019). Landscape structure and species interactions drive the distribution of

salmon carcasses in coastal watersheds. *Frontiers in Ecology & Evolution* 7,192. doi: 10.3389/fevo.2019.00192.
Holt, C.A. and Michielsens, C.G.J. 2019. Impacts of time-varying productivity on estimated stock-recruitment parameters and biological reference points. Can. J. Fish. Aquat. Sci. http://dx.doi.org/10.1139/cjfas-2019-0104
Holt, C.A., Rutherford, M.B., and R.M. Peterman. 2008. International cooperation among nation-states of the North Pacific Ocean on the problem of competition among salmon for a common pool of prey resources. Marine Policy, 32, 607–617.
Houde, ALS, A Akbarzadeh, S Li, DA Patterson, AP Farrell, SG Hinch, and KM Miller. 2019. Salmonid gene expression biomarkers indicative of physiological responses to changes in salinity, temperature, but not dissolved oxygen. Journal of Experimental Biology 222, doi:10.1242/jeb.198036
Houde ALS, AD Schulze, KH Kaukinen, J Strohm, DA Patterson, TD Beacham, AP Farrell, SG Hinch, and KM Miller. 2019. Transcriptional shifts during juvenile coho salmon (*Oncorhynchus kisutch*) life stage changes in freshwater and early marine environments. Comparative Biochemistry and Physiology Part D: Genomics and Proteomics. 29:32–42.
Houde, ALS, OP Günther, J Strohm, S Li, H Kaukinen, DA Patterson, AP Farrell, SG Hinch, and KM Miller. 2019. Discovery and validation of candidate smoltification gene expression biomarkers across multiple species and ecotypes of Pacific salmonids. Conservation Physiology 7(1) coz051
Hunt, B.P.V., B.T. Johnson, S.C. Godwin, M. Krkosek, E.A. Pakhomov, and L. Rogers. 2018. The Hakai Institute Juvenile Salmon Program: early life history of sockeye, pink and chum salmon in British Columbia, Canada. NPAFC Doc. 1788. 14 pp. Institute for the Oceans and Fisheries and Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Hakai Institute, Earth to Ocean Research Group, Simon Fraser University, Department of Ecology and Evolutionary Biology, University of Toronto, and Salmon Coast Field Station (Available at https://npafc.org).
Irvine, JR, S Akenhead, T Beacham, CM Deeg, SCH Grant, KD Hyatt, C Holt, BVP Hunt, BT Johnson, J King, KM Miller, and C Neville. 2019. Update on Canadian research relevant to the 2016–2020 NPAFC Science Plan. NPAFC Doc. 1841. 6 pp.
Iverson, SJ, AT Fisk, SG Hinch, JM Flemming, SJ Cooke, and FG Whoriskey. 2019. The Ocean Tracking Network: Advancing Frontiers in Aquatic Science and Management. Canadian Journal of Fisheries and Aquatic Sciences. 76(7): 1041–1051
Johnson, B.T., J.C.L. Gan, S.C. Godwin, M. Krkosek, and Hunt BPV. 2019. Juvenile salmon migration observations in the Discovery Islands and Johnstone Strait in British Columbia, Canada in 2018. NPAFC Doc. 1838. 25 pp. Hakai Institute, Institute for the Oceans and Fisheries and Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Earth to Ocean Research Group, Simon Fraser University, Department of Ecology and Evolutionary Biology, University of Toronto, and Salmon Coast Field Station (Available at https://npafc.org).
Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta*, populations released from Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Bull. 1: 90–102.
Kanigan, AM, SG Hinch, AL Bass, and W Harrower. 2019. Gillnet fishing effort predicts physical injuries on Sockeye Salmon captured near spawning grounds. North American Journal of Fisheries Management. 39(3):441–451

Little, AG, T Dressler, K Kraskura, E Hardison, B Hendriks, T Prystay, AP Farrell, SJ Cooke, DA Patterson, SG Hinch, and EJ Eliason. 2020. Maxed out: Optimizing accuracy, precision and power for field measures of maximum metabolic rate in fishes. Physiological and Biochemical Zoology https://doi.org/10.1086/708673

MacDonald, BL, SCH Grant, DA Patterson, KA Robinson, JL Boldt, K Benner, J King, L Pon, DT Selbie, CM Neville, and JA Tadey. 2019. State of the Salmon: Informing the survival of Fraser Sockeye returning in 2019 through life cycle observations. Can. Tech. Rep. Fish. Aquat. Sci. 3336: V + 60 p. https://waves-vagues.dfo-mpo.gc.ca/Library/40819103.pdf

Naydenko, S.V. 2009. The role of Pacific salmon in the trophic structure of the upper epipelagic layer of the western Bering Sea during summer–autumn 2002–2006. N. Pac. Anadr. Fish Comm. Bull. 5: 231–241.

Nelson, B. W., A. O. Shelton, J. H. Anderson, M. J. Ford and E. J. Ward. 2019. Ecological implications of changing hatchery practices for Chinook salmon in the Salish Sea. Ecosphere 10(11): e02922.

Neville, C.M., and J.R. King. 2020. Canadian juvenile salmon surveys in 2020–2021. NPAFC Doc. 1906. 12 pp.

NPAFC (North Pacific Anadromous Fish Commission). 2019. Report of the Proceedings for the IYS Workshop International Year of the Salmon Workshop, First International Year of the Salmon Data Laboratory (ISDL) Workshop, S. Akenhead, N. Bendriem, and J. Park (Eds.). NPAFC Tech. Bull. 14: 31pp. https://npafc.org/technical-report/

Nguyen, VM, N Young, M Corriveau, SG Hinch, and SJ Cooke. 2019. What is "usable" knowledge? Perceived barriers for integrating new knowledge into management of an iconic Canadian fishery. Canadian Journal of Fisheries and Aquatic Sciences. 76(3): 463–474

Peterman, R.M., Holt, C.A., and M.R. Rutherford. 2012. The need for international cooperation to reduce competition among salmon for a common pool of prey resources in the North Pacific Ocean. North Pacific Anadromous Fish Commission Technical Report, 8, 99–101.

Pakhomov, E.A, C. Deeg, S. Esenkulova, G. Foley, Hunt BPV, A. Ivanov, H.K. Jung, G. Kantakov, A. Kanzeparova, A. Khleborodov, C. Neville, V. Radchenko, I. Shurpa, A. Slabinsky, A. Somov, S. Urawa, A. Vazhova, P.S. Vishnu, C. Waters, L. Weitkamp, M. Zuev, and R. Beamish. 2019. Summary of preliminary findings of the International Gulf of Alaska expedition onboard the R/V *Professor Kaganovskiy* during February 16–March 18, 2019. NPAFC Doc. 1858. 25 pp. Canada, Japan, Korea, Russia, and USA (Available at https://npafc.org).

Prystay, TP, R de Bruijn, SG Hinch, DA Patterson, AP Farrell, EJ Eliason, and SJ Cooke. 2020. Cardiac performance of free-swimming wild sockeye salmon during the reproductive period. Integrative Organismal Biology: Integrative Organismal Biology, 2 (1) obz031, https://doi.org/10.1093/iob/obz031

Ruggerone, G. T., Agler, B. A., Connors, B. M., Farley, E. V. Jr, Irvine, J.R., Wilson, L. I. and E.M. Yasumiishi. 2016. Pink and sockeye salmon interactions at sea and their influence on forecast error of Bristol Bay sockeye salmon. North Pacific Anadromous Fish Commission Bulletin, 6, 349–361.

Ruggerone, G.T., and B.M. Connors. 2015. Productivity and life history of sockeye salmon in relation to competition with pink and sockeye salmon in the North Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences, 72, 818–833.

Ruggerone, G. T., and J.R. Irvine. 2018. Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 10, 152–168.

Ruggerone, G.T. and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Reviews in Fish Biology and Fisheries, 14, 371–90.

Ruggerone G.T., Zimmerman, M., Myers, K.W., Nielsen, J.L., and D.E. Rogers. 2003. Competition between Asian pink salmon (*Oncorhynchus gorbushca*) and Alaskan sockeye salmon (*O. nerka*) in the North Pacific Ocean. Fisheries Oceanography, 12, 209–19.

Shaul, L. D., and H. J. Geiger. 2016. Effects of climate and competition for offshore prey on growth, survival, and reproductive potential of Coho Salmon in Southeast Alaska. North Pacific Anadromous Fish Commission Bulletin 6, 329–347.

Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers and M. S. Webster 2010. Population diversity and the portfolio effect in an exploited species. Nature, 465 (7298), 609-612.

Shuntov, V. P., O. S. Temnykh, and O. A. Ivanov. 2017. On the persistence of stereotypes concerning the marine ecology of Pacific salmon (*Oncorhynchus spp.*). Russian Journal of Marine Biology 43, 1–28.

Stevenson, CF, AL Bass, NB Furey, KM Miller, S Li, EL Rechisky, AD Porter, DW Welch, and SG Hinch. 2020. Infectious agents and gene expression differ between sockeye salmon (*Oncorhynchus nerka*) smolt age groups but do not predict migration survival determined by telemetry. Canadian Journal of Fisheries and Aquatic Sciences. 77(3): 484–495

Stevenson CF, S. Hinch, AD Porter, EL Rechisky, DW Welch, SJ Healy, AG Lotto, and NB Furey. 2019. The influence of smolt age on freshwater and early marine behavior and survival of migrating juvenile sockeye salmon (*Oncorhynchus nerka*). Transactions of the American Fisheries Society. 148 (3): 636–651

Teffer, AK, Hinch, SG, Miller, KM, Jeffries, KM, Patterson, DA, Cooke, SJ, Farrell, AP, Kaukinen, KH, Li, S & F Juanes. 2019. Cumulative effects of thermal and fisheries stressors reveal sex-specific effects on infection development and early mortality of adult coho salmon (*Oncorhynchus kisutch*). Physiological and Biochemical Zoology 92(5):505–529.

Walsh, J.C., Pendray, J.E., Godwin, S.C., Artelle, K.A., Kindsvater, H.K., Field, R.D., Harding, J.N., Swain, N.R. & Reynolds, J.D. In Press (a). Relationships between Pacific salmon and aquatic and terrestrial ecosystems: a quantitative review. *Ecology*.

Walsh, J.C., Connors, K., Hertz, E., Kehoe, L., Martin, T.G., Connors, B., Freshwater, C., Frid, A., Halverson, J., Moore, J.W., Price, M.H.H. & Reynolds, J.D. In Press (b). Prioritizing conservation actions for Pacific salmon recovery. *Journal of Applied Ecology*

Ward, E., B. Hanson, L. Weitkamp and M. Ford. 2010. Modeling killer whale prey size selection based upon available data. Report prepared by Northwest Fisheries Science Centre, Seattle, WA

Young, N, SJ Cooke, SG Hinch, C DiGiovanni, M Corriveau, S Fortin, VM Nguyen, and AM. Solås. 2020. “Consulted to death”: personal stress as a major barrier to environmental co-management. Journal of Environmental Management: 254, 109820