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Canadian Bibliography of Recent Publications Linked to the 2016–2020 NPAFC Science Plan

by

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Abstract
The current bibliography lists publications in primary scientific journals and other documents published primarily during 2019 by Fisheries and Oceans Canada scientists and their collaborators relevant to the 2016–2020 NPAFC Science Plan. The bibliography lists 112 publications, many with abstracts, corresponding to the key research components of the NPAFC Science Plan.

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

The current bibliography lists recent publications in primary scientific journals and other documents published during by Fisheries and Oceans Canada scientific staff and their collaborators. These documents outline results from Canadian research relevant to the current NPAFC Science Plan. The bibliography lists publications, many with abstracts, corresponding to the first three research components of the Science Plan. Although each publication is listed under one research theme, some are relevant to more than one research theme.

Theme 1: Status of Pacific Salmon and Steelhead Trout

Grant, S.C.H., MacDonald, B.L., and Winston, M.L. 2019. State of Canadian Pacific Salmon: Responses to Changing Climate and Habitats. Can. Tech. Rep. Fish. Aquat. Sci. 3332. ix + 50 p. technical report: http://www.dfo-mpo.gc.ca/species-especes/publications/salmon-saumon/state-etat-2019/abstract-resume/index-eng.html e-book: http://www.dfo-mpo.gc.ca/species-especes/publications/salmon-saumon/state-etat-2019/ebook/index-eng.html

At DFO's first State of the Salmon meeting in 2018, scientists concluded that Canadian Pacific salmon and their ecosystems are already responding to climate change. Northeast Pacific Ocean warming trends and marine heatwaves like "The Blob" are affecting ocean food webs. British Columbia and Yukon air and water temperatures are increasing and precipitation patterns are changing, altering freshwater habitats. The effects of climate change in freshwater are compounded by natural and human-caused landscape change, which can lead to differences in hydrology, and increases in sediment loads and frequencies of landslides. These marine and freshwater ecosystem changes are impacting Pacific salmon at every stage of their life-cycle. Some general patterns in Canadian Pacific salmon abundances are emerging, concurrent with climate and habitat changes. Chinook numbers are declining throughout their B.C. and Yukon range, and Sockeye and Coho numbers are declining, most notably at southern latitudes. Salmon that spend less time in freshwater, like Pink, Chum, river-type Sockeye, and ocean-type Chinook, are generally not exhibiting declines. These recent observations suggest that not all salmon are equally vulnerable to climate and habitat change.

Irvine, J.R. 2017. Summary of non-coastal salmon catch data from the North Pacific Ocean. NPAFC Doc. 1716 (Rev. 1). 4 pp. (Available at https://npafc.org)

NPAFC. 2019. Report of the proceedings for the IYS Workshop: International Year of the Salmon Workshop on Salmon Status and Trends. Irvine, J.R., Chapman, K., Park, J., (editors). North Pacific Anadromous Fish Commission Technical Report 13. (Available at https://npafc.org)

A 2019 workshop attended by 25 international salmon experts and scientists with expertise in the Pacific, Atlantic, and Arctic oceans is summarised. Presentations on state changes and trends for Sockeye (Hyatt), Pink (Grant), Chum (Hertz), Chinook (Thiess), and Atlantic Salmon (Chaput) with incidental information for Steelhead, Coho, and Cherry Salmon. Legacy datasets were identified, state changes and trends were discussed in relation to potential drivers and mechanisms, and future work needs identified.

Workshop participants received a questionnaire shortly after the workshop. Results from the first section that dealt with abundance indicators found general consensus that pre-fishery abundance estimates are useful indicators of adult abundance in both the Pacific and the Atlantic, especially at the ocean and regional scales. The majority of respondents indicated that total aggregate catch and commercial catch were useful proxies of adult abundance in the Pacific at the ocean and regional scales only (except in Japan where they were identified as useful proxies at all scales because of very high commercial fishing). Concerns were raised around the reliability of catch data, and the potential masking influence of changes in fisheries management and regulations. In the Atlantic, as there are virtually no commercial fisheries remaining, catch data are not useful proxies for adult abundance. In the Arctic, subsistence harvest is the primary means by which salmon abundance is monitored; salmon are a bycatch. However bycatch data and their utility are limited. In both the Pacific and the Atlantic, juvenile abundance indices were useful abundance proxies for individual populations, recognizing the post-smolt mortality events have not yet occurred. The majority disagreed with their usefulness for assessing abundance at ocean and regional scales (all disagreed in the case of the Atlantic).

The 2nd and 3rd sections of the questionnaire examined indices of survival, distribution, and productivity and data quality respectively. Survival, distribution, and productivity metrics were considered essential by all to assess state changes and trends in both the Atlantic and Pacific. The importance of incorporating local and aboriginal knowledge on survival, distribution, and productivity was recognized in the Pacific, Atlantic, and Arctic. The value of biological trait information in assessing state changes and trends at all scales was recognised in both the Pacific and the Atlantic. Finally, there was agreement in both the Pacific and Atlantic of the importance of standardizing datasets, defining data standards, documenting uncertainty and assumptions, highlighting differences between self-reporting and catch monitoring, providing transparency about whether and how uncertainty is included in models, and providing and describing metadata.

Price, M.H.H., Connors, B.M., Candy, J.R., McIntosh, B., Beacham, J.D., Moore, J.W., Reynolds, J.D. 2019. Genetics of century-old fish scales reveal population patterns of decline. Conservation Letters 2019; e12669. https://doi.org/10.1111/conl.12669

Conservation scientists rarely have the information required to understand changes in abundance over more than a few decades, even for important species like Pacific salmon. Such lack of historical information can underestimate the magnitude of decline for depressed populations. We applied genetic tools to a unique collection of 100-year-old salmon scales to reveal declines of 56%–99% in wild sockeye populations across Canada's second largest salmon watershed, the Skeena River. These analyses reveal century-long declines that are much greater than those based on modern era abundance data, which suggested that only 7 of 13 populations declined over the last five decades. Populations of larger-bodied fish have declined the most in abundance, likely because of size-selective commercial fisheries. Our findings illustrate how a deep historical perspective can expand our understanding of past abundances to a time before species incurred significant losses from fishing, and help inform conservation for diminished populations.

McKinnell, S. 2018. Modelling salmon migration as a mixture problem. Can. J. Fish. Aquat. Sci. 76: 856–870 (2019) dx.doi.org/10.1139/cjfas-2017-0546

Pulses of abundance in salmon migrations can arise from single populations arriving at different times, from multiple populations with different timing characteristics, or as a combination of these. Daily observations typically record an aggregate measure of abundance passing some location rather than the abundances of the individual components. An objective method is described that partitions a compound migration into its component parts by exploiting differences in the characteristics of each pulse. Simulated data were used to demonstrate when greater model complexity may be desirable. Three case studies of increasing complexity (Chilko Lake sockeye salmon smolts (*Oncorhynchus nerka*), large adult Columbia River Chinook salmon (*Oncorhynchus tshawytscha*), Fraser River salmon test fishery) demonstrate how the model can be applied in practice. Results indicated that Chilko Lake smolts rarely emigrate to sea as a single pulse, that the dates used to distinguish the spring run of Chinook salmon in the Columbia River may be overestimating its abundance, and that pulses of sockeye salmon abundance in a Fraser River ocean test fishery in 2014 may have arisen from some factor other than population composition.

Michielsens, C.G.J, and Cave, J.D. 2019. In-season assessment and management of salmon stocks using a Bayesian time–density model. Can. J. Fish. Aquat. Sci. 76: 1073–1085 dx.doi.org/10.1139/cjfas-2018-0213

We document a time–density model for in-season assessment of salmon stocks that integrates both relative and absolute indicators of abundance and incorporates preseason information on run size and migration timing using a Bayesian framework. We evaluate different data collection programs for Fraser River sockeye salmon (*Oncorhynchus nerka*) by examining the precision, bias, and timeliness of resulting run-size estimates with a retrospective analysis of 20 years of data. We quantify the run-size bias if migration was early versus late and evaluate the impact of run-size uncertainty on the ability to reach management objectives. In-season assessments greatly improve the accuracy and precision of run-size estimates compared with preseason forecasts. For the in-season assessment of Fraser River sockeye, catch-per-unit-effort (CPUE) data from seaward marine test fisheries, although less precise, were more informative at the peak marine migration than more precise terminal, in-river hydroacoustic data obtained on the same date due to the time lag associated with migration from the marine test fishing locations to the lower river. Throughout the season, the best fisheries management results were obtained by relying on in-season assessments using both marine CPUE data as well as marine reconstructed abundance estimates derived from in-river hydroacoustic estimates, thereby taking advantage of the benefits of both sources of information.

Wade, J., and Irvine, J.R. 2018. Synthesis of smolt and spawner abundance information for coho salmon from South Coast British Columbia Streams. Can. Manuscr. Rep. Fish. Aquat. Sci. 3161: vi + 39 p. http://publications.gc.ca/collections/collection_2018/mpo-dfo/Fs97-4-3161-eng.pdf

Theme 2: Pacific Salmon and Steelhead Trout in a Changing North Pacific Ocean

Banet, A.I., Healy, S.J., Eliason, E.J., Roualdes, E.A., Patterson, D.A., Hinch, S.G. 2019. Simulated maternal stress reduces offspring aerobic swimming performance in Pacific salmon. Conservation Physiology. 7 (1), coz095, https://doi.org/10.1093/conphys/coz095

Batten, S.D., Ruggerone, G.T., and Ortiz, I. 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.

We examined the hypothesis of top-down (predator) control of plankton populations around the Aleutian Islands and in the southern Bering Sea using a 15 year time series (2000–2014) of plankton populations sampled during summer by Continuous Plankton Recorders. Our analyses reveal opposing biennial patterns in abundances of large phytoplankton and copepods. This pattern is likely caused by the predation pressure on copepods from biennially abundant eastern Kamchatka Pink Salmon that results in a trophic cascade. In odd years, Pink Salmon are exceptionally abundant, large copepod abundance is low, and abundance of large diatoms grazed by copepods is high. Furthermore, large copepod abundance was inversely correlated, and diatom abundance was positively correlated, with Pink Salmon abundance. In addition to influencing the abundance of diatoms and large copepods we also report an effect on phytoplankton taxonomic composition. We find regional differences in the expression of these effects with alternating odd/even year patterns being strongest in the central Southern Bering Sea and eastern Aleutians and reduced, or absent, in the western Aleutians. When the abundance of 2013 Pink Salmon was unexpectedly low, there were consequent changes in the plankton populations, with highest recorded numbers in the time series of large copepods and microzooplankton (hard-shelled ciliates). These findings emphasise the importance of variability in predator abundance and its effect across the ecosystem, which in this case was greater than physical oceanographic variability.

Beacham, T.D., Wallace, C., Jonsen, K., McIntosh, B., Candy, J.R., Willis, D., Lynch, C., and Withler, R.E. 2019. Variation in migration pattern, broodstock origin, and family productivity of coho salmon hatchery populations in British Columbia, Canada derived from parentage-based tagging. Ecology and Evolution 2019:9:9891–9906.

In salmonid parentage-based tagging (PBT) applications, entire hatchery broodstocks are genotyped, and subsequently progeny can be non-lethally sampled and assigned back to their parents using parentage analysis, thus identifying their hatchery of origin and brood year (i.e. age). Inter- and intra-population variability in migration patterns, life history traits, and fishery contributions can be determined from PBT analysis of samples derived from both fisheries and escapements (portion of a salmon population that does not get caught in fisheries and returns to its natal river to spawn). In the current study of southern British Columbia coho salmon (*Oncorhynchus kisutch*) populations, PBT analysis provided novel information on intra-population heterogeneity among males in the total number of progeny identified in fisheries and escapements, the proportion of progeny sampled from fisheries versus escapement, the proportion of two-year old progeny (jacks) produced, and the within-season return time of progeny. Fishery recoveries of coho salmon revealed heterogeneity in migration patterns among and within populations, with recoveries from north and central coast fisheries distinguishing ‘northern migrating’ from ‘resident’ populations. In northern-migrating populations, the mean distance between fishery captures of sibs (brothers and sisters) was significantly less than the mean distance between non-sibs, indicating the possible presence of intra-population genetic heterogeneity for migration pattern. Variation among populations in productivity and within populations in fish catchability indicated that population selection and broodstock management can be implemented to optimize harvest benefits from hatcheries. Application of PBT provided valuable information for assessment and management of hatchery-origin coho salmon in British Columbia.

Boldt, J.L., Leonard, J., and Chandler, P.C. (Eds.). 2019. State of the physical, biological and
selected fishery resources of Pacific Canadian marine ecosystems in 2018. Can. Tech. Rep. Fish.
Aquat. Sci. 3314: vii + 248 p. https://waves-vagues.dfo-mpo.gc.ca/Library/4081306x.pdf

Crozier, W., Whelan, K., Buoro, M., Chaput, G., Daniels, J., Grant, S.C.H., Hyatt, K., Irvine, J., Ó'Maoiléidigh, N., Prévost, E., Rivot, E., Russell, I., Schmidt, M., and Wells, B.. 2018. Atlantic salmon mortality at sea: Developing an evidence-based "Likely Suspects" Framework. Based on a workshop organised by the Atlantic Salmon Trust, held in Edinburgh, 6-8 November 2017. Atlantic Salmon Trust Blue Fisheries Book. www.atlanticsalmontrust.org

DFO. 2020. Recovery Potential Assessment for Fraser River Sockeye Salmon (*Oncorhynchus nerka*) – Nine Designatable Units – Part 1: Probability of Achieving Recovery Targets. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/012. 30 pp. https://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2020/2020_012-eng.pdf

This Science Advisory Report covers the recovery targets and modelling elements for the Recovery Potential Assessment for 9 Endangered or Threatened Fraser Sockeye DUs, plus an additional 3 DUs of Special Concern for which there are long term stock-recruit time series available. A tenth Endangered DU (Cultus Lake Sockeye) is covered in a separate paper. Two nested recovery targets are proposed for the DUs, with Recovery Target #1 approximating the objective that a DU that would not be characterized as Endangered or Threatened by COSEWIC or as the Red biological status of the Wild Salmon Policy (WSP) and Recovery Target #2 approximating the objective of COSEWIC for Not At Risk or WSP Green. Stock-specific stock-recruit models that account for recent productivity were used in a simulation model to evaluate the likelihood of DUs reaching the two Recovery Targets over the next three generations (12 years) over a wide range of mortality rates. A method for evaluating impacts of the Big Bar landslide on the six impacted DUs was explored, and the impacts from a range of future changes in productivity were modelled for all DUs.

Espinasse B, Hunt B.P.V., Doson Coll Y., Pakhomov E.A. (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.

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. We used carbon and nitrogen stable isotopes (SI) from salmon scales to reconstruct aspects of the marine environment experienced by Rivers Inlet sockeye salmon (*Oncorhynchus nerka*) over the last century (1915–2016). Time series of SI compositions of salmon scales showed a greater variability after 1950, probably linked to more dynamic high seas environmental conditions. However, climate indices (e.g., Pacific Decadal Oscillation, El Niño Southern Oscillation) did not explain the SI variability. We assessed the time series with respect to changes in food web dynamics, including shifting trophic baselines, changes in prey–salmon diet, and changes in salmon foraging location. A significant correlation ($r = 0.53$) between sea surface temperature and $\delta^{13}C$ enabled us to define the area of potential salmon distribution in the open ocean for approximately 9 months prior to sampling. This method shows high potential for stock-specific high seas distribution mapping that could be combined with prey isotope values to inform stock-specific foraging experience.

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.**

The disproportionate effects of some species can drive ecosystem processes and shape communities. This study investigates how distributions of spawning Pacific salmon within streams, salmon consumers, and the surrounding landscape mediate the distribution of salmon carcasses to riparian forests and estuaries. This work demonstrates how carcass transfer can vary spatially, within and among watersheds, through differences in pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon distributions within 16 streams on the central coast of British Columbia over a five-year period. Spawning pink salmon concentrated in the lower reaches of all streams, whereas chum salmon shifted from lower to upper stream reaches as the area of spawning habitat increased. Salmon carcasses transferred to riparian areas by gray wolves (*Canis lupus*) were concentrated in estuaries and lower stream reaches, particularly shallow reaches of larger streams surrounded by large meadow expanses. Black and grizzly bears (*Ursus americanus* and *U. arctos*) transferred higher numbers and proportions of salmon carcasses to riparian areas compared to wolves, transferred more carcasses in areas of higher spawning density, and tended to focus more on chum salmon. Riparian subsides were increasingly driven by bear-chum salmon associations in upper stream reaches. In addition, lower proportions of salmon carcasses were exported into estuaries when densities of spawning salmon were lower and spawning reaches of streams were longer. This study demonstrates how salmon subsidies vary between and within watersheds as a result of species associations and landscape traits, and provides a nuanced species-specific and spatially explicit understanding of salmon-subsidy dynamics.

Houde, A.L.S., A. Akbarzadeh, S. Li, D.A. Patterson, A.P. Farrell, S.G. Hinch, and K.M. 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 A.L, A.D. Schulze, K.H. Kaukinen, J. Strohm, D.A. Patterson, T.D. Beacham, AP. Farrell, S.G. Hinch, and K.M. 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, A.L.S., O.P. Günther, J. Strohm, S. Li, H. Kaukinen, D.A. Patterson, A.P. Farrell, S.G. Hinch, and K.M. 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).

The Hakai Institute Juvenile Salmon program is an ongoing initiative that was established in 2015 in partnership with the University of British Columbia, University of Toronto, Simon Fraser University and Salmon Coast Field Station. This program researches the early life history of juvenile salmon in coastal British Columbia. Primary research objectives are determining: 1) Migration timing rates and routes; 2) Migration habitat, including physical and chemical oceanographic conditions, and availability of plankton prey; 3) The impacts of prey phenology, quantity and quality on juvenile salmon growth and condition; 4) Species and stock specific feeding biology and competitive interactions; 5) Pathogen and parasite infection dynamics; and 6) Mortality estimates. The program targets Fraser River sockeye, and pink and chum salmon, but additionally provides information on coho, chinook and herring through incidental capture. The field program operates between May and July during the peak of the juvenile sockeye outward migration. Purse seine and oceanographic sampling is conducted in the northern Strait of Georgia / Discovery Islands region (~ 220 km from the Fraser River mouth) and the Johnstone Strait / Queen Charlotte Strait region (~ 180 km from the northern Strait of Georgia. As such, this program informs early life history across two critical legs of the Fraser salmon northward migration.

Irvine, J.R., S. Akenhead, T. Beacham, C.M. Deeg, S.C.H. Grant, K.D. Hyatt, C. Holt, B.V.P. Hunt, B.T. Johnson, J. King, K.M. Miller, and C. Neville. 2019. Update on Canadian research relevant to the 2016–2020 NPAFC Science Plan. NPAFC Doc. 1841. 6 pp. (Available at https://npafc.org)

Irvine, J.R., T. Beacham, M. Trudel, C. Neville, K. Dunmall, and S.C.H. Grant. 2018. Canadian bibliography of 2012–2018 publications linked to the 2016–2020 NPAFC Science Plan. NPAFC Doc. 1787. 42 pp. (Available at https://npafc.org)

Johnson, B.T., J.C.L. Gan, C.V. Janusson, and Hunt BPV. 2018. Juvenile salmon migration dynamics in the Discovery Islands and Johnstone Strait; 2015–2017. NPAFC Doc. 1790. 10 pp. Hakai Institute, Institute for the Oceans and Fisheries and Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia (Available at https://npafc.org)

The majority of out-migrating juvenile Fraser River salmon (*Oncorhynchus spp.*) pass northwest through the Strait of Georgia, the Discovery Islands, and Johnstone Strait. The Discovery Islands to Johnstone Strait leg of the migration is a region of poor survival for sockeye salmon

(*Oncorhynchus nerka)* relative to the Strait of Georgia. High resolution spatiotemporal measurements of migration timing and abundance of juvenile sockeye salmon and the relative species composition of co-migrating juvenile salmon are needed to understand the factors influencing early marine survival through this region. Here we report on migration dynamics in the Discovery Islands to Johnstone Strait region based on purse seine data collected by the Hakai Institute Juvenile Salmon Program from 2015–2017. The peak migration period in the Discovery Islands in which 50 % of sockeye passed through occurred between May 25 and June 4 and in Johnstone Strait between May 30 and June 12. Peak abundance was observed earlier than normal in 2015 and 2016, likely due to anomalously warm winter and spring weather. Sockeye migrated at 2.0 BL•s-1 between the Discovery Islands and Johnstone Strait based on the peak migration date in each region, faster than the 1.1 BL•s-1 observed in the Strait of Georgia. Sockeye abundance was much lower in 2017 compared to 2015 and 2016. Species composition was dominated by sockeye in 2015 and 2016, and by chum *(Oncorhynchus keta)* in 2017.

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).

The Hakai Institute Juvenile Salmon Program has been monitoring juvenile salmon migrations in the Discovery Islands and Johnstone Strait since 2015 with the specific purpose to understand how ocean conditions experienced by juvenile salmon during their early marine migration impacts their growth, health and ultimately survival. We found that during the two of the warmest years of sea-surface temperature recorded in British Columbia, juvenile sockeye, pink, and chum left the Strait of Georgia one to two weeks earlier than previously. The temporal distribution of sockeye migration timing out of the Strait of Georgia north through the Discovery Islands was skewed right, indicating that many sockeye migrate together in late May and abundance tails off late into June and July. Pink and chum migrations are more protracted, lasting from early May to late July. Our results indicate that juvenile sockeye exit the Strait of Georgia en masse, likely in response to ocean temperature and foraging conditions. This report summarizes migration timing, fish length and weight, sea-louse loads, purse seine catch composition, and ocean temperatures observed from the first four years of this research and monitoring program. Combining key variables from this research program with observations from freshwater and high-seas sampling will provide, for some stocks, a complete account of the conditions salmon experience during their migration from their natal river to the high seas. These measures will further our knowledge of what drives early marine mortality, and better our understanding of how salmon are adapting to climate change.

MacDonald, B.L., Grant, S.C.H., Patterson, D.A., Robinson, K. A.., Boldt, J.L., Benner, K., King, J., Pon, L., Selbie, D.T., Neville, C.E.M., and J.A. 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: 61 + vi pp. https://waves-vagues.dfo-mpo.gc.ca/Library/40819103.pdf

The 2019 Fraser Sockeye Science Integration workshop brought experts together to compile and integrate environmental and biological observations spanning the life cycle of four year old Fraser sockeye returning in 2019. The goals of this process are to improve our understanding of factors influencing Fraser Sockeye survival, and to provide advice on survival and abundances of these stocks in the upcoming return year. This process concluded that the four year old Fraser Sockeye cohort returning in 2019 will continue to exhibit survival that is lower than the 64 year average. Four year old Fraser sockeye returning in 2019 experienced notably warm conditions through most of their freshwater residence. This includes well above average Fraser River temperatures during the upstream migration of their parents, and warm water temperatures during egg and juvenile freshwater rearing stages. During the winter prior to their downstream migration as smolts, some environments encountered by the 2019 return cohort transitioned to more typical conditions. Freshwater temperatures and hydrology patterns were closer to average, and some physical and biological processes in the Northeast Pacific Ocean began to transition to more favourable conditions for fish growth. However, similar to the previous few years, warm water southern species continued to dominate the zooplankton composition in nearshore and offshore Vancouver Island surveys, providing a sub-optimal food source, compared to cold water northern zooplankton species.

NPAFC 2019. Second NPAFC-IYS Workshop on Salmon Ocean Ecology in a Changing Climate. Park, J. & Tessier, L., editors. North Pacific Anadromous Fish Commission Technical Report 15. (Available at https://npafc.org)

The International Year of the Salmon (IYS; https://yearofthesalmon.org) is an international framework for collaborative outreach and research, and seeks to increase understanding and raise awareness of the challenges facing salmon and the measures to support their conservation and restoration against increasing environmental variability. The overarching theme of the IYS is "Salmon and People in a Changing World", and the proposed research themes are (1) status of salmon; (2) salmon in a changing salmosphere; (3) new frontiers: (4) human dimension; and (5) information systems. These five research themes are integrated into the current NPAFC Science Plan (2016–2020), whose goal is to understand variations in Pacific salmon production in a changing climate (https://npafc.org/science-plan/). The North Pacific Anadromous Fish Commission (NPAFC), in a partnership with Salmon Ocean Ecology Meeting (SOEM), hosted the Second NPAFC-IYS Workshop on "Salmon Ocean Ecology in a Changing Climate" on May 18–20, 2019 at the Embassy Suite by Hilton Portland Downtown, Portland, OR, USA.

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).

The international expedition to the Gulf of Alaska was the first large-scale, integrated winter pelagic ecosystem research survey, with a particular focus on Pacific salmon. The expedition covered an area of approximately 700,000 km2 between February 16 and March 18, 2019. The research team of 21 included scientists from Canada, Japan, Korea, Russia and the United States of America and was a major contribution to the International Year of the Salmon Program. The expedition leader, Dr. Richard Beamish of Canada, secured funding for the expedition from both governmental organizations and private individuals. The intent of the expedition was to demonstrate that international collaboration could be effective, to provide baseline measurements of major pelagic ecosystem components including abundance of Pacific salmon in the Gulf of Alaska in the winter season and to test key hypotheses on factors regulating salmon survival in the ocean during their seasonal activities. In total, 423 salmon (223 chum, 93 coho, 73 sockeye, 31 pink, and 3 Chinook salmon) were caught during trawl survey. In addition, two coho salmon caught with a live-box were tagged with NPAFC disc tags and released in the eastern Gulf of Alaska. Content below provides an overview of samples collected and some preliminary results from the survey.

Pitman, K.L., J.W. Moore, M.R. Sloat, A.H. Beaudreau, A.L. Bidlack, R.E. Brenner, E.W. Hood, G.R. Pess, N.J. Mantua, A.M. Milner, V. Radic, G.H. Reeves, D.E. Schindler, and D.C. Whited. 2020. Glacier Retreat and Pacific Salmon. BioScience: 70(3): 220–236.

Glaciers have shaped past and present habitats for Pacific salmon (*Oncorhynchus spp*.) in North America. During the last glacial maximum, approximately 45% of the current North American range of Pacific salmon was covered in ice. Currently, most salmon habitat occurs in watersheds in which glacier ice is present and retreating. This synthesis examines the multiple ways that glacier retreat can influence aquatic ecosystems through the lens of Pacific salmon life cycles. We predict that the coming decades will result in areas in which salmon populations will be challenged by diminished water flows and elevated water temperatures, areas in which salmon productivity will be enhanced as downstream habitat suitability increases, and areas in which new river and lake habitat will be formed that can be colonized by anadromous salmon. Effective conservation and management of salmon habitat and populations should consider the impacts of glacier retreat and other sources of ecosystem change.

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. Relationships between Pacific salmon and aquatic and terrestrial ecosystems: a quantitative review. Ecology (in press).

Pacific salmon influence temperate terrestrial and freshwater ecosystems through the dispersal of marine-derived nutrients and ecosystem engineering of stream beds when spawning. They also support large fisheries, particularly along the west coast of North America. We provide a comprehensive synthesis of relationships between the densities of Pacific salmon and terrestrial and aquatic ecosystems, summarize the direction, shape, and magnitude of these relationships, and identify possible ecosystem-based management indicators and benchmarks. We found 31 studies that provided 172 relationships between salmon density (or salmon abundance) and species abundance, species diversity, food provisioning, individual growth, concentration of marine-derived isotopes, nutrient enhancement, phenology, and several other ecological responses. The most common published relationship was between salmon density and marine-derived isotopes (40%), while very few relationships quantified ecosystem-level responses (5%). Only 13% of all relationships tended to reach an asymptote (i.e. a saturating response) as salmon densities increased. The number of salmon killed by bears and the change in biomass of different stream invertebrate taxa between spawning and non-spawning seasons were relationships that almost consistently reached saturation. Approximately 46% of all relationships were best described with linear or curved non-asymptotic models, indicating a lack of saturation. In contrast, 41% of datasets showed no relationship with salmon density or abundance, including many of the relationships with stream invertebrate and biofilm biomass density, marine-derived isotope concentrations, or vegetation density. Bears required the highest densities of salmon to reach their maximum observed food consumption (i.e. 9.2 kg m-2 to reach 90% threshold of the relationship's asymptote), followed by freshwater fish abundance (90% threshold = 7.3 kg m-2 of salmon). While the effects of salmon density on ecosystems are highly varied, it appears that several of these relationships, such as bear food consumption, could be used to develop indicators and benchmarks for ecosystem-based fisheries management.

Theme 3: New Technologies

Anttila, K., A.P. Farrell, D. Patterson, S.G. 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

Brown, C.J., Parker, B., Hocking, M.D. & Reynolds, J.D. Use of satellite imagery to detect effects of salmon nutrients on trees. *Science of the Total Environment* (in press).

Little, A.G, Dressler, T, Kraskura, K, Hardison, E., Hendriks B., Prystay, T. Farrell, A.P., Cooke, S.J., Patterson, D.A., Hinch, S.G., and Eliason, E.J. 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.

Prystay, T.P, de Bruijn, R., Peiman, K.S., Hinch, S.G., Patterson, D.A., Farrell, A.P., Eliason, E.J., and Cooke, S.J. 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

Rechisky, E.L., and D.W. Welch. 2018. Report on the RAFOS Ocean Acoustic Monitoring (ROAM) Workshop (June 7–8, 2018, Woods Hole, MA). Available from erin.rechisky@kintama.com

Stevenson, C.F., A.L. Bass, N.B. Furey, K.M. Miller, S. Li, E.L. Rechisky, A.D. Porter, D.W. Welch, and S.G. 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 C.F., S.G. Hinch, A.D. Porter, E.L. Rechisky, D.W. Welch, S.J. Healy, A.G. Lotto, and N.B. 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

Theme 4: Management Systems

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. Limnology and Oceanography

Landscape models are increasingly used to classify and predict the structure and productivity of data-limited aquatic ecosystems. One such suite of ecosystems is on the remote North and Central Coast (NCC) of British Columbia, where sockeye salmon (*Oncorhynchus nerka*) rear in more than 150 lakes. Given their remoteness, and limited resources for assessment, limnological and population monitoring in many of these lakes has been periodic, or absent, limiting understanding of the status of populations and their habitats. Lake photosynthetic rate (PR) estimates are foundational to models of sockeye salmon nursery lake productive capacity. Using data from 61 lakes across the NCC, we compared a suite of landscape and lake variables in an information theoretic framework producing a set of models relating these characteristics to lake PR. A categorical variable related to lake biogeochemistry—whether a lake is humic stained, clear, or glacially turbid—was the most important variable predicting lake PR and was included in all models. Lake surface area relative to upstream catchment size and lake perimeter to surface area ratio were also important, with smaller upstream catchments yielding higher production, and high shoreline complexity correlated with lower productivity as measured by limnetic PR. Model averaged coefficient values yielded the most accurate predictions of PR, based on leave-one-outcross validation, allowing predictions of PR in 96 other lakes currently lacking limnological assessments. These landscape-scale models therefore represent a valuable starting point for evaluating lake-specific carrying capacities for data-poor sockeye salmon populations under Canada’s Wild Salmon Policy.

Bass, A.R, S.G. Hinch, A.K. Teffer, D.A. Patterson, and K.M. 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

Beamish, R.J. (Ed.). 2018. The Ocean Ecology of Pacific salmon and Trout. American Fisheries Society, Bethesda, Maryland.

Introduction: An Overview of the Ocean Ecology of Pacific Salmon and Trout (Richard J. Beamish)

1. Ocean Ecology of Pink Salmon (Vladimir I. Radchenko, Richard J. Beamish, William R. Heard, and Olga S. Temnykh)

2. Ocean Ecology of Chum Salmon (Shigehiko Urawa, Terry D. Beacham, Masa-aki Fukuwaka, and Masahide Kaeriyama)

3. Ocean Ecology of Sockeye Salmon (Edward V. Farley, Jr., Terry D. Beacham, and Alexander V. Bugaev)

4. Ocean Ecology of Coho Salmon (Richard J. Beamish, Laurie A. Weitkamp, Leon D. Shaul, and Vladimir I. Radchenko)

5. Ocean Ecology of Chinook Salmon (Brian R. Riddell, Richard D. Brodeur, Alexander V. Bugaev, Paul Moran, James M. Murphy, Joseph A. Orsi, Marc Trudel, Laurie A. Weitkamp, Brian K. Wells, and Alex C. Wertheimer)

6. Ocean Ecology of Masu (Cherry) Salmon
6.1 Masu Salmon Group (Kentaro Morita)

6.2 General Biology of Masu Salmon (Kentaro Morita)

6.3 Ocean Life History of Masu Salmon from Ocean Entry to Upstream Migration (Toru Nagasawa)

6.4 Ocean Survivals and Abundance (Yasuyuki Miyakoshi)

7. Ocean Ecology of Steelhead (Katherine W. Myers)

8. Ocean Ecology of Anadromous Coastal Cutthroat Trout (William G. Pearcy, Richard D. Brodeur, Stewart M. McKinnell, and James P. Losee)

9. Methods Used to Study the Ocean Ecology of Pacific Salmon and Trout
9.1 Physical Oceanography Sampling Techniques (Thomas Royer)

9.2 Micronekton and Fish Sampling (Nancy D. Davis)

9.3 High-Seas Pacific Salmon Tagging (Masa-aki Fukuwaka and Robert V. Walker)

9.4 Methods for Pacific Salmon Scale Studies (Nancy D. Davis)

9.5 Otolith Marking (Dion S. Oxman, Kevin W. McNeel, and Andrew R. Munro)

9.6 Genetic Stock Identification of Pacific Salmon (Lisa W. Seeb, William D. Templin, Christopher Habicht, Fred M. Utter, and James E. Seeb)

9.7 Methods for the Analysis of Diet and Food Consumption Rates of Pacific Salmon in the Marine Environment (Marc Trudel, Strahan Tucker, Alexander V. Zavolokin, and Richard D. Brodeur)

9.8 Pacific Salmon Stock Assessment (James R. Irvine)

Cook, K.V., S.G. Hinch, S.M. Drenner, G.D. Raby, D.A. Patterson, and S.J. Cooke. 2019. 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, K.V., A.J. Reid, D.A. Patterson, K.A. Robinson, J.M. Chapman, S.G. Hinch, and S.J. Cooke. 2019. 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.

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

Population diversity can reduce temporal variability in aggregate population abundances in a process known as the portfolio effect. Portfolio effects may weaken, however, due to greater synchrony among component populations. While weakened portfolio effects have been previously documented, the consequences of reduced stability on meeting conservation goals for population aggregates that are harvested (e.g., stock aggregates in fisheries) are rarely quantified. Here, we demonstrate how changes in variability within components, synchrony among components, and population productivity interact to influence the probability of achieving an array of management objectives for Fraser River sockeye salmon: a stock aggregate of high economic, ecological, and cultural value. We first present evidence that component variability and synchrony have increased over the last two decades, consistent with a weakening portfolio effect. We then parameterize a stochastic, closed-loop model that simulates the population dynamics of each stock, the fishery that harvests the stock aggregate, and the management framework used to establish mixed-stock exploitation rates. We find that while median aggregate abundance and catch through time were relatively insensitive to greater aggregate variability, catch stability and performance metrics associated with achieving management targets generally declined as component variability and synchrony increased. A notable exception we observed is that harvest control means that scale exploitation rates based on aggregate abundance may be more effective as synchrony increases. Reductions in productivity led to broad declines in performance, but also moderated the impacts of component variability and synchrony on the proportion of component stocks above management targets and catch stability. Our results suggest that even precautionary management strategies that account for declines in productivity may underestimate risk, particularly to socioeconomic objectives, if they fail to consider changes in aggregate variability. Adequately incorporating changes in portfolio effect strength may be particularly relevant when developing recovery strategies that are robust to climate change, which is likely to increase synchrony and component variability.

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

Population diversity can stabilize ecological dynamics and increase resilience to future environmental change. In exploited systems, however, management goals to preserve diversity may be in tension with harvest objectives. For example, fisheries managers may forgo opportunities to sustainably harvest abundant populations to reduce risks to less productive populations. Increasing the stock selectivity of fisheries is one management lever that may allow for both conservation- and catch-based objectives to be met. We developed a model that simulates the dynamics of a Pacific salmon stock aggregate and its fishery to evaluate how changing allocations between mixed- and single-stock fisheries influences management performance. We focused on relatively generic management strategies that may be implemented in a range of salmon fisheries. Additionally, we examined how the relative performance of mixed- and single-stock fisheries may change under alternative ecological and management scenarios. We found that increasing single-stock fishery allocations increased aggregate abundance and improved the status of some stocks relative to their conservation benchmarks. However, these improvements did not occur uniformly–relatively abundant, productive stocks exhibited no change, or even declines, in conservation performance as single-stock fishery allocations increased. Furthermore, differences in performance between mixed- and single-stock fisheries were reduced when productivity was uniformly low, when the mixed-stock fishery was managed conservatively, or when mortality during freshwater migrations was high. While single-stock fisheries can increase the probability that conservation-based objectives will be met, they are not a panacea and may only be effective when specific conditions are met.

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

Models with time-varying parameters are increasingly being considered in the assessment of fish stocks, but their reliability when used to derive biological reference points or benchmarks has not been thoroughly evaluated. Here, we evaluated stock-recruitment models with and without time-varying productivity in a simulation framework for sockeye salmon (*Oncorhynchus nerka*) under different scenarios of productivity and exploitation. Ignoring trends in productivity led to overestimates of productivity and underestimates of capacity when both exploitation rates and productivity declined over time, resulting in an underestimation on average of benchmarks of biological status. Despite being less biased, time-varying models had relatively poor fit based on AICc and BIC model selection criteria. Our simulation results were compared with empirical analyses of 12 Fraser River sockeye salmon stocks in British Columbia, Canada. Although benchmarks were less biased based on time-varying models, underlying true benchmarks based on spawner abundances at maximum sustainable yield, SMSY, trend downwards when productivity declines, which may not be aligned with conservation objectives. We conclude with best practices when adapting biological benchmarks to time-varying productivity.
Keywords: time-varying productivity, stock-recruitment model, benchmarks, biological reference points, Ricker model, Kalman filter, sockeye salmon, Fraser River, simulation

Kanigan, A.M., S. G. Hinch, A. L. Bass, and W. L 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

Oke, K.B., Cunningham, C.J., Westley, P.A.H., Baskett, M.L., Carlson, S.M., Clark, J., Hendry, A.P., Karatayev, V.A., Kendall, N.W., Kibele, J., Kindsvater, H.K., Kobayashi, K.M., Lewis, B., Munch, S., Reynolds, J.D., Vick, G.K., and Palkovacs, E.P. Accelerating declines in salmon body size impact ecosystems and people. *Nature Communications* (accepted pending revision).

Teffer, A.K., Hinch, S.G., Miller, K.M., Jeffries, K.M., Patterson, D.A., Cooke, S.J., Farrell, A.P., Kaukinen, K.H., Li, S. and 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.

Vélez-Espino, L.A., Parken, C.K., Clemons, E.R., Peterson, R., Ryding, K., Folkes, M., and Pestal, G. 2019. ForecastR: tools to automate procedures for forecasting of salmonid terminal run and escapement. Final Report submitted to the Southern Boundary Restoration and Enhancement Fund, Pacific Salmon Commission, Vancouver BC. 117 p. Available Online: https://www.psc.org/publications/fund-backgrounders-final-reports/#453-information-1501025108

The annual exercise of forecasting annual returns to natal streams is a critical aspect of management and conservation of Pacific salmon. This project involves the enhancement and further development of a computer program (henceforth called ForecastR) primarily in response to recommendations to the PSC in 'Review of Methods for Forecasting Chinook Salmon Abundance in the Pacific Salmon Treaty Areas' (Peterman et al. 2016). ForecastR relies on the open-source statistical software R (R Core Team 2018) to generate age-specific (or total abundance) forecasts of salmon escapement or terminal run using a variety of generic models and enabling users to perform interactive tasks with the help of a Graphical User Interface (GUI). These tasks include: (a) the selection of forecasting approaches from a wide set of statistical and/or mechanistic models for forecasting terminal run and escapement ; (b) the selection of several measures of retrospective forecast performance (e.g., MRE, MAE, MAPE, MASE, RMSE); (c) the comparison of forecasting models and model selection and ranking; and, (d) the reporting of forecasting results (point forecasts and interval forecasts) and diagnostics by producing either detailed reports or executive-summary reports. The original design of ForecastR involved the generation of age-specific or total-abundance forecasts using several forecasting approaches, including: (i) simple and complex sibling regressions with the ability to include environmental/biological covariates; (ii) time series models such as ARIMA, exponential smoothing, and naïve models (based on preceding 1 year, 3 years or 5 years in abundance time series); and (iii) mechanistic models such as average return rate models that depend on auxiliary data such as the number of outmigrant juveniles, the number of hatchery fish released or the number of spawners in previous years. For both age-structured and non-age-structured data, AIC-based model selection (Burnham and Anderson 2002) takes place within model types (e.g., ARIMA and exponential smoothing) prior to model ranking across model types based on the abovementioned metrics of retrospective evaluation. The latest release, 'forecastR_phase4', incorporated improvements and refinements to the GUI and incorporated a Kalman-Filter sibling regressions module to consider the effects on forecasts of potential trends in survival and/or maturity. The inclusion in ForecastR of a Kalman filter module responded to recommendations to the PSC in Peterman et al. (2016). In addition, two important developments took place during this phase of the ForecastR project: (1) the code has been converted into and R-package to facilitate distribution of the program, allow optimal tracking of functions, and provide the ideal environment for future development; and, (2) an html-based *Shiny* application has been produced to allow online forecasting exercises. Progress was made also on two other forecasting approaches, namely the complex-sibling-regression module and the return-rate mechanistic module. These two modules will be incorporated in the future and made available in a new ForecastR release.

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. Prioritizing conservation actions for Pacific salmon recovery. Journal of Applied Ecology (in press).

Current investment in conservation is insufficient to adequately protect and recover all ecosystems and species. The challenge of allocating limited funds is acute for Pacific salmon (Oncorhynchus spp.) in Canada, which lack a strategic approach to ensure that resources are spent on actions that would cost-effectively recover diminished populations. We applied the Priority Threat Management framework to prioritize strategies that are most likely to maximize the number of thriving Pacific salmon populations on the Central Coast of British Columbia, Canada. These included 79 genetically, ecologically and spatially distinct population groups called Conservation Units (CUs) for five salmon species. This region has high salmon biodiversity and spans the territories of four First Nations: the Heiltsuk, Nuxalk, Kitasoo/Xai'xais and Wuikinuxv. Using structured expert elicitation of Indigenous and other experts, we quantified the estimated benefits, costs and feasibility of implementing 10 strategies. Under a business-as-usual scenario (i.e., no additional investments in salmon conservation or management), experts predicted that only one in four CUs would have >50% chance of achieving a thriving status within 20 years. Limiting future industrial development, which was predicted to safeguard CUs from future declines, was identified as the most cost-effective strategy. Investment in three strategies: 1) removal of artificial barriers to fish migration, 2) watershed protection, and 3) stream restoration – at 11.3M CAD per year – was predicted to result in nearly half (34 of 79) of the CUs having a >60% chance of meeting the conservation objective. If all conservation strategies were implemented, experts estimated a >50% probability of achieving a thriving status for 78 of 79 CUs, at an annual cost of 17.3M CAD. However, even with the implementation of all strategies, most sockeye salmon CUs were unlikely to achieve higher probability targets of reaching the objective. Policy implications: We illustrate how Priority Threat Management can incorporate the perspectives and expertise of Indigenous peoples and other experts to evaluate and prioritize conservation strategies

Theme 5. Integrated Information Systems

Brooks, J.L., Chapman, J., Barkley, A., Kessel, S., Hussey, N., Hinch, S.G., Patterson, D.A., Hedges, K., Cooke, S.J., Fisk, A., Gruber, S., and Nguyen, V.M. 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

Iverson, S.J., Fisk, A.T., Hinch, S.G., Mills Flemming, J., Cooke, S.J., and Whoriskey, F.G. 2019. The Ocean Tracking Network: Advancing Frontiers in Aquatic Science and Management. Canadian Journal of Fisheries and Aquatic Sciences. 76(7): 1041–1051

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. Rep. 14: 31pp. (Available at https://npafc.org)

Leading salmon ecologists and information technologists met to discuss the modernization of data processing in the context of salmon research and management. Salmon data processing problems are not unique; the problems of data assembly, cleaning, standardization, integration, and reproducible analyses are universal, and solutions from leading edge of information technology are applicable to salmon problems. Experiments to apply these new technologies to salmon datasets and analyses—hence the International Salmon Data Laboratory (ISDL)—were discussed as next steps. Participants expressed interest in communicating what they had learned about the efficacy of labeled graph databases to other salmon research fora and to granting agencies.

In order for salmon ecologists to improve the resilience of salmon to unmitigated anthropic climate change, a paradigm shift is required: from monitoring, passive conservation, optimal harvesting, and enhancement to predicting how salmon will respond to changes that exceed the range of historical observations. To be useful, that new prediction ability must be translated into effective actions; salmon managers need to be fully informed and able to react quickly to surprising events.

The International Year of the Salmon (IYS) has presented this as a challenge for the world to respond to. ISDL is one response, with initial support from DFO (Fisheries & Oceans Canada), IYS, and Neo4j Inc. (Graphs For Good). The workshop asked *what* information flow the salmon ecologists need, and *how* that can be successfully delivered. Reliable prediction ability requires mechanistic models as opposed to correlations. Developing and applying those models requires:

- A new perspective on what drives salmon population dynamics.
- Assembling and integrating an unprecedented breadth and depth of information about salmon and the habitats they encounter.
- Modernization of salmon data processing from field collections to integration and analysis.
- Mobilizing data for improved decision support.
- Effective knowledge transfer from scientists to policy makers.

Nguyen, V.M., Young, N., Corriveau, M., Hinch, S.G., and Cooke, S.J. 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

Young, N, S.J. Cooke, Hinch, S.G., DiGiovanni, C., Corriveau, M., Fortin, S., Nguyen, V.M., and Solås, A.M. 2020. "Consulted to death": personal stress as a major barrier to environmental co-management. Journal of Environmental Management. 254, 109820