Proven Potential of Integrated Ecosystem Research in Expanding Human Understanding of the High Seas Environment

By Moronke Harris
Assistant IYS Coordinator, North Pacific Region
2019 NPAFC Intern

Moronke Harris was born and raised in land-locked Richmond Hill, Ontario, and joins the NPAFC from the Environmental and Community Health Services sectors of the Regional Municipality of York. In 2017, she graduated with a BSc (Honours) in Biological Science at the University of Guelph (Guelph, Ontario), where she completed studies on furunculosis and cold-water disease diagnosis in brook and rainbow trout. An aspiring oceanographic biogeochemist, Moronke strongly believes that observation of the largely unexplored ocean offers unmatched opportunity for revolutionary discoveries and scientific advances. Her research placements have taken her from studying climate engineering tactics in the Bermudian ocean, to the hydrochemical effects of Floridian seagrass beds on ocean acidification mitigation. Moronke is positioned at the NPAFC as Assistant International Year of the Salmon Coordinator. As a Supporting Member of the British Columbia High Seas Research Council, she facilitates 2019 International Gulf of Alaska High Seas Expedition hydrochemical data processing, and preparation for the 2021 International Pan-Pacific High Seas Expedition. Moronke aims to pursue a MSc and PhD in Oceanography.

In the autumn of 2019, the North Pacific Anadromous Fish Commission (NPAFC; npafc.org) successfully completed three days of meetings (October 19–21) associated with the 2019 annual the North Pacific Marine Science Organization (PICES) conference in Victoria, BC, Canada. Significant funding was provided by the British Columbia Salmon Restoration and Innovation Fund (BCSRIF). As an integral part of the International Year of the Salmon (IYS; yearofthesalmon.org) initiative led by the NPAFC in the North Pacific and the North Atlantic Salmon Conservation Organization (NASCO; nasco.int) in the North Atlantic, two workshops during the three days convened oceanographers, ichthyologists, climatologists, and resource managers from around the Pacific Rim and abroad to: (i) explore findings from the ground-breaking 2019 winter expedition to the Gulf of Alaska (GoA), the first comprehensive winter expedition examining Pacific salmon in the GoA that successfully established a baseline of environmental and ecosystem-level measurements for future comparisons; and (ii) plan for an expanded Pan-Pacific expedition in March of 2021.

2019 International GoA Expedition

The high seas pelagic ecosystems of the North Pacific support six species of Pacific salmon; chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), sockeye (*Oncorhynchus nerka*), pink (*Oncorhynchus gorbuscha*), Chinook (*Oncorhynchus tshawytscha*) and masu (*Oncorhynchus masou*) salmon. During winter, approximately 55 million salmon, spanning all species but the Asian endemic masu, inhabit the GoA. Despite the importance of this region, the vast majority of previous salmon research has focused solely on freshwater and coastal habitats. The present scarcity of baseline data on salmonids in the GoA adds uncertainty to the already challenging task of forecasting returns and predicting salmon behavior and responses to the changing North Pacific ecosystem. Communities and resource managers around the Pacific Rim are challenged to understand the impacts of an increasingly uncertain climate on the distribution and productivity of these culturally and economically important fish. New knowledge is required to determine how climate uncertainty is affecting distribution and productivity across scales

from coastal to high seas, as well as how human intervention through hatchery production impacts the structure of North Pacific ecosystems in relation to carrying capacity.

To bridge the knowledge gap concerning salmon overwintering conditions, the NPAFC as part of the IYS and along with NGOs, governments, academic and private partners, conducted a high seas expedition with scientists from around the Pacific Rim in winter 2019. The International GoA Expedition was completed with 21 scientific personnel from the five NPAFC member countries (Canada, Japan, the Republic of Korea, the Russian Federation, and the United States of America) aboard the chartered 62 m Russian R/V *Professor Kaganovskiy* (Figure 1, Figure 2). Organized by Richard J. Beamish, the Pacific Salmon Foundation (PSF) and NPAFC with funding from private individuals, government agencies and NGOs, it was the first in decades to study salmon in the winter high seas and set a precedent for addressing gaps in our knowledge through survey work concerning salmon, plankton, hydrochemical and physical conditions in the central GoA (Figure 3). The expedition covered an area of approximately 700,000 km^2 between February 16 and March 18, 2019 (Figure 1). In total, 425 salmon (223 chum, 95 coho, 73 sockeye, 31 pink, and three Chinook salmon) were caught during the trawl surveys.

Though the overarching objective was to test key hypotheses on factors regulating salmon survival in the open ocean during the critical overwintering period of their life history, the intent of the expedition was threefold:

i. to demonstrate that international collaboration among scientists from salmon producing countries could be used to effectively investigate factors regulating marine survival of Pacific salmon in shared international waters;

ii. to identify the stock specific rearing areas for all species of salmon, as well as their abundances and condition in order to test the hypothesis that the survival rate of salmon is mostly determined by conditions experienced during the first ocean winter; and

iii. to provide baseline measurements of environmental parameters and major pelagic

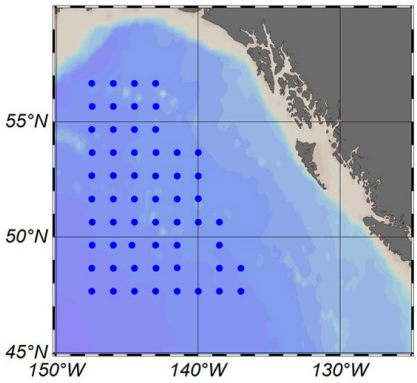

Figure 1. *Left: R/V Professor Kaganovskiy. Photo credit: PSF. Right: 58 expedition survey stations sampled between February and March 2019 in the GoA (Pakhomov et al. 2019).*

Figure 2. *Members of the 2019 International GoA scientific team on board the R/V Professor Kaganovskiy at the departure event in Vancouver, BC, Canada (February 16, 2019). Left: From the left, Gennady Kantakov (Russia), Shigehiko Urawa (Japan), Evgeny Pakhomov (Canada) and Igor Shurpa (Russia). Right: From the left, Laurie Weitkamp (USA), Chrys Neville (Canada), Christoph Deeg (Canada) and Hae Kun Jung (Korea). Photo credit: PSF*

ecosystem components including the abundance of Pacific salmon in the GoA in the winter season.

With these findings, scientists hope to create a strong research baseline for future expeditions leading to a program of coordinated integrated surveys across the entire North Pacific that will investigate the mechanisms affecting salmon distribution and productivity. The results of the 2019 survey will directly inform planning for tentative surveys in the GoA in March 2020 and across the full breadth of the North Pacific in 2021. In time, these efforts will provide communities and resource managers with the timely scientific advice needed to manage salmon and ecosystems in a rapidly changing world.

GoA Survey Results: PICES 2019 W16

W16: Developing a collaborative, integrated ecosystem survey program to determine climate/ ocean mechanisms affecting the productivity and distribution of salmon and associated pelagic fishes across the North Pacific Ocean

On October 19–20, 2019, the NPAFC co-hosted a two-day workshop, which was co-sponsored by the PICES, NPAFC and the North Pacific Fisheries Commission (NPFC; npfc.int). W16 centered around results of the 2019 International GoA Expedition. Presentations were given by representatives from a wide variety of expedition partner organizations including Fisheries and Oceans Canada (DFO), National Oceanic and Atmospheric Administration (NOAA) Fisheries, NPAFC, the Pacific Branch of the Russian Federal Research Institute of Fisheries and Oceanography (TINRO), PSF, the University of British Columbia (UBC), the University of Victoria (UVic) and Hokkaido National Fisheries Research Institute (HNF) of Japan Fisheries Research and Education Agency (FRA), and included members of the 2019 GoA scientific team. In total, W16 brought 24 researchers and multiple participants from over six countries together to network, discuss, and share their respective research (Figure 4).

I. Water Dynamics and Chemistry

Spanning approximately 10° latitude (47 to 57°N) and longitude (138 to 148°W), the GoA study area encompassed the eastern extreme of the North Pacific Current, the Sub-Arctic Current, and the beginning of the northbound Alaskan Current. These dynamics produced clear spatial variation in water conditions and biota catches across the study area (Figure 5). Temperature and salinity showed inverse N-S gradients. The cooler, saltier waters were located at the northwestern part of the grid and the warmest, freshest waters in the southeastern grid

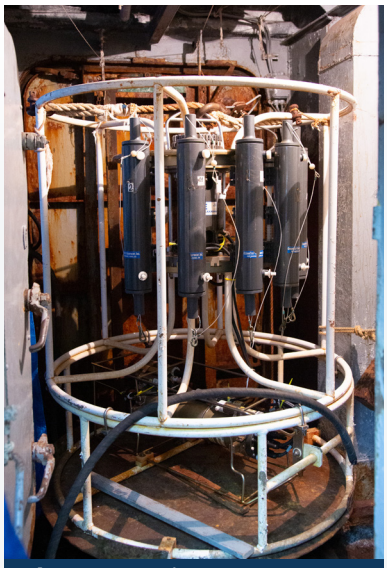

Figure 3. *Niskin rosette used to collect sea surface Particulate Organic Matter at every station as part of the food web biogeochemistry analysis via collection of stable carbon and nitrogen isotopes and fatty acids of all pelagic food web components in the GoA. Photo credit: PSF*

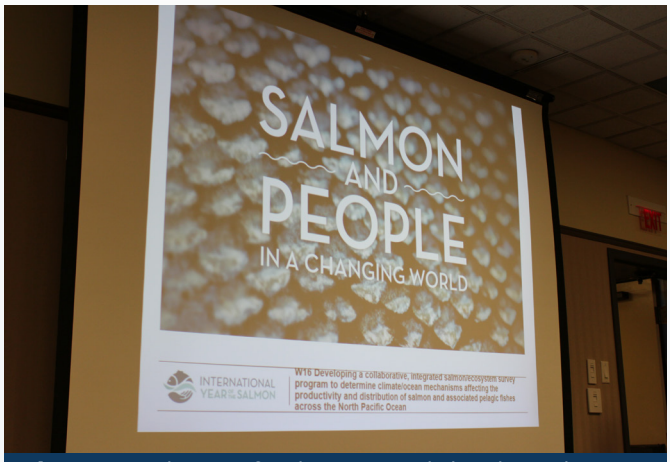

Figure 4. *Title page for the W16 workshop hosted at the PICES 2019 Annual Meeting in Victoria, BC, Canada, October 19–20, 2019. Photo credit: Stephanie Taylor, IYS*

Figure 5. *Anna Vazhova (Russia) delivered a presentation concerning the "Nutrients and oxygen distribution in the open part of the GoA in winter 2019". These hydrochemical observations made it possible to identify the areas of heightened productivity and assess the state of the ecosystem. Photo credit: PSF*

corner (Figure 6).

Two domains were determined within the surveyed area. The first domain was located in the northwestern part of the area, where the cyclonic circulation of the Subarctic gyre provided high concentrations of dissolved oxygen and nutrients. The second domain was influenced by both Subarctic front and the coastal processes that forms its transformed waters of the GoA. In this area, oxygen content and pre-vegetative concentrations of nutrients were lower. Below the thermocline (~200 m), the maximum concentrations of silicate, ammonium, dissolved phosphate and nitrogen were observed within the centre of Subarctic gyre, therefore being the highest at the northwestern section of the grid. Concentrations of these macronutrients decreased southward, being lowest at the southeastern parts of the grid. Highest and lowest nutrient concentrations closely tracked the coldest and warmest parts of the survey, respectively (Figure 6; Figure 7).

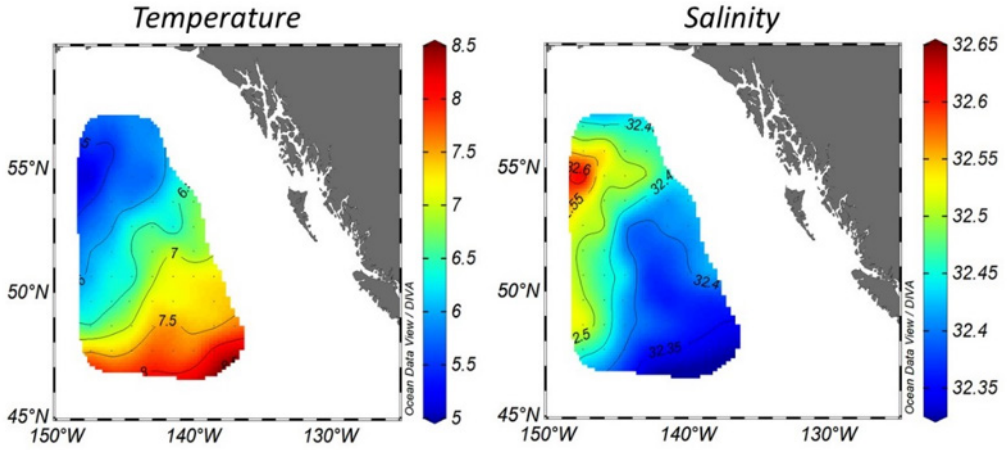

Figure 6. *Surface temperature and salinity of the GoA survey area from February to March of 2019. Colder and warmer parts of the survey were demarcated by a surface 7°C isotherm boundary (Pakhomov et al. 2019).*

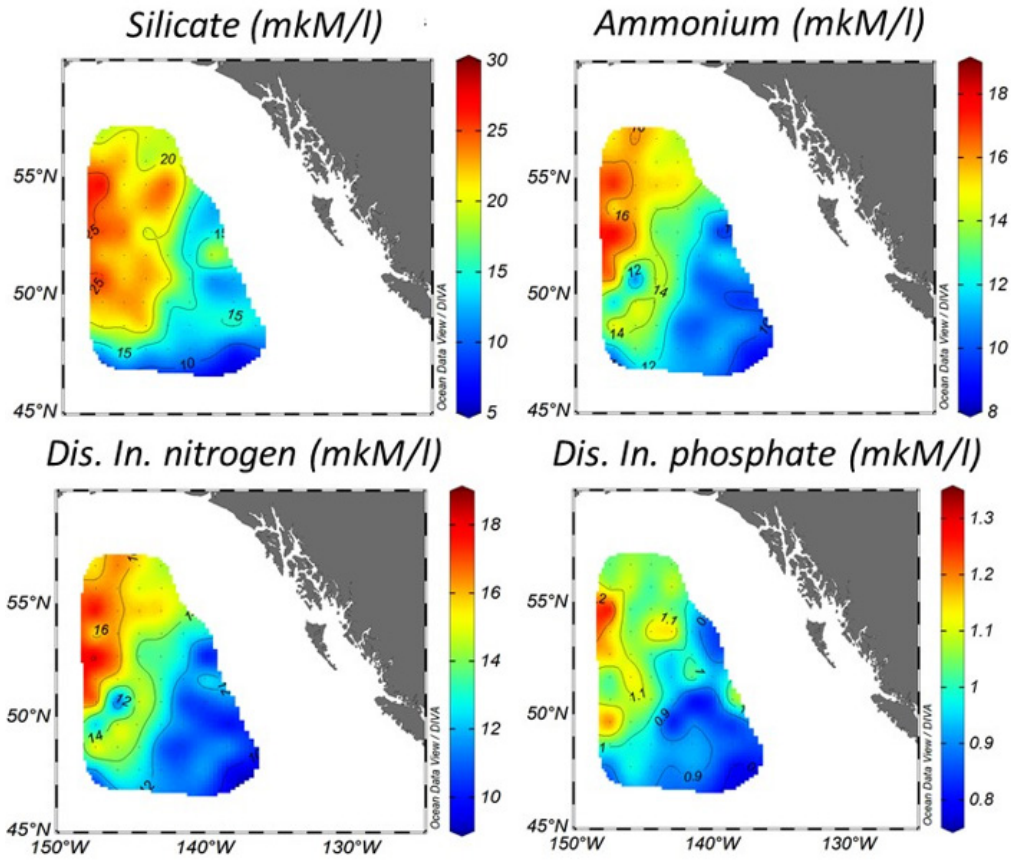

Figure 7. *Surface distribution of macronutrients during February–March 2019 in the GoA (Pakhomov et al. 2019).*

II. Salmonid Distributions and Genetic Stock Identification

The scientific results of the winter 2019 survey also revealed that salmon species distributions in the GoA differed and appeared to correlate with the environmental characteristics of water masses such as higher or lower ambient temperatures as well as productivity, mesozooplankton composition and macroplankton/micronekton distributional patterns (Table 1). Most surprising was the abundance of coho within the center of the GoA, given they were previously thought to be coastal in distribution, and the appearance of North American sockeye in the small set of western North Pacific samples taken as the R/V *Professor Kaganovskiy* made the journey from Russia to Canada to begin the 2019 expedition. Novel genomic tools allowed researchers to conduct at-sea DNA analyses for stock identification as well as assess physiological condition and test for the presence of pathogens for the first time. Interestingly, stock composition was largely independent of capture site, suggesting that distant stocks do not segregate according to origin but instead readily mix within the open ocean. For example, chum salmon of both Asian and North American origin co-mingled in the survey area (Figure 8). Genetic stock identification (GSI) using a Pacific-wide single nucleotide polymorphism baseline indicated a mixture of 20% Japanese, 20% Russian and 60% North American chum salmon.

III. Future Directions

Several discussions on new perspectives and ideas generated by the presentations were held between sessions. Participants suggested additional considerations and improvements for future expeditions including sampling eDNA at greater depths to better understand vertical distribution of species, installing cameras in the trawl nets to determine if predators enter and exit the net during sets, having dedicated marine mammal and bird observers on board and determining the vertical migration of salmon during the day and night. More on the preliminary results of the 2019 International GoA Expedition can be found at yearofthesalmon.org/gulf-of-alaska-expedition.

2021 International Pan-Pacific Expedition

Building on the successful single vessel expedition conducted from February to March 2019 in the GoA, a 2021 International Pan-Pacific Expedition has been proposed. If implemented, it will employ up to five research vessels operating simultaneously to survey the full breadth of the North Pacific Ocean (NPO) in winter 2021. These vessels will carry leading scientists from Canada, Japan, the Republic of Korea, the Russian Federation, and the United States of America committed to answering questions concerning mechanisms affecting the productivity and distribution of salmon. This expedition will provide a platform for international collaborative ecosystem research to monitor the distribution, abundance, and productivity of salmon—information that will directly inform fisheries management and enforcement decisions to be made in an increasingly uncertain future.

At the present time, notional requests for vessels are being considered by the five NPAFC member countries. Three or four vessels will cover a pan-Pacific grid, consisting of five regions for simultaneous sampling of biophysical oceanography and biota on a grid of stations that are spaced at 60 nautical mile intervals, while it has been proposed to have another vessel conduct fine-scale research to provide greater detail on our

Table 1. Survey area dominance, frequency of occurrence in trawl catches, estimated numbers and biomass of Pacific salmon species in the upper epipelagic layer (0–30 m) throughout the investigated area in the GoA during winter 2019 at a catchability coefficient (q) of 0.3 (Pakhomov et al. 2019).

Salmon Species	Survey Area Dominance	Frequency of Occurrence (%)	Numbers (million fish)	Biomass (thousand tons)
Chum (*Oncorhynchus keta*)	widely distributed	55.2	24.17	26.96
Coho (*Oncorhynchus kisutch*)	southern and westerly stations	37.9	13.59	10.37
Sockeye (*Oncorhynchus nerka*)	northern stations	31.0	8.94	10.28
Pink (*Oncorhynchus gorbuscha*)	southern and westerly stations	17.2	4.21	1.63
Chinook (*Oncorhynchus tshawytscha*)	rarely and sporadically occurred	5.17	0.37	1.32

Figure 8. *Shigehiko Urawa (Japan) gave a presentation titled "Origins and status of chum salmon caught in the GoA in the winter of 2019". Although chum salmon were widely distributed within the survey area, they were relatively abundant in southern warm waters (average sea-surface temperature 6.7°C). GSI indicated a mixture of Japanese, Russian and North American chum salmon, as well as demonstrating that the majority of Japanese chum salmon were distributed south of 52°N. Fifteen percent of chum salmon displayed a "skinny" physical condition (Condition Factor < 0.9), most of which were ocean age 2 or 3 and originated from North America and Asia. It is unknown whether the condition of these underweight salmon will recover in the following spring/summer season. Photo credit: Stephanie Taylor, IYS*

understanding of how salmon interact with the high seas environment (Figure 9). In conjunction with the 2021 winter surveys, the NPAFC member countries will conduct coastal and high seas salmon surveys during the spring, summer, and fall of 2020–2021. Several hypotheses will be employed to examine how increasingly extreme climate variability in the NPO and the associated changes in the physical environment will influence the population distribution patterns, migration, growth, survival and fitness of Pacific salmon, and dependent human populations.

The 2021 Expedition is being planned primarily by agencies of the five NPAFC member countries. However, successful implementation of the Canadian role in the 2021 Pan Pacific High Seas Research Expedition will be facilitated by the British Columbia High Seas Research Council. Members include invited scientific and executive representatives from IYS partner organizations spanning academia, governments, First Nations and industry.

2021 High Seas Planning Workshop

On October 21, 2019, a third day of meetings

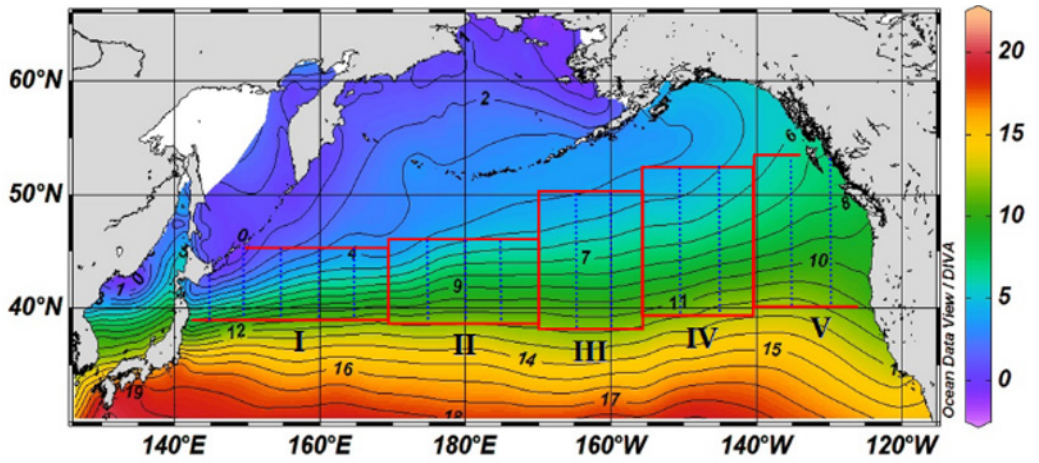

Figure 9. *The proposed five region survey area for the 2021 International Pan-Pacific Expedition. Image credit: NPAFC*

hosted by the NPAFC at Ocean Networks Canada (ONC) resulted in preliminary survey plans involving a minimum four vessels operating simultaneously in the winter of 2021. Similarly to the successful workshop held at PICES 2019, invited participants included scientific, government, and NGO personnel from the five NPAFC member countries.

Central to the 2021 International Pan-Pacific Expedition initiative is the intention that all five countries will develop the overarching program in conjunction, with scientific collaborators from all countries pursuing a survey design that will enable testing of hypotheses regarding mechanisms affecting the current and future salmon distribution and productivity in the North Pacific. This includes the provision of ship time, hypotheses and standardized methods of data collection, analysis, and storage.

At ONC, following the presentations of key aspects of the planned expedition by facilitators, Mark Saunders (IYS, NPAFC) and Mark Winston (Simon Fraser University), attendants readily contributed to discussions for the following development points:

i. Formulate highest priority hypotheses for the 2021 Expedition

ii. Evaluate current survey logistics (consider the efficacy of potential designs and their capability in providing accurate forecasts)

iii. Advise the redesigning of expedition logistics if necessary (identify new data, new analyses, new participants, and new research to include in the process)

iv. Strategize specific methods for international data integration and coordinated analysis

v. Clarify the compelling connection between 2021 efforts and management in survey rationale

The workshop and associated activities were intended to increase collaboration and build linkages and synergies among scientists from around the Pacific Rim. Ultimately, multi-nation surveys of the high seas will provide the missing science that will allow humans to both understand the mechanisms that drive salmon productivity and effectively manage salmon in a highly uncertain future.

Effectiveness of International Collaboration

The defining feature of both the PICES 2019 and ONC high seas expedition workshops, as well as the 2019 survey was the enthusiasm that the international team of ocean and salmon scientific experts from around the Pacific Rim displayed. The excitement was palpable as they revealed novel findings from winter 2019 and began planning for an unprecedented suite of surveys to cover the entire NPO in 2021:

"*This has been a really wonderful experience [because of] how well everyone is working together…the level of enthusiasm [displayed by] everybody has been fantastic*"—Laurie Weitkamp, NOAA, USA

"*We have a baseline that has never been available before, we have observations about species distributions that we cannot explain right now.*"—Richard Beamish, DFO Emeritus, Canada

"*I believe that [aside from] our scientific findings, this will bring our nations closer [diplomatically].*"—Arkadii Ivanov, TINRO, Russia

"*Being able to work in real time with [international] scientists, looking at similar questions [of interest] from around the North Pacific is fabulous…it's very, very exciting.*"—Chrys Neville, DFO, Canada

Pacific salmon are an important cultural, commercial and biological resource for British Columbia and countries of the North Pacific Rim. As a changing climate and associated anomalous events within the large marine ecosystems of the NPO progressively expose Pacific salmon to conditions that are outside standard climate cycles, society will be confronted by new, augmented resource management issues. International collaboration facilitates a large-scale exchange of information, experience and capacity to most efficiently and effectively address the significant gap in our understanding of rapidly changing climate/ocean processes in the high seas and how they impact salmon. With high seas monitoring and research capacity there is the potential to understand mechanisms affecting survival across the full life history and make sound short term (in-season) or longer-term decisions that can utilize climate projections of changing marine distribution and productivity. In addition, knowledge of changing distribution will be important to effective and affordable high seas enforcement and informing

investments in restoration and hatcheries.

IYS: Salmon and People in a Changing World

Both the 2019 and 2021 expeditions are Signature Projects of the IYS. The IYS is a five year initiative (2018–2022) of the NPAFC and its North Atlantic partner, NASCO, aiming to establish a new hemispheric-scale partnership of governments, Indigenous Peoples, academia, NGOs and industry to effectively address the scientific and social challenges facing salmon and people in an increasingly uncertain environment. The IYS can be found on Twitter, Facebook and Instagram.

Acknowledgements

Many thanks to PICES, ONC, NPFC, Vladimir Radchenko (NPAFC Executive Director) and the extended North Pacific IYS team: Mark Saunders (IYS Director), Stephanie Taylor (IYS High Seas Expeditions Coordinator) and Laura Tessier (IYS Coordinator). The NPAFC sincerely acknowledges their dedication and contribution to facilitating and steering the October 2019 workshop activities. In addition, many thanks to the tremendous efforts of IYS partners, international scientists and media professionals without whom these meetings would not have taken place.

References

Pakhomov, E.A, C. Deeg, S. Esenkulova, G. Foley, B.P.V. Hunt, 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. N. Pac. Anadr. Fish Comm. Doc. 1858. 25 pp. (Available at https://npafc.org)

Chinook and coho salmon collected during the 2019 International GoA Expedition. Photo credit: Chrys Neville, DFO and Svetlana Esenkulova, PSF