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North Pacific Anadromous Fish Commission
Science Plan 2016–2022

by

The Science Sub-Committee (SSC)
The Committee on Scientific Research and Statistics (CSRS)

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North Pacific Anadromous Fish Commission Science Plan 2016–2022

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EXECUTIVE SUMMARY

The Science Sub-Committee (SSC) of the North Pacific Anadromous Fish Commission (NPAFC) was charged with developing a new NPAFC Science Plan (2016–2022) that would be integrated with a proposal for the International Year of the Salmon (IYS). Pacific salmon face many challenges and uncertainties associated with environmental variability such as climate change. It is more important than ever that we promote new international cooperative research that provides better scientific information on the ecological mechanisms regulating production of anadromous populations and climate impacts in North Pacific marine ecosystems.

The 2016–2022 Science Plan is germane to NPAFC's primary objective of promoting the conservation of anadromous populations of Pacific salmon and steelhead trout within the Convention Area. The primary goal of the Science Plan is to understand variations in Pacific salmon productivity in a changing climate. Research objectives are to: (1) improve knowledge of their distribution, growth and survival in the ocean (current status); (2) increase understanding of the causes of variations in Pacific salmon and steelhead trout production (mechanisms); and (3) anticipate future changes in the production of Pacific salmon and steelhead trout and the marine ecosystems producing them (e.g., modelling). Improved understanding of the mechanisms that regulate the distribution and abundance of Pacific salmon and steelhead trout will promote the conservation of anadromous populations in the North Pacific Ocean, allow for better forecasts of salmon production trends in the future, and enhance the sustainable fisheries management, food security, and economic security in member nations.

The new NPAFC Science Plan is aligned to a large extent with the proposed IYS program (2016–2022), but there are differences due to the greater geographic extent and additional salmonid species within the IYS initiatives. NPAFC Science Plan research themes (followed by IYS themes in brackets) are: (1) Status of Pacific salmon and steelhead trout (status of salmon); (2) Pacific salmon and steelhead trout in a changing North Pacific Ocean (salmon in the salmosphere); (3) New technologies (new frontiers); (4) Management systems (human dimension); and (5) Integrated information systems (information systems).

Relevant approaches to cooperative research under the Science Plan will include collection and synthesis of existing data and associated metadata to generate and test specific hypotheses, integrate ecological monitoring programs in the ocean using research vessels and/or remote sensing, conceptual and quantitative modeling, process-oriented field and laboratory studies, and retrospective analyses. Scientific results from cooperative studies will progressively reduce major gaps in knowledge with respect to the research themes, as well as make significant contributions to the IYS initiative in collaboration with other partners including PICES and NASCO. New scientific information will also contribute to effective enforcement activities by member nations to protect Pacific salmon from illegal, unreported, and unregulated (IUU) fishing in the Convention Area.

Keywords: NPAFC Science Plan, 2016–2022, Pacific salmon, steelhead trout, North Pacific Ocean, International Year of the Salmon (IYS)

INTRODUCTION

Pacific salmon including chum (*Oncorhynchus keta*), coho (*O. kisutch*), pink (*O. gorbuscha*), sockeye (*O. nerka*), Chinook (*O. tshawytscha*) and cherry salmon (*O. masou*), and steelhead trout (*O. mykiss*; hereafter referred to as Pacific salmon) are an important biological and economic resource in North Pacific rim countries. Pacific salmon face many challenges and uncertainties in the future not the least those associated with climate change. There is a need to advance understanding and awareness of the issues facing Pacific salmon, and their implications for communities that benefit from the resource, through implementation of a program of new research, collaboration and outreach.

The primary objective of the North Pacific Anadromous Fish Commission (NPAFC) Convention is to provide a mechanism for international cooperation to conserve anadromous populations in the North Pacific Ocean. Pacific salmon producing countries need the best available scientific information to make appropriate decisions for sustainable fisheries management that optimize economic opportunities and consider the capacity for Pacific salmon production in changing environments. Article VII of the Convention mandates extensive cooperation among member nations in conducting scientific research. The NPAFC Science Plan is a framework for international cooperative research to achieve the NPAFC's primary objective. Member nations conduct national research with respect to the Science Plan, and the plan is revised usually every 5 years after reviewing scientific progress pertaining to the previous plan.

The goal of the previous Science Plan (2011–2015) was identified by the overarching research theme, "Forecast of Pacific Salmon Production in the Ocean Ecosystems under Changing Climate," and five research topics: (1) migration and survival mechanisms of juvenile salmon in the ocean ecosystems; (2) climate impacts on Pacific salmon production in the Bering Sea (BASIS) and adjacent waters; (3) winter survival of Pacific salmon in the North Pacific Ocean ecosystems; (4) biological monitoring of key salmon populations; and (5) development and applications of stock identification methods and models for management of Pacific salmon (Anonymous 2010). Progress in each research topic was reviewed at an international symposium held in Kobe, Japan on May 17–19, 2015, summarized in a document (SSC and Review Panels 2016), and published in the NPAFC Bulletin 6 (Urawa et al. 2016).

The response of salmon to climate-driven environmental changes is variable and differs by species, populations, life stages, geographical locations, and/or seasonal timing. The future of salmon remains uncertain under several alternate scenarios of climate change. It is more important than ever that we promote new cooperative international research that provides better scientific information on the ecological mechanisms regulating the distribution and abundance of anadromous populations and climate impacts in North Pacific marine ecosystems (NPAFC-PICES Study Group 2014).

NPAFC has been instrumental in the development of a proposal for an International Year of the Salmon (IYS Working Group 2016). The NPAFC Science Sub-Committee (SSC) was charged with developing a new NPAFC Science Plan (2016–2022) that would be integrated with a proposal for the International Year of the Salmon (IYS).

THE INTERNATIONAL YEAR OF THE SALMON (IYS)

The proposal for the IYS was developed by the IYS Working Group convened by NPAFC that comprised representatives of NPAFC and North Atlantic Salmon Conservation Organization (NASCO), and other partners (IYS Working Group 2016). The proposal is intended to support

NPAFC and NASCO in promoting the concept of an international focus on salmon in the North Pacific and North Atlantic oceans and potentially also the Baltic and Arctic regions.

The IYS seeks to raise awareness of what humans can do to better ensure salmon and their varied habitats are conserved and restored in the "salmosphere" (current and future geographic range of salmon in the Subarctic and Arctic). It also seeks to stimulate research to better understand the factors affecting salmon to inform their conservation, rational harvest, and sustainable management. The IYS initiative comprises three phases: planning (2016-2018), launch (2018), and research and reporting (2019–2022).

The overarching theme of the IYS is "Salmon and People in a Changing World", and the proposed themes are:

- **Status of Salmon**: to understand the present status of salmon and their environment;
- **Salmon in a Changing Salmosphere**: to understand and quantify the effects of natural environmental variability and anthropogenic factors affecting salmon distribution and abundance and to make projections of their future changes;
- **New Frontiers**: to develop new technologies and analytical methods to advance salmon science and to explore the uncharted regions of the salmosphere;
- **Human Dimension**: to investigate the cultural, social, and economic elements that depend upon sustainable salmon populations; and
- **Information Systems**: to develop an integrated archive of accessible electronic data collected during the IYS and tools to support future research.

The governance of the IYS needs to be inclusive, flexible and supportive and its success will depend on the involvement of a wide range of partners. It is recognized that there are numerous issues affecting salmon within the salmosphere, various research priorities and region-specific activities. It is anticipated that most of the IYS activities will be undertaken at the regional level and there will be a range of objectives that will need to be coordinated at multiple levels: salmosphere (International Coordinating Committee), regional/RFMO (Regional Steering Committees), and individual Parties/jurisdictions. There would be Steering Committees in the two main regions (North Pacific and North Atlantic), led by NPAFC in the North Pacific and NASCO in the North Atlantic. It is a mandate for the Regional Steering Committees to identify research priorities and develop a research plan.

The 2016–2022 NPAFC SCIENCE PLAN

Primary Goal and Research Objectives

The primary goal of the 2016–2022 Science Plan is to: "Understand Variations in Pacific Salmon Productivity in a Changing Climate".

Research objectives are to:

(1) Improve knowledge of the distribution, growth and survival of Pacific salmon in the ocean (current status);
(2) Increase understanding of the causes of variations in the production of Pacific salmon (mechanisms); and
(3) Anticipate future changes in the production of Pacific salmon and the marine ecosystems producing them (e.g., modelling).

Improved understanding of the mechanisms that regulate the distribution and abundance of Pacific salmon will promote the conservation of anadromous populations in the North Pacific

Ocean, allow for better forecasts of Pacific salmon production trends in the future, and enhance the sustainable fisheries management, food security, and economic security in member nations.

The timing of the NPAFC 2016–2022 Science Plan overlaps with the proposed implementation of the IYS (2016–2022). There are differences, however, resulting from the greater geographic extent (Pacific Ocean plus the Atlantic, Baltic, and probably the Arctic oceans), additional salmonid species (e.g., Atlantic salmon), and increased focus on people by the IYS compared to the NPAFC mandate. As a result, the research themes of 2016–2022 NPAFC Science Plan are not totally aligned with the IYS themes.

NPAFC Research Themes

The NPAFC Science Plan research themes (corresponding IYS themes in brackets) are:

(1) Status of Pacific salmon and steelhead trout (status of salmon);
(2) Pacific salmon and steelhead trout in a changing North Pacific Ocean (salmon in the salmosphere);
(3) New technologies (new frontiers);
(4) Management systems (human dimension); and
(5) Integrated information systems (information systems).

Each theme is summarized below, along with major research topics. Although some research topics could fit under more than one theme, they are only listed once.

Theme 1. Status of Pacific Salmon and Steelhead Trout

Time series of regional salmon production and biological and physical characteristics of key salmon populations and their ocean habitat provide broad scale perspectives necessary to examine the underpinnings of ocean salmon production and marine ecosystem conditions. The purpose under this theme is to understand and effectively report the present status of Pacific salmon and their habitats, and the factors influencing biological traits such as seasonal migration, distribution, abundance, growth, and survival.

(1-1) Biological Monitoring of Key Salmon Populations

There is a continuing need to maintain and improve monitoring of spawning escapement, catch, smolt production and other biological information for potential use in the forecasting of salmon return strength or ocean survival. Long-term time series are particularly valuable in understanding linkages between climate and Pacific salmon production. Data on hatchery fish should be maintained separately from data on wild fish as much as practicable. Biological information such as age composition of a population, body size, fecundity and egg size are monitored whenever feasible.

- *Key Populations*—Continue ongoing monitoring programs for key salmon populations and identify new sampling opportunities. Identify additional key populations that can be monitored to provide status information for co-existing salmon populations and their ecosystems.
- *Data Quality*—Improve the quantification and documentation of uncertainty associated with existing and new data time series, and maintain wild and hatchery salmon data separately in the time series.
- *Baseline Information*—Update baseline information, and establish data standards for future comparisons. Expand existing databases to store important time series datasets including biological traits and associated metadata.

(1-2) Seasonal Migration and Distribution

Anadromous salmon migrate in the ocean to maximize their growth and survival. Their seasonal migration and distribution are stock specific, and fundamental migration routes may be genetically fixed. Increasing information on seasonal ocean migration and distribution of key salmon populations contributes to: planning effective ocean monitoring surveys, better climate modelling and forecasting, better management to avoid incidental salmon bycatch, and efficient enforcement activities to protect salmon in the ocean.

- *Seasonal Migration and Distribution*—Estimate population-specific migrations and distributions of key salmon populations through their ocean life stages using genetic and otolith markers, and other techniques.
- *Migration Mechanism*—Examine how salmon navigate in the open ocean and finally return to their natal watersheds to spawn. Several hypotheses have been proposed for salmon navigation methods in the ocean, but there is no consensus.
- *Physiological Condition*—Examine physiological changes in immature and maturing salmon during their ocean migration, and how these physiological changes are associated with the migration behavior of salmon and marine environments.

(1-3) Growth and Survival

Variation in the early marine survival of Pacific salmon has been hypothesized to have a major role in determining the numbers of adults that return to spawn. However, there has been limited evidence to support this hypothesis. We need to understand the causes of mortality at each stage of the salmon life cycle, and evaluate whether any particular life history period is critical. With the potential of limited food resources in the ocean, it is important to understand the implications of habitat utilization by Pacific salmon populations at various levels of abundance, the productive capacity of habitats for each life stage, and the potential implications of density dependent effects.

- *Critical Period*—Understand the causes of mortality at each life stage, and evaluate whether there is any critical period that determines brood year strength.
- *Ocean Entry*—Juvenile abundance, timing and body size at ocean entry may be important parameters that are critical to understanding and quantifying mortality at sea. Examine how these parameters are associated with salmon survival or brood year strength.
- *Growth*—Increased energy efficiency for growth of juveniles in the early marine period may be a key to their survival and optimization of hatchery production.
- *Prey Organisms*—Identify which prey organisms are important for salmon growth at each stage and region, and examine if the abundance of prey organisms limits salmon production.
- *Salmon Health* – Examine effects of pathogens and stressors on the growth and survival of salmon in the ocean.
- *Density Dependence* and *Carrying Capacity*—Understand how salmon growth and survival are affected by hatchery and wild salmon abundance, and quantify the current limits to salmon production at each life stage. The ability of the ocean to produce salmon is not constant, and for the most part, the limits are not known. A general concern is that competition among different salmon populations may lead to lower growth and survival at high abundances, especially during periods of lower biological productivity.

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

Climate change may result in significant variability and overall declines in the carrying capacity and usable habitat (distribution) of Pacific salmon in the North Pacific Ocean, potentially leading to expanded use of the Arctic Ocean, at least seasonally. An improved understanding of linkages between environmental changes and Pacific salmon production will help to plan for the economic consequences of these changes. The objectives are to understand and quantify the effects of environmental variability and anthropogenic factors affecting salmon distribution and abundance, and to project future changes with efficient forecast models.

(2-1) Retrospective Salmon Studies

Historical surveys of salmon on the high seas and in coastal waters have produced rich collections of data and samples that have been under-utilized. Samples deposited in archives decades ago may now provide new information, particularly by utilizing analytical techniques not available when the samples were originally collected.

(2-2) Linkage between Pacific Salmon Production, Climate and Ocean Changes

In recent years, there have been increases in the abundance as well as shifts in the distribution of salmon in northern regions, but some decreases at the southern edges of distribution along the Asian and North American continents. These geographical shifts in salmon abundance may be related to climate-induced changes in habitat/environments operating at regional and local scales.

- *Marine Survival*—Examine linkages between marine survival of salmon, changes in climate and the ocean such as primary production, and prey resources.
- *Distribution and Abundance*—Predict the effect of natural environmental variability on stock-specific distribution and abundance of salmon.
- *Salmon Habitats*—Predict the potential impacts of global climate change on marine salmon habitats.
- *Comparative Studies*—Compare survival and growth patterns of salmon at different life history stages and in different marine habitats/environments.

(2-3) Modeling the Future for Salmon

Reliable forecasting of salmon distribution, abundance and survival is important for the sustainable resource management and for projecting future variations in production due to changing climate. Modelers are encouraged to continue developing statistical models as well as ecosystem models coupled with biophysical models to estimate the impact of climate change on salmon populations, and to create future scenarios for salmon distribution and abundance.

- *Short-term and Long-term Forecast Models of Salmon Returns*—Forecast impacts of climate change on salmon and make progress in understanding unexplained variability in salmon abundance, migration, growth, and survival.
- *Energy Budget Models*—Investigate conditions that optimize energy budgets for growth and determine how climate-related ecosystem changes could alter these energy budgets. Maximizing the amount of energy available for growth in the early marine period may be a mechanism that increases survival among all Pacific salmon species.
- *Biophysical Models*—Linking variability in growth and survival of salmon to biophysical and environmental parameters may improve forecasts of abundance.

Theme 3. New Technologies

Novel stock and fish identification methods including new molecular techniques, hatchery mass marking, and intelligent tags continue to develop, and these tools are integral to the formulation of effective models predicting the distribution and abundance of salmon populations.

- *Molecular Identification*—Develop effective molecular techniques and baselines to identify the geographical origin of individual fish/population.
- *Genomics*—Use genomic technology for the rapid assessment of the physiological health status and cause of the condition of salmon.
- *Environmental DNA (eDNA)*—Develop eDNA methods for the rapid and non-lethal estimation of salmon distribution and potentially abundance.
- *Mass Marking*—Develop mass marking techniques to identify hatchery salmon in mixtures of populations. Thermal otolith marking is a successful tool for mass marking, but available mark patterns are limited.
- *Intelligent Tags*—Develop tagging methods to investigate the habitat conditions, predators and navigation mechanism of salmon migrating in the ocean.
- *Salmon Observation Systems*—Improve tracking technologies to increase knowledge of stock-specific patterns of migration and survival at each life stage.
- *Remote Sensing*—Application of remote sensing technologies such as ocean gliders and satellite imagery to understand changes in the biophysical environment experienced by salmon.

Theme 4. Management Systems

The objective is to provide scientific advice that effectively informs management systems including their cultural and socioeconomic aspects. Enforcement of NPAFC's convention measures that prohibit directed fishing for anadromous fish within the Convention Area is the responsibility of NPAFC's Committee on Enforcement (ENFO). The CSRS is increasingly playing a role in providing information on the probable distribution of Pacific salmon at different times of the year, and therefore likely locations of illegal, unreported, and unregulated (IUU) fishing.

Theme 5. Integrated Information Systems

The objective is to improve the ability to share information and collaborate on research efficiently using a modern web-based framework. Data assembled as part of the other themes are to be linked in a central data system.

- *Common Information*—Integrate data products with existing data systems and use archives of accessible electronic data collected during the research period to support future research and public understanding of the role of salmon in ocean ecosystems.
- *Collaboration*—Improve cooperation and communication through collaboration.

Cooperative Research Approaches and Implementation of the Science Plan

Pertinent approaches to cooperative research under the 2016–2022 Science Plan will include compilation and synthesis of existing data and metadata to generate and test specific hypotheses, integration of ecological monitoring research in the ocean using research vessels and/or remote sensing, conceptual and quantitative modeling, process-oriented field and laboratory studies, and

retrospective analyses.

Scientific results from cooperative studies using these approaches will progressively reduce major gaps in knowledge with respect to the research themes, as well as make significant contributions to new IYS research in collaboration with other relevant partners such as PICES and NASCO. New scientific information will also contribute to effective enforcement activities by member nations to protect Pacific salmon from IUU fishing in the Convention Area.

Progress on research themes or issues of the 2016–2022 Science Plan will be reviewed annually during the NPAFC Annual Meeting. Symposia, workshops, and other science meetings will be scheduled during the time period as appropriate.

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