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A LONG-TERM RESEARCH AND MONITORING PLAN (LRMP) FOR PACIFIC SALMON (*ONCORHYNCHUS* SPP.) IN THE NORTH PACIFIC OCEAN

NPAFC

North Pacific Anadromous Fish Commission

The North Pacific Anadromous Fish Commission is an international governmental organization where researchers can share their data and interpretations to determine how to forecast the effects of a changing ocean ecosystem on Pacific salmon production.

A Long-term Research and Monitoring Plan (LRMP) for Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean

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Summary

Each of the Pacific salmon producing countries conducts research and monitors its salmon fisheries to protect and utilize a resource that provides food and economic opportunities. Effective management requires an understanding of the mechanisms that regulate the production of Pacific salmon in fresh water and in the ocean. Each country can study Pacific salmon within their own jurisdiction, but international cooperation is needed to understand the processes that control Pacific salmon on the high seas.

The North Pacific Anadromous Fish Commission is a trusted organization where researchers can share their data and interpretations to determine how to forecast the effects of a changing ocean ecosystem on Pacific salmon production. The authors of this report agree that it is now possible to use new technologies and a new spirit of international cooperation to identify the fundamental processes that influence Pacific salmon survival in the ocean. This Long-term Research and Monitoring Plan represents a consensus of a large group of researchers from all Pacific salmon producing countries that the approaches identified in the plan will improve the ability of each country to forecast how their salmon populations will respond to the changing freshwater and marine ecosystems. International cooperation is always a challenge, but the North Pacific Anadromous Fish Commission has proven that it can provide the framework for this cooperation.

In this report, researchers in each country identify their own visions of future research needs in addition to reaching agreement on key areas of research. It is known that there is a large mortality of juvenile Pacific salmon in the early marine period. In addition, the conditions in the winter can also determine brood year strength. Comprehensive winter ecosystem surveys are needed to determine the distribution and condition of Pacific salmon from all countries to identify the sources and magnitude of the winter mortalities. Linking this information with biotic and abiotic factors will improve forecasts of brood year strength as well as improve the understanding of how the capacity of the ocean to produce salmon will be affected by climate.

Each country also identified key areas of ocean research and long-term monitoring requirements. Surveys of juvenile salmon are needed to determine the factors affecting early marine survival. Pink salmon were identified as a key species for monitoring because they are the most abundant Pacific salmon species and because their life history characteristics make them an ideal ecological indicator of marine ecosystems. Consensus on genetic baselines for sockeye, Chinook and chum salmon and the development of genetic baselines for pink salmon are necessary to monitor stock specific ocean distributions and abundance. This information is needed to produce more accurate estimates of the timing and abundance of adults that are returning to coastal rivers. Research and monitoring programs in the ocean will also identify the capacity of the ocean to produce the various species of Pacific salmon. The continued development of a North Pacific marking strategy is necessary to study hatchery production and to monitor the proportions of hatchery fish in the ocean and within total returns to coastal communities. International, integrated studies need to include specialists that are familiar with physical, chemical and climatological processes as well as experienced modellers. The integration of research and monitoring associated with the management of all Pacific salmon is challenging, but it is now possible as this plan indicates.

“It is always important to understand what is known and know what needs to be understood”

Excerpt from: NPAFC Science Plan 2006-2010

1. Broad Scientific Questions

Overarching hypotheses that emerged from the results of scientific research under previous NPAFC science plans, as well as from research by other organizations and independent scientists, are that (1) anadromous stocks play an important role in North Pacific marine ecosystems, and (2) there is a close relation between climate and climate change and subsequent changes in marine productivity and survival of anadromous stocks in the ocean. The Science Sub-Committee (SSC) identified two broad scientific questions relevant to the program goals of NPAFC that would further an ecosystem-based approach to conservation of North Pacific anadromous stocks, as well as contribute substantial new scientific information to the marine ecosystem research, fishery management, and conservation activities planned by relevant organizations:

- What are the current status and trends in marine production of anadromous stocks; and how are these trends related to population structure (spatial and temporal) and diversity of anadromous stocks in marine ecosystems of the North Pacific?
- How will climate and climate change affect anadromous stocks, ecologically related species, and their North Pacific marine ecosystems?

Over the past decade, there have been significant variations in the marine production of Asian and North American anadromous stocks that appear to be linked to climate change. There is a strong need for new international cooperative research that provides better scientific information on the status and trends in marine production of anadromous stocks, identifies the roles of anadromous stocks in North Pacific marine ecosystems, and examines the extent to which anadromous stocks, since they return to coastal regions, can be used as indicators of conditions in North Pacific marine ecosystems.

http://www.npafc.org/new/publications/Science%20Plan/SciPlan(2006-2010).pdf

Introduction

This is an international strategic plan to coordinate research among countries that will improve the forecast of the impacts of a changing climate on all aspects of the life history of Pacific salmon. Although research is needed throughout the life history of Pacific salmon, the focus of the strategic plan is to improve forecasts of marine survival, produce more accurate estimates of the timing and abundance of adults returning to coastal rivers and determine the capacity of the subarctic Pacific to produce Pacific salmon. The objective is to produce a strategic research and monitoring plan that is the consensus of an international team of scientists who are recognized experts on the dynamics and population ecology of Pacific salmon. The plan will be a "blueprint" for funding from government and non-government organizations as well contribute to the five-year research plan for the North Pacific Anadromous Fish Commission (NPAFC).

An international effort to identify the mechanisms that regulate Pacific salmon production will also help stabilize fisheries. This strategic plan will build on the collaboration and success of the initial five-year research plan of the NPAFC Bering-Aleutian Salmon International Survey (BASIS), but will include all marine areas such as the Sea of Okhotsk and the Gulf of Alaska. By focusing on the response of Pacific salmon populations to climate in the North Pacific, the plan will integrate the physical environment with biological production, monitor interactions between biological components of the marine ecosystem as it varies in time and space and ultimately examine the interactions between different species of Pacific salmon and populations of each species during critical periods of their life history.

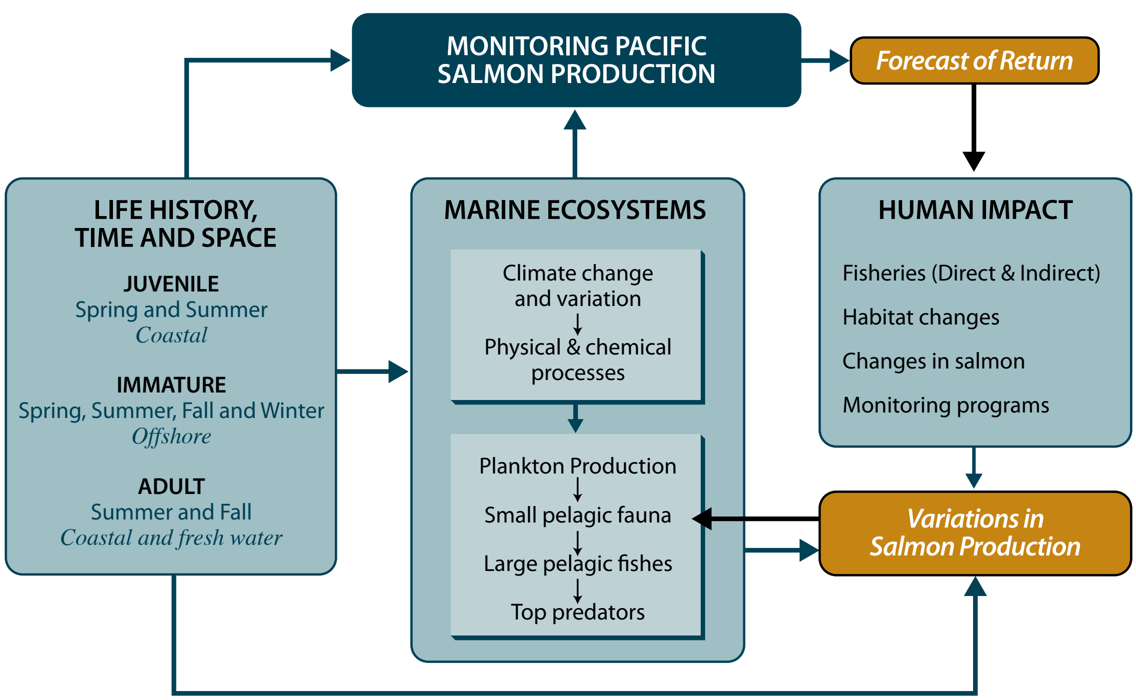

Figure1. A scheme of long-term research and monitoring for Pacific salmon in marine ecosystems.

Photo by Auke Bay Labs

Background

This initiative follows an agreement at the April 2007 Research Planning and Coordinating Meeting (RPCM) of the NPAFC and is consistent with the NPAFC Science Plan (page 4).

Within the NPAFC, member countries are naturally interested in Pacific salmon, sustainable fisheries and the associated benefits that these provide for people of each country. Each country also shares an increasing concern about the potential effects of climate change on ecosystems of the northern North Pacific and ultimately on the production of Pacific salmon. This leads to a common scientific objective to describe a long-term research and monitoring program to understand how climate and marine ecosystems interact to determine salmon production in the North Pacific region. This will be a major challenge scientifically, organizationally and financially. The three major steps needed to achieve this objective include: 1) A synthesis of existing knowledge, 2) Defining the scope for the issues and 3) Agreeing on the required processes including monitoring, logistic coordination and data management and sharing.

The synthesis of existing knowledge will include;

1. A bibliography of publications related to the impacts of a changing climate on Pacific salmon,
2. A synthesis of current research of all countries that includes studies of the early ocean life history of Pacific salmon in coastal areas, and
3. An identification of the other initiatives related to North Pacific ecosystems and climate impacts.

In developing a Long-term Research and Monitoring Plan, the basic question becomes "What do we need to establish the linkage between monitoring and modelling in order to assess the climate impacts and ecological mechanisms that determine production of Pacific salmon?" Research and monitoring will involve a need to unravel the complex linkages among climate and the physical, chemical and biological components of these ecosystems. The goal is to be able to explain and forecast the annual variation in Pacific salmon production (Figure 1). Figure 1 emphasizes the scope of the research and monitoring needed to consider a) the spatial and temporal scales of effects and b) other potential impacts on Pacific salmon production that may be confounded with changes associated with climate. Adequate sampling designs and monitoring programs are required to explain changes in salmon production (e.g. juvenile marking programs to assess harvest and marine survival rates). It is important to focus on the central issue of climate effects on components of the marine ecosystem but that may not be sufficient to associate climate changes with changes in salmon production.

The spatial and temporal scales of study require:

a. Geographic coverage and details considered within each area of interest. For example, what level of detail is needed in coastal seas? What spatial scales are important in the open ocean?

b. Temporal variation includes daily, monthly, seasonal, and annual trends. Do we need toconsider short-term variation or does long-term imply annual monitoring programs that are needed to understand the mechanisms causing the changes?

c. What do considerations of spatial and temporal variation require in our experimental or statistical sampling designs? Are there new "tools" and information sources that we need to consider in acquiring future data (e.g., remote sensing)?

The effectiveness of integrated ecosystem studies (from climate and hydrology to higher trophic levels) will be much greater with the collection of information relating to nutrients, primary productivity, conductivity and temperature at depth, zooplankton (biomass and species composition), pelagic fish (biomass and species composition) as well as indicators of fish health including distribution, length and weight, fat content and trophic relationships. Total abundance and biomass of every ecosystem component (as well as Pacific salmon and ecologically related species) must be estimated. Real knowledge of the scale of biological processes and conclusions will be important for the understanding of ecosystem processes.

Small scale and short-term studies are not sufficient because ocean distribution ranges of Pacific salmon are very large. Therefore, it is necessary to conduct large-scale research over vast areas during ecosystem surveys as the oceanic habitat of Pacific salmon is geographically heterogeneous. The best way to improve scientific quality of research is the organization of large-scale multi-national expeditions concurrently by several vessels from different member-countries (for example, one ship from each participating country). In the beginning, each vessel should plan to cover its region of responsibility. This approach will make it possible to obtain information on the entire marine habitat of salmon (from Asia to North America) in a short time period. To gain an experience of joint multi-national research in the high-seas, it is best to start with one large expedition in winter, which is a critical season for salmon survival.

In monitoring changes in salmon production, can we account for other potential causes of change that may be confounded with climate impacts? There are other well known human-driven causes of change that we need to consider. Fishing has a direct effect on abundance and an indirect impact on ecosystems. Changes in hatchery production may cause density related impacts. Any new habitat disruptions (freshwater and coastal) can affect productivity. Changes in monitoring of Pacific salmon catches and spawning escapements within jurisdictions can be important because of the need for a consistent network of escapement monitoring programs.

Monitoring of physical conditions of watersheds needs to be made available in time and space scales appropriate to understanding the effects of climate change on adult run timing, spawning success and the activity of pathogens. Monitoring of key watersheds needs to be available in a form amenable to analysis by salmon researchers. Needs of salmon research should be identified and incorporated into planning for new monitoring technologies such as satellite deployments and other watershed monitoring activities.

Photo by PBS

There is a need to maintain and improve basic monitoring of escapement, catch and smolt migration. Some of these long-term programs are disappearing for a variety of reasons. Understanding the linkages between climate and Pacific salmon production depends upon these basic data. In areas where hatcheries are present, data on hatchery fish abundance should be separated from wild fish abundance. Biological information such as age composition of a population, body size, fecundity and egg size should be included in the monitoring.

As strategic plans are developed to address our primary objective, each of the boxes in Figure 1 could be considered in our research and monitoring plans. The process of developing the plan should also create an international team of scientists that will continue to find ways to integrate research to make optimal use of funds, vessel time and data. BASIS is an example of such a team. Although NPAFC has discussed the need to establish a fully shared data system, data management and communication issues are frequently not fully considered in the implementation of programs. In summary, it is important to create a team, optimize the use of scientific resources and make data available.

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Canada

Canada supported research on the freshwater phase of Pacific salmon for approximately one century. However, research of the ocean phase of Pacific salmon did not begin until the 1950s. Currently, Canada has two major programs that study the factors that affect the behaviour, survival and growth of wild and hatchery Pacific salmon. Initially, this research was limited by sampling gear, but became more efficient with the use of modified trawl nets in the mid-1990s. In the relatively short time that trawl gear has been available, a number of important discoveries have been made. However, like many discoveries, the new information indicated how much more there is to learn before we are able to forecast the impacts of a changing climate.

Current research shows that it is necessary to maintain programs for a long time to be able to detect climate related trends in the dynamics of Pacific salmon. Since the early 1980s there has been a gradual decline in the marine survival of coho and Chinook salmon that enter the Strait of Georgia. Associated with this decline was a change in the behaviour of coho salmon in the mid-1990s that resulted in virtually all juveniles leaving the Strait of Georgia late in the year and not returning until it was close to the time that they entered their spawning rivers. This behavioural change collapsed one of the major recreational and commercial fisheries on the Pacific Coast of Canada. Surveys to study juvenile Pacific salmon in the Strait of Georgia have been continuous since 1997 and show that there was a declining trend in early marine survival from ocean entry until September. Over the study period, the amount of mortality in the summer gradually increased, indicating that the mechanism causing the mortality gradually increased. The longer time series was needed to show that the abundance of juvenile coho salmon in the Strait of Georgia in September provides a good estimate of the number of adults that will return to spawn during the next year indicating that the brood year strength was strongly related to the ocean conditions in the Strait of Georgia in the first four months of ocean residence.

There are several recent examples of climate related effects on the population dynamics of Pacific salmon that had major impacts on the fisheries. An example is the large scale reduction in survival and growth within populations of Pacific salmon that occurred in 2005 and the winter of 2005/06. Neither the cause of the climate impact nor the mechanisms that affected individual fish has been determined. In the Strait of Georgia in 2005 there was a major mortality of juvenile coho and Chinook salmon shortly after they entered salt water. Juvenile Pacific salmon in other areas from California to the Gulf of Alaska were also affected, resulting in very poor returns of many populations. Pink salmon populations ranging from the southern limits into Alaska that entered the ocean in 2005 and returned in 2006 exhibited very poor marine survivals. It appears that ocean production of prey for Pacific salmon was also poor during the winter of 2005 through to the spring of 2006 as the size of returning adults in 2006 was extremely small.

Canada has legislation and policies that require government actions when populations of Pacific salmon reach critically low levels. The linkage between these policies and climate change is not explicit; however, the legislation does provide protection for populations that are negatively impacted by trends in climate. The government required protection is based mainly on the assumption that the critically low abundances resulted from actions that can be reversed or mitigated. The probability that trends could not be reversed because of reductions in productivity and marine survival is a relatively new consideration in Canada's management of Pacific salmon. Consequently, the existing strategies have more of a focus on conservation in relation to fishing and freshwater habitat protection than on natural declines in productivity.

Canada needs a strategic program that is committed to understanding the impacts of a changing climate on the marine ecology of the six major species of Pacific salmon. The concept of linking fisheries to oceanography has been around for decades, but a linkage directly to climate is an approach that needs to be considered because there are trends in Pacific salmon production that correspond to trends in climate. There is synchrony in these trends on regional scales, indicating basin-scale relationships.

Canada has a major hatchery salmon enhancement program. The original concept was based on a belief that there was unused capacity for Pacific salmon that could be used if more juveniles were added to the marine ecosystem. It was estimated that the total production in the late 1970s could be doubled by about 2000. Canada currently releases about 64 million chum, 44 million Chinook, 9 million coho, 2.5 million sockeye and 1.5 million pink salmon into areas surrounding Strait of Georgia, off the west coast of Vancouver Island and the north/central coast. Hatcheries in Canada also produce about 370,000 steelhead trout. Hindsight shows us that the assumption of unused ocean carrying capacity was not valid. In fact, since the start of the hatchery program, the Canadian catch of Pacific salmon actually decreased by more than 50%. The reasons for the decrease relate to management actions as well as to ocean carrying capacity changes. Thus, Canada needs to understand how hatcheries can be used in the future. Some researchers believe that studies of the effects of climate change on nearshore ecosystems will allow for better use of the salmon enhancement program by optimizing the numbers released and the time and size of releases. There is evidence that hatchery and wild fish respond differently to changes in the ecosystem. Thus, it is important to study wild populations directly and not rely only on extrapolations from hatchery populations. A focus on wild salmon is important; however, it is the aggregate of information gathered on wild and hatchery salmon that will eventually identify the mechanisms that link productivity to climate.

Research on the factors affecting marine survival shows that a faster rate of growth in the early marine period results in better survival, either because fast growing fish quickly reach a size that is sufficiently large to avoid predators in the spring and summer or because they accumulate enough energy reserves to survive their first winter at sea. Thus, research efforts should be focussed on the winter as well as the summer. Recent research shows that while plankton productivity and temperatures tend to be higher in the California Current System, juvenile Pacific salmon are generally larger and fatter and have better growth in the Alaska Coastal Current. The poorer growth and condition of Pacific salmon in the northern California Current System may be related to a calorie-deficient diet as well as to lower rates of food consumption or higher metabolic rates. Thus, ocean conditions could affect Pacific salmon production through changes in prey community composition and quality.

Photo by PBS

Several hypotheses have been proposed to explain the regional, interannual and interdecadal variability in Pacific salmon production. In marine ecosystems, these hypotheses often invoke changes occurring at multiple levels from climate to ocean circulation, nutrient concentration, phytoplankton and zooplankton biomass and composition, salmon bioenergetics, and fish and predator community assemblages. However, the intermediate steps linking salmon to climate are rarely measured simultaneously. Thus, it will be necessary to conduct integrated ecosystem research in which physical, chemical and biological components are measured together. While ecosystem modelling may help to identify critical processes regulating salmon production, a strong emphasis should be placed on data collection, as ecosystem models will require large quantities of data to generate realistic scenarios and predictions.

Canada needs to be able to separate the effects of fishing from the effects of climate on the dynamics of Pacific salmon. Ocean studies to identify the major factors that cause mortality and highlight the relative importance of predation, disease and growth during the early marine period are important. One hypothesis to be tested is that the amount of lipid storage early in the summer is related to marine survival through the ability to survive the first ocean winter. Very little is known about the distribution of the major populations of Pacific salmon in their first marine year off the coast of British Columbia. Without this knowledge, it will be difficult to link climate models to the population dynamics of Pacific salmon. Marine surveys using genetic stock identification could map where the major populations rear in British Columbia and adjacent waters and for how long. The baseline required for DNA stock identification is well developed for some species such as Chinook and sockeye salmon, but less so for others such as pink and coho salmon. Thus, the continual development of the DNA baseline is essential.

Many juvenile Pacific salmon produced in Canada rear in the Gulf of Alaska. Canada needs to participate in international survey programs that identify the distributions of juvenile salmon of Canadian origin. Distributions need to be determined, particularly in the winter.

Thermal marking is an effective and efficient method of identifying hatchery fish. Canada could expand its program of thermal marking and establish an efficient method of detecting thermal marks. Genomic research and acoustic tagging provide new technologies that will help understand the ocean ecology of Pacific salmon. These technologies are expensive and thus are currently confined to small sample sizes. Non governmental agencies wishing to help understand how a changing climate will affect Pacific salmon may want to help with the application of these new technologies. It is beneficial to continue studies relating to age determination and stomach content analysis, as the continuation of these time series will help understand the linkages between biology and climate. A method of ageing older and larger Chinook salmon needs to be established. Preliminary research indicates that a method using fin-ray sections may provide reliable ages.

Canadians relate the health of Pacific salmon to the health of the environment in general. Thus, communication to the public of the results of marine research on Pacific salmon is a function that needs to be taken seriously by all researchers. Pacific salmon are an icon for the west coast of British Columbia. They are economically, socially and culturally important for commercial, recreational, and native fisheries. There is an obligation to protect Pacific salmon, particularly in the light of climate change. Most biologists now recognize that long-term research and monitoring programs are needed to ensure that Pacific salmon will inhabit the waters of British Columbia for many generations to come. The current approach to Pacific salmon management in Canada and in other countries does not include scenarios of future climate impacts. If reliable forecasts are not available, the

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management of our fisheries and hatchery programs will have to react to inevitable surprises and hope that the responses are correct. Management must involve more than short-term responses to the almost instantaneous issues that arise when Pacific salmon return to their natal rivers. Management needs to be based on a reasonable appreciation of how a particular species or population responds to the changing environment throughout its life history. Science and managers need to accept that past assumptions of constant natural mortality and constant impacts of climate are not correct.

Canadian researchers support the concept of an integrated, multi-disciplinary study of all aspects of the life history of Pacific salmon. It is necessary to move away from short-term, local research and establish a long-term, integrated, international research plan. The history of carrying out small projects provided some information but our hindsight shows us that the understanding that we need for future management requires a different approach that links the dynamics of ecosystems with the population ecology of Pacific salmon. Our past approach to research and monitoring also indicates that we need to be more careful about oversimplifying the mechanisms that affect the productivity of Pacific salmon. Shortcuts to understanding would be nice, but this approach is risky.

In British Columbia, the Fraser River which produces the largest percentage of our Pacific salmon, is now about 2°C warmer during the summer than it was in the 1940s. In fact, in recent years, some returning populations are experiencing temperatures that are 5°C warmer than in the 1940s. The juvenile Pacific salmon that leave the Fraser River enter the Strait of Georgia and it is about 2°C warmer during this early marine period that it was in the 1960s. In British Columbia, it is also important to recognize that there is a transition zone on land and in the ocean in about the middle of the province. At this transition area, there is a decadal-scale oscillation in the flow patterns of large rivers and in the ocean ecosystem which is separated by currents and winds. Many of the Pacific salmon produced in British Columbia rear in the Gulf of Alaska, yet there is no understanding of the factors in the Gulf of Alaska that affect their survival. Thus, it is particularly important to carry out research on Pacific salmon in the Gulf of Alaska in the winter.

New research methods are being used in British Columbia that could be introduced to other researchers. Our use of genomics analyzes thousands of gene transcripts at one time that identify what genes are turned on and off. This cellular approach identifies if an individual fish is responding to stresses such as disease. Other technologies such as environmental metabolomics, or metabolic profiling, are not in use but could be developed by a team of scientists. Metabolic profiling identifies the end products of the gene expression. DNA stock identification is well developed at the Pacific Biological Station

allowing the monitoring of the distribution of Pacific salmon at the population level. Combining DNA stock identification with telemetry, genomics and metabolomics offers exciting new ways to understand the linkages between climate and physiological processes of Pacific salmon.

Canadian research requirements are both short- and long-term as probably are the research needs of the other Pacific salmon producing countries. Short-term requirements are for abundance and for in-season models that characterize the behaviour of key stock units, with respect to the run timing. Longer-term requirements are to determine what populations are best able to adapt to the expected changes in climate. Can salmon adapt to changes and if so, how fast can some species and some populations of these species adapt? Is the response of very poor survival that we observed in 2005 going to become more frequent? Can we parameterize a mechanistic model or models that link components of the life history of the various species to climate? We need to revisit the issue of key populations and key rivers. Previous studies showed that small numbers of populations generally did not represent the response of other populations, yet there is a need for reliable indicator stocks.

Canada recognizes that it is now time to move away from piecemeal studies and focus on international research efforts. An international research plan requires regular meetings of invited participants. Such an international council of Pacific salmon researchers can be associated with NPAFC, but the participants on the council need to be scientists that are generally recognized for their contributions to the understanding of the population ecology of Pacific salmon. We strongly support the concept of an International Year of the Salmon and we will continue to look for ways of making this concept a reality.

Japan

Japan maintains an average catch of about 200,000 t of chum salmon that represents 65% of all chum salmon caught and 25% of all species of Pacific salmon in the total catch by all countries. Pink salmon catch is the second largest catch in Japan, ranging from 9,000-21,000 t. There are small, wild populations of masu salmon, and even smaller populations of coho, Chinook and sockeye salmon that produce minor amounts of catch, but are commercially and culturally important to regional communities. Virtually all of the chum salmon produced in Japan come from 285 hatcheries that release about 2 billion fry each year.

In general, the returns of chum salmon to Japan are stable or have increased in recent years. Because chum salmon are produced in hatcheries, all returning fish are caught. Thus, it is possible to monitor the returning fish for size, scales, fecundity, egg size, stock identification and other biological parameters. Japan has a long history of conducting high seas research on Pacific salmon, dating back to 1952. Unfortunately, budget and staff restrictions now mean that it will be difficult for Japanese scientists to continue this level of research and monitoring. Recent research is dominated by studies of chum salmon in Japanese coastal zones and extends into the Bering Sea and the North Pacific. There is a focus on migration routes and feeding ecology. It was Japanese research that first showed that chum salmon of Japanese origin spent their second and subsequent marine winters in the Gulf of Alaska. Future research will focus on understanding the reasons for changes in the body size of returning adult chum salmon. It is hypothesised that changes in size may result more from prey abundances and the resulting effects of population density, and less from competition with other species such as pink salmon. Hypotheses that separate the effects of predators, competitors and prey availability on size at maturity need to be formulated and tested. Thus, the possible change in the carrying capacity of the ocean to produce chum salmon is an important research issue.

It is proposed that as climate changes, Pacific salmon habitat in the ocean will increase in the winter, but decrease in the summer. Bioenergetic modelling is one way to understand how these habitat changes will affect the future abundance and size at maturity of returning adult chum salmon. Monitoring total lipid content will also contribute to an understanding of how climate changes affect body size. Understanding how and when lipid is stored may be a key to understanding how chum and other species of salmon are affected by their first ocean winter. It would be useful to refine the rapid method of analyzing

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lipid content for juvenile and adult Pacific salmon. The use of standardized methods by all countries to measure lipids while at sea and the establishment of a common database through NPAFC would accelerate the understanding of energy budgets and improve forecasting by assessing the condition of the fish during their marine residence.

Considerable effort has been spent studying the early marine period of chum salmon in the Okhotsk Sea with the priority of determining how the physical environment and the density of juvenile chum salmon in the rearing areas affect survival. Japanese researchers are interested in the sympatric interaction between hatchery and wild salmon in an ecosystem and how long-term climate change will affect their productivity. Similar research by other researchers on the biological interaction between hatchery and wild salmon in other areas such as on pink salmon in Prince William Sound or on chum salmon in southeast Alaska would contribute to an improved understanding. The degree to which the utilization of the ecosystem may differ between hatchery and wild salmon is important to measure and to understand. For example could hatchery rearing practices determine the degree of niche overlap through the manipulation of size at age and time of salt water entry?

Both chum and pink salmon may have key populations that can be used in forecasting. It may be possible to establish a suite of populations throughout the distribution of these species that indicate general responses to basin- and regional-scale climate changes, as well as to climatic events such as El Niño and La Niña. The intensity of the Aleutian Low also affects the capacity of the subarctic Pacific to produce salmon. Regional responses are important, but there are long-term trends in production that are related to the degree of winter storm intensity in the North Pacific. Unfortunately, there is not an understanding of how to model the Aleutian Low and how a changing climate may affect the Aleutian Low. In fact, there are studies that predict both an increase and a decrease in the intensity of the Aleutian Low. Recent studies indicate that the Aleutian Low may become stronger, that is, there will be increased winter storm intensity. It is believed that growth and survival of Hokkaido chum salmon is highly affected by sea surface temperature and that the warming climate is currently beneficial for chum salmon in the Okhotsk Sea. However, it is also predicted by some researchers that in the future, global warming will decrease the carrying capacity in the North Pacific Ocean, and that Hokkaido chum salmon could be extinct by 2100.

Genetic studies remain a key area of research for Japanese scientists. It is timely that all countries focus on a standardized approach to identify populations of the five main species of Pacific salmon. Standardized baselines need to be maintained and results made available quickly. Routine genetic sampling at sea is a commitment that all countries need to support so that the rearing areas used by populations of Pacific salmon from all countries can be identified. Access to data by all researchers will speed up the collective ability to understand how the ocean ecosystem regulates the production of Pacific salmon, how salmon are distributed in marine areas, and how they respond to climate and habitat changes.

Japanese Researchers agree that there is an immediate need to study Pacific salmon in the winter. However, there are very few vessels that are capable of conducting research in the open ocean in the winter. There are also a limited number of biologists that can do this kind of work in the winter. In fact, there is some evidence that the recruitment of salmon biologists may be declining, particularly biologists willing to spend extended periods at sea. The funding reductions in Japan are a concern to researchers in all countries and thus, it may be even more urgent that international teams of researchers coordinate their efforts to maximize the amount of information obtained from the resources available.

Carrying capacities for Japanese chum salmon differ in time and space from the juvenile state to returning adults. Key ecosystems are the coastal waters off Japan in the spring, the Okhotsk Sea in summer, the western North Pacific in winter, the

Bering Sea in summer and the Gulf of Alaska in winter. Japanese future research consists of four components such as (1) Juvenile Salmon Studies, (2) Bering Sea Salmon Ecology Studies, (3) Monitoring of Salmon and Environment in the North Pacific Ocean, and (4) Monitoring of Major Salmon Stocks. Details are described in the Japanese Research Plan on salmon stocks (NPAFC 2008).

In general, the following are priorities for research and monitoring:

- Determine the seasonal distribution of chum salmon after they leave coastal areas;
- Understand the role of Pacific salmon in the surface waters of the subarctic Pacific;
- Explore factors affecting the growth and survival of chum salmon in the first ocean year, particularly in the Okhotsk Sea;
- Determine the effects of climate and ocean on the primary production and prey resources in the coastal areas of Japan and the Okhotsk Sea;
- Examine linkages between basin- and regional-scale climate and ocean indices and early marine growth of chum salmon;
- Explore synchrony in the productivity of Japanese chum salmon and other hatchery and wild chum salmon populations;
- Determine adaptive strategies of chum salmon in the winter;
- Cooperative monitoring and reporting of standard biological and population parameters of chum salmon; including prey, size and age at maturity, fecundity, egg size, wintering and lipid levels;
- Cooperative sampling of chum salmon throughout their ocean distribution;
- Support for an International Year of the Salmon that would have as a major goal, the mapping of populations of all five species (or six if steelhead trout are included) in the winter and in the summer.

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Photo by Auke Bay Labs

Korea

Chum salmon is the species of Pacific salmon that is of most importance to Korean researchers. Chum salmon hatcheries were established in the northern Korean Peninsula in 1913 and in South Korea in 1967. Despite the hatchery production, the catch of chum salmon declined from 553 t in 1997 to less than 200 t at present. Hatcheries release fry into an area of the ocean that is at the southern range of chum salmon distribution, an area where Pacific salmon production is known to be negatively impacted by climate change. It is recognized by Korean scientists that natural shifts in the climate and ocean ecology affect the production of chum salmon.

Thus, future changes that warm the surface waters would be expected to reduce the production of chum salmon. It is also understood that the production of chum salmon in the subarctic Pacific is increasing and that some populations of a particular species of Pacific salmon adapt to these climate changes better than other populations. The marine survival of chum salmon from Korean hatcheries is less than 2% which is lower than the average of almost 3% obtained from hatchery and wild chum salmon in more northern latitudes. If the factors that affect early marine survival were better understood, it may be possible to sustain or even improve Korean chum salmon production in the immediate future. In the coastal areas around Korea, juvenile chum salmon growth was greater in the early 1990s than in the 1980s, but growth in the open ocean was greater in the 1980s than in the 1990s, suggesting that changes in climate are affecting different stages of the life history of Korean chum salmon. This highlights the need for continuous data collection in coastal and open ocean environments and for a focus on the effects of climate change on the distribution and abundance of Korean chum salmon. It would be helpful to Korean scientists if all countries would publish escapement estimates and the methods for determining these escapements for hatchery and wild populations.

Long-term monitoring of basin- and regional-scale climate and ocean indices will improve the understanding of the relationship between the size and timing of releases of hatchery fish and the numbers that return. An improved understanding of the causes of early marine mortality would also provide information that is needed to optimize hatchery production. It is important to Korean researchers to know the spatial and temporal distribution of chum salmon in the open ocean to help understand the sources and timing of mortality. Thermal marking of the otoliths of hatchery fish and shared international databases for otolith marks and DNA stock identification will help determine the ocean distribution of chum salmon of Korean origin. The cause of the large mortality of chum salmon in the ocean is perhaps the least understood and least studied aspect of their life history. As the sources of mortality become better understood, the processes that regulate chum salmon production will be clearer, resulting in models that more accurately forecast the timing and abundance of returning adults. Managing chum salmon in the absence of this information may be too speculative in the future. Chum salmon are also produced in North Korea and information about the state of their populations will be useful to scientists from South Korea and the international community in general.

The factors that regulate the timing and accuracy of the coastal migration of adults are also poorly known. Timing of return in 2003 was about 15 days earlier than it was 20 years ago and it appears that larger salmon return earlier. An ability to capture and identify maturing chum salmon in the open ocean, combined with the promising contributions from genomics, may begin to unravel the mysteries of how and why salmon decide to return to spawn. Eventually, the improved understanding of the marine phase of Pacific salmon in general, and chum salmon in particular, needs to find its way into forecasting models. It makes sense that international teams of modellers will make faster progress than individual efforts. Thus, any effort to coordinate long-term research and monitoring of Pacific salmon should have an international team of modellers that use existing information and identify new information needed to improve forecasts.

An issue that has not been discussed in Pacific salmon research is the genetic manipulation of fish produced in hatcheries. Pacific and Atlantic salmon have been genetically altered to improve growth, indicating that the genetic manipulation of salmon is possible. It is probable that as our understanding of marine mortality improves, there may be interest in artificially improving the survival of Pacific salmon, particularly at the southern limit of their range.

In general, the following are the priorities for research and monitoring:

- Continue the data collection in coastal areas and in the open ocean;
- Improve the understanding of the effects of global warming on distribution, abundance and run timing;
- Develop an ability to forecast climate-induced variation in marine survival;
- Explain and measure carrying capacity;
- Continue life history studies;
- Identify and protect the habitat critical for wild salmon production.

Photo by NFRDI

Photo by NFRDI

Russia

Pacific salmon catches are at historic high levels in Russia. It is recognized that even these reports of high catches may underestimate the real catches by about 25% because of the massive poaching issue. Despite the poaching problem, spawning escapements are also at historic high abundances. The current abundance (production) of the Russian salmon stocks is a result of the high carrying capacity of their ocean habitat and the favourable conditions for reproduction in rivers.

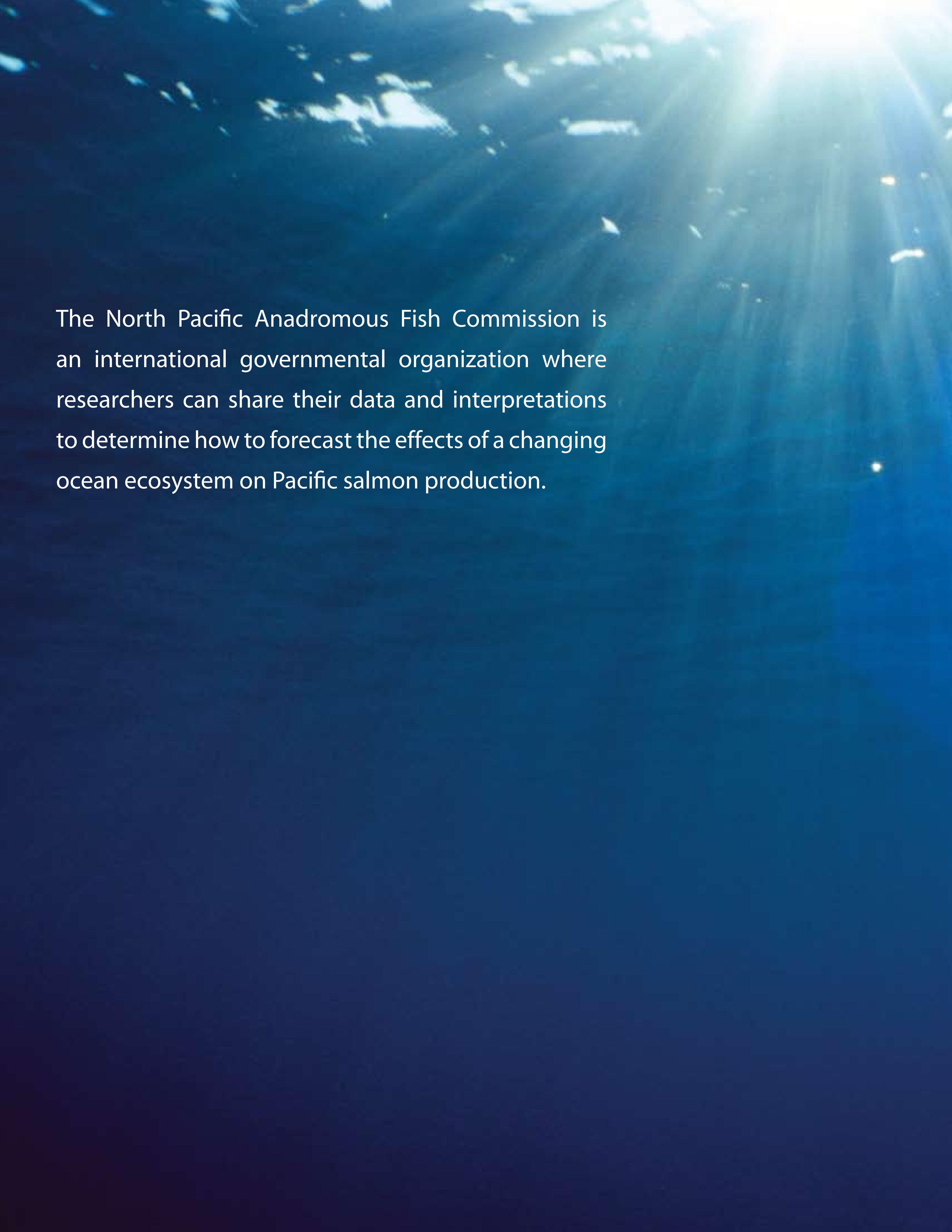
According to the opinion of some experts, trends in abundance are related to large-scale atmospheric processes that can be indexed by the Aleutian Low (ALPI) or the Pacific Decadal Oscillation (PDO). According to other researchers, ALPI and PDO (as well as other climatic indices) don't reflect adequately the observed patterns of oceanographic and biological processes. These atmospheric processes occur in cycles and the current cycle which is favourable for Russian Pacific salmon production is expected to end soon, perhaps within the next five years. However, the mechanisms of how climate related changes in the ocean influence marine species are still not sufficiently understood. There has been a general increase in abundance of Russian populations, but species-specific differences in abundance dynamics are also noted. Despite the influence of global factors, closely located Pacific salmon populations exhibit different trends in abundance and biological parameters indicating that regional influences are also important.

Pink salmon are the most important species in the Russian salmon fishery, accounting for 75% of the catch. Chum and sockeye salmon account for 16% and 6%, respectively. Coho, Chinook and masu salmon catches are not significant. In fact, there has been a continuous decline in the catches of coho and Chinook salmon. The dominance of wild and hatchery pink salmon has a strong influence on future research and monitoring plans which are generally large-scale as it has been shown that small and short-term studies in local areas can give a distorted picture of the population ecology of Pacific salmon.

High salmon catches can result, in part, from increased release of Pacific salmon from hatcheries. However, hatchery production accounts for only 25-30,000 t of the total catch. Currently, Russia has 41 Pacific salmon hatcheries that produce 0.6 billion juvenile Pacific salmon. Most (85%) of these hatcheries are in the Sakhalin Island region. By 2010, the Sakhalin Island region expects to add 10 more hatcheries. If these hatcheries are successful, there is a plan to build 19 more that collectively will produce 1.8 billion juvenile pink and chum salmon each year. The expansion and success of the Pacific salmon hatchery program makes it necessary to determine an appropriate ratio of natural and artificial reproduction. This determination will require a major effort to thermally mark otoliths of hatchery fish. There is concern that fisheries need to be maintained through a balance of wild and hatchery populations which may be affected differentially by climatic influences. Associated with the marking of hatchery fish is the need for reliable DNA baselines for the major spawning populations. DNA currently is not used to estimate abundances of individual populations in different regions off the coast of Russia. Thus, an important component of the next science plan in Russia is to estimate abundances of individual populations, and determine the appropriate ratio of hatchery and wild populations in the ocean.

Historically there have been as many scientists studying Pacific salmon in Russia as in all other countries combined. However, the number of researchers has declined in recent years. In Russia, a major research effort is still given to the study of salmon during marine life. Every year, four or five integrated salmon surveys (expeditions) are carried out in the Sea of Okhotsk, the Bering Sea, and in the northwest Pacific (oceanic waters off Kamchatka and Kuril Islands, western Subarctic Gyre). Recently, several surveys were conducted in the Chukchi Sea. These surveys will be continued in the future because of the high salmon abundance in the northern areas of the Russian Far Eastern seas.

Pacific salmon research generally operates under five year strategic research plans. The next five year plan for Pacific salmon research is currently being finalized. These plans are detailed descriptions of annual activities including vessel



The North Pacific Anadromous Fish Commission is an international governmental organization where researchers can share their data and interpretations to determine how to forecast the effects of a changing ocean ecosystem on Pacific salmon production.

plans and specific programs such as genetic stock identification, thermal marking of otoliths, disease, predator and diet studies. Standardized procedures used in the studies are published separately in a manual approved by the Federal Fisheries Agency of the Russian Federation called "Methodical re commendations on the implementation of fisheries resources marine surveys of Pacific salmon 2004". A second publication was produced in 2005 called "Planning, organization and maintenance of the studies of the north western part of the Pacific Ocean". The current five year strategic research and monitoring plan (2006-2010) identifies the following as priorities:

The fresh water juvenile stage and resident period of adults in fresh water including:

- the identification of spawning areas and ranking of watersheds in order of their contribution to the abundance of Pacific salmon;
- an assessment of the status of populations and spawning areas in each region;
- the development of protocols for real-time monitoring of commercial fisheries, in accordance with the principles of multispecies fisheries;
- the production of a genetic baseline database for major spawning populations;
- the mass marking of the otoliths of Pacific salmon produced in hatcheries;
- Studies to determine the optimal production level of hatchery and wild Pacific salmon.

The estuarine stage of juvenile Pacific salmon including:

- Determining the forage base limitations for juvenile Pacific salmon;
- Determining the rate of predation on juvenile Pacific salmon;
- Examining the differences in survival and adaptation mechanisms of hatchery and wild juvenile Pacific salmon;
- Collecting better information on the abundance of predators and the selective mortality of juvenile Pacific salmon;
- Determining if hatchery populations make better use of the forage base than wild populations of Pacific salmon;
- Improving the information on the phenology of the forage base available to various populations of juvenile Pacific salmon migrating into nearshore areas, particularly for habitats that support large hatchery populations.

Photo by TINRO Center

Photo by TINRO Center

The marine and oceanic stages of Pacific salmon including:

- Improving the quality and reliability of real-time forecasts during the fishing season and improve the medium-term forecasts of returning abundances;
- The assessment of the temporal dynamics and carrying capacity of the epipelagic environment of the North Pacific Ocean;
- Improving the knowledge of the structure, productivity and dynamics of plankton and nekton communities;
- The continuation of biochemical studies of forage species;
- Improving the methods for estimating the abundance and biomass of Pacific salmon;
- The extension of trophic surveys through international cooperation;
- Studies of anadromous and catadromous migration patterns that include an assessment of the impacts of limiting factors on the distribution of Pacific salmon during foraging;
- An emphasis on understanding mortality i.e.) predation, disease, migration ability, parasites, rather than the traditional emphasis on survival;
- Research on diurnal and seasonal vertical distribution with an emphasis on the variability and impacts of the forage base;
- Monitoring of seasonal changes in physiological condition of Pacific salmon.

The rapid publication of the results of all studies and international cooperation in future studies.

Future research and monitoring will focus on improved forecasting that will lead to better management. There is a long history of marine and freshwater research on Pacific salmon in Russia, but despite the research, some feel that there has not been significant progress in forecast accuracy. However, researchers are confident that the accuracy of forecasts can be improved if more of the factors that regulate abundance can be integrated and relationships with single influences such as sea surface temperatures are deemphasized. It is always important to understand what is known and know what needs to be understood. At present not enough is known to be confident that any particular management approach will be effective. There is a clear recognition of what needs to be done. Valuable time series need to be maintained. Understanding the population ecology of Pacific salmon in fresh water, the estuarine-coastal areas and the open ocean phases are all equally important. Juvenile trawl surveys are an essential part of the long-term approach to improving forecasting. Without annual surveys, it is difficult or even impossible to expect progress in forecasting return rates.

The difficulty associated with forecasting is the understanding that fish abundance dynamics, as a natural impact on survival, occur at a variety of stages. Fishing effects and hatchery production also complicate the relationship. Russian research has not identified a depletion of forage species as a result of large-scale artificial and natural reproduction. However, the suite of factors that affect the carrying capacity of the ocean for the various species of salmon are still poorly understood. A serious issue is the continuous use of unproven assumptions, particularly in modeling. Common assumptions which may or may not be stated can be critical, yet there is no proof that they apply to the extent used. Local factors in the ocean are also important. The recognition of basin-scale trends in carrying capacity does not exclude the important dynamics that occur at regional scales. Every regional population of every species has its own peculiarities. Progress is possible, but research must be planned, with a specific set of research monitoring tasks. The necessary approaches require more staff and efficient cooperation, including international cooperation. New resources are absolutely necessary.

The strategy in Russia for the next five years maintains the proven monitoring programs and places emphasis on poorly understood and controversial issues of Pacific salmon population biology and ecology. There is a focus on several major ocean rearing areas; far-eastern marginal seas and the western Subarctic Gyre (oceanic waters off Kamchatka and Kuril Islands). Traditional freshwater research and monitoring remain important and are strongly supported. The current marine research plan recognizes that Pacific salmon are not a schooling type of fish once they leave the nearshore area. Thus, their behaviour differs from many other commercially important species. Research over the past 15-20 years produced a detailed understanding of feeding behaviour and prey abundances, resulting in the understanding that the current food supply for Pacific salmon is good or satisfactory. Past research also indicated that direct measurements of prey abundance are necessary to evaluate carrying capacity and may have been significantly underestimated in the past. Indirect indicators such as changes in growth rate are not considered to be reliable indicators of prey related interactions among species. Therefore, an emphasis on the actual causes of mortality in the ocean is needed. More extensive laboratory and field measurements to support bioenergetic modeling are necessary to understand the relationships among growth, prey availability and mortality. It is remarkable how little is known about the causes of marine mortality, considering how few individual Pacific salmon survive in the ocean. In particular, there is an urgent need to improve the understanding of disease impacts. Epizootic diseases may be a significant source of mortality. The documentation of the sources of mortality is also an appropriate area for international cooperation.

The factors affecting the return of pink salmon to their spawning rivers is a priority as researchers are still struggling to understand how to define a population and if there is validity to the "fluctuating stock hypothesis". This hypothesis was developed to explain the surprise return of unexpected large abundances of pink salmon to some areas, at the same time that very poor returns occurred in other areas. Related to this issue is the possibility of navigational problems by returning adults.

Russian researchers have a reputation for rapid publication of research results and spirited communication among colleagues. There is interest in international cooperation to produce a monograph that interprets the information resulting from the BASIS program. In particular, the monograph would contain an assessment of the place and role of Pacific salmon in the marine ecosystem. It is expected that such a publication would help to quantify the parameters that regulate the marine carrying capacity for Pacific salmon.

Monitoring has always been an essential component of the Russian studies of Pacific salmon. Priorities for monitoring programs that can assist future research can be summarized into four categories:

1. Diversification and improvement of field research methodology and standardization.
2. Building time series of trawl surveys at standard locations for both juvenile and adult Pacific salmon.
3. Building up hierarchical Pacific salmon data infrastructure to improve retrospective analysis and plan future surveys.
4. Expansion of surveys into poorly investigated areas such as the central North Pacific Ocean and adjacent waters.

An international monitoring effort and an associated database are strongly supported by Russian researchers. Russian researchers also support the International Year of the Salmon which provide a platform for the creation of collaborative research and data sharing.

Photo by TINRO Center

Photo by TINRO Center

United States

Alaska

Five species of Pacific salmon are produced in Alaska, accounting for approximately 20% of the total catch by all countries. Pink salmon are the most abundant (58% of total catch), followed by sockeye (27%) and chum salmon (10%). Coho and Chinook salmon are produced in some Alaskan streams, but in smaller numbers. Recent changes in climate have been beneficial for salmon production in Alaska, particularly following the 1977 regime shift and catches are at historic high levels. It is believed by some researchers that climatic impacts act mainly on regional scales, but larger ocean basin-scale impacts are also recognized. The long-term production of Pacific salmon originating in Alaska is expected to continue, with the exception of some populations from western Alaska.

The increase in abundance of Alaskan Pacific salmon has been attributed to a change in management policies, elimination of the high-seas driftnet fishery, hatchery production, increased fishing effort, increased sea surface temperature in the North Pacific Ocean, increased zooplankton productivity, and climate change that favours the production of pink, chum and sockeye salmon and inhibits the production of coho and Chinook salmon. The recent 'warm regime' dynamics in the eastern Bering Sea have resulted in increased growth and survival of juvenile salmon in the first few months in the marine environment which has translated to more robust juveniles that are better able to survive the winter in the Gulf of Alaska. Trends in production of western Alaskan salmon are difficult to generalize. However, in contrast to the general success of Pacific salmon in Alaska, western Alaska stocks are declining. Since the late 1990s, western Alaska has experienced very low Chinook and chum salmon returns. Chum salmon returns to the Yukon River have been particularly poor in recent years. Rapid increases in northern populations of pink salmon in Norton Sound appear to have exacerbated declines in chum salmon that preceded the increase in pink salmon populations.

Sharp increases in average air temperature in the Yukon River watersheds since 1950 may have had mixed effects on abundances of Chinook and chum salmon. Increased average temperatures can enable pathogens such as Ichthyophonus to become more infectious and decrease or increase spawning success. However, the impact of short term temperature decreases due to weather during spawning may enable individual year classes to escape the negative effects of climate effects.

Southeast Alaska is one of Alaska's most productive salmon producing areas, with over 2000 rivers contributing 47% of pink salmon, 61% of coho salmon, and 72% of Alaska's chum salmon. Hatchery production has nearly doubled the abundance of chum salmon, resulting in record harvests averaging 12.3 million fish (77% hatchery origin) in recent years. Over 60 reports on the marine ecology of Pacific salmon from southeast Alaska have been produced, focussing on juvenile migrations, the physical environment, competition and predation. However, many questions remain unanswered, and implementation of a long-term research and monitoring program using new stock identification techniques such as genetics, thermal marking of otoliths, coded-wire tags and data storage tags is needed. This would result in a better understanding of migration patterns and timing, marine growth, carrying capacity, predation, and hatchery and wild interactions; as well as the impact of climate change on these variables.

Hatcheries in Alaska produce about 800 million pink, 600 million chum, 60 million sockeye, 25 million coho and 10 million Chinook salmon every year. The central Alaska region produces mainly pink and sockeye salmon while southeast Alaska produces mostly chum salmon. Prince William Sound alone produces more than 600 million hatchery and about 190 million wild pink salmon fry each year. Total pink salmon returns in this area have averaged 31 million fish (25.3 million hatchery and 5.7 million wild) from 1990 to 2000. Hatchery fish are reared in net pens during the spring and released into optimal feeding conditions in the ocean when zooplankton abundances peak.

Photo by Auke Bay Labs

It is believed that juvenile Pacific salmon consume only 1-3% of the available food resources in Prince William Sound, raising questions about the validity of concerns regarding the carrying capacity of nearshore ecosystems. The interaction of artificially produced Pacific salmon with wild populations is poorly understood and there is difficulty in separating the effects of environmental and management influences on the success of these populations. Long-term research and monitoring of hatchery and wild populations, including larger temporal scales, would greatly benefit the management of these populations.

There is concern over density dependent impacts and the carrying capacity of the Pacific Ocean, following such a drastic increase in Alaskan Pacific salmon abundance. Prior to the mid 1990s, many populations of pink, chum and sockeye salmon experienced increases in age at maturity and decreases in size at maturity. It was believed that these changes were a carrying capacity issue in the North Pacific and that the ocean was unable to sustain the high numbers of fish being produced by

Alaskan hatcheries. However, after the mid-1990s, adult sizes began to increase again, suggesting that carrying capacity is not constant, but varies with changing environmental and biological factors. As was the case for trends in abundance of western Alaska salmon, trends in size at age are difficult to generalize. For example, size at age in most Bristol Bay sockeye salmon stocks declined during the 1990s.

It has been suggested by some scientists that growth and survival of sockeye salmon in their second year in the ocean is impacted by high abundances of Asian pink salmon when populations of these two species interact in the high seas. This potential for interaction has highlighted the need for a multispecies, international investigation of interactions between wild and hatchery salmon. Trawl monitoring studies need to continue to understand salmon-prey interactions and the carrying capacity for Pacific salmon. The Auke Bay Laboratory's Marine Ecosystem Stock Assessment program, BASIS group, focuses on juvenile salmon research along the eastern Bering Sea Shelf. The objectives of this program are to 1) understand juvenile migrations from rivers to the eastern Bering Sea 2) describe the physical environment of the eastern and northeastern Bering Sea shelf waters and 3) collect biological information on other ecologically important species. As the early marine period is a time of high mortality when up to 75% of juvenile salmon mortality may occur, growth of juvenile Pacific salmon may be a key indicator of ecosystem change. The ocean conditions in the coastal environment may be a key link between climate change and salmon abundance. Understanding these physical and biological parameters will provide insight into the relationship between salmon and their habitat and identify mechanisms linking production to climate change, but will require continued long-term research and monitoring. The ability to reliably forecast salmon returns would be a great accomplishment for fisheries managers. To do this, it is necessary to understand the impacts of climate change on Pacific salmon, specifically the distribution, abundance, and migration patterns with respect to environmental conditions.

Future research needs include:

- The development of new technologies and international baselines for salmon stock identification;
- shipboard research and monitoring programs that provide a platform for process studies, as well as data on interannual variation in ocean growth, distribution and run timing of key populations;
- the development and dissemination of international databases useful for research on ocean production of Pacific salmon;
- the identification of specific mechanisms that affect marine survival of Pacific salmon;
- the continued sampling of zooplankton;
- the measurement of prey abundance such as larval fishes and euphausiids;
- the measurement of abundance and identification of feeding habits of predators;
- the measurement of growth rates in the ocean;
- the identification and mapping of critical ocean feeding habitats and migration routes;
- the assessment of the effects of interactions among populations including both Asian and North American and hatchery and wild;
- methods of accounting for hatchery releases need to be carefully examined as numbers released by species may not be geographically comparable due to differences in rearing and feeding practices and in basic methods of enumeration of releases.

Photo by Auke Bay Labs

Washington, Oregon and California

Coho and Chinook salmon dominate the research and monitoring efforts of researchers in Washington, Oregon and California. Steelhead trout are also of interest, but receive considerably less attention. Marine studies of factors affecting the early marine survival of juvenile Pacific salmon began in the 1980s and have continued to the present, with a focus on coho and Chinook salmon that are produced in the wild and in hatcheries.

Hatchery production of coho and Chinook salmon is a major contributor to the number of juveniles entering the ocean. Trawl surveys for juvenile Pacific salmon in Puget Sound captured coded-wire tagged fish which were used to approximate the percentages of hatchery and wild individuals. Approximately 50% and 85% of coho and Chinook salmon were from hatcheries, respectively. In Puget Sound, hatcheries annually release about 10 million coho and 30 million Chinook salmon. They also produce about 40 million chum, 10 million sockeye and 0.8 million pink salmon fry, in addition to 2 million steelhead trout. In other areas of Washington (outside of Puget Sound), hatcheries release about 10 million Chinook and 6 million coho salmon. They also release about 1.5 million chum and 100,000 sockeye salmon fry and 2 million steelhead trout. Approximately 100 million Chinook and 20 million coho salmon are released into the Columbia River, along with 1.5 million sockeye and 175,000 chum salmon fry. Approximately 15 million steelhead trout are also released into the Columbia River. Off the coast of Oregon, hatcheries release about 1.2 million coho and 10 million Chinook salmon in addition to about 150,000 steelhead trout.

In California, 20 million Chinook salmon, minimal numbers of coho salmon and 1.5 million steelhead trout are released from hatcheries. Information from the population ecology of these hatchery fish is used to study the dynamics of wild Pacific salmon in the ocean as wild populations are more difficult to study. Researchers agree that they need to be careful about the standard assumption that the dynamics of hatchery fish closely represent the dynamics of wild fish. Future research needs to separate information on hatchery and wild salmon and ensure that there is more information about the dynamics of wild populations.

The relative abundance, species composition and timing of zooplankton production are monitored in relation to the stomach contents of juvenile Pacific salmon. Predators, including birds and marine mammals, are studied but the sources of marine mortality of coho and Chinook salmon are still poorly understood. It is recognized that marine survival is related to ocean growth, particularly in the early marine period. Prior to the 1970s, years of good early marine growth could be linked to the production of jack coho salmon (male salmon that spend less than one year in the ocean), creating an index of marine survival. However, the relationship became unreliable, indicating that a suite of factors affect marine mortality and that it is risky to rely on single factor relationships when forecasting returns. It is a priority to integrate ecological information with climate and ocean information to improve forecasting. A limitation is the shortage of acceptable research vessels and funds. A new program is underway to improve the ability of identifying populations using genetic analysis. As this genetic baseline develops, it will be possible to map the critical feeding areas off the coasts of California, Oregon and Washington as well as areas farther north. Because it is particularly important to find out where immature fish rear in the winter, the development of the genetic baseline is critical. To do this, international cooperation (with Canada) and interstate cooperation (with Alaska) is essential. Genetic stock identification is important, but the maintenance of a scale database, in association with routine digitizing of scales is still important. Rescuing scales that were collected in the past is valuable. It is essential that the seasonal distribution of juvenile and immature coho and Chinook salmon is determined. As regional climate models become more reliable, the use of these models to manage Pacific salmon depends on the knowledge of where salmon are in the ocean.

There is missing information on winter ecology that is needed to understand the ocean phase of the life history of Pacific salmon from Washington, Oregon and California. It is difficult and expensive to study Pacific salmon in the ocean in the winter, thus it is important to cooperate with other countries when conducting such research. In addition, it is necessary to link freshwater research on Pacific salmon so that it is closely associated with ocean research. As in other countries, teams of scientists need to focus on understanding the factors affecting the dynamics of Pacific salmon throughout their entire life cycle. It is essential that past and future data including ocean and climate data are available to all researchers, perhaps in an international data base managed by the NPAFC or another agency.

Acoustic tags are a useful way of studying the behaviour and mortality of hatchery and wild fish. Acoustic and archival tags are expensive, requiring that their use be well planned and the results widely distributed. Perhaps the most immediate use of acoustic tags would be to study the sources of early marine mortality of steelhead trout. The use of these tags could help determine if predation is the major source of early mortality of juvenile steelhead trout and if this predation mortality is related to ocean structure. The impacts of ocean acidification are missing from current strategic research plans. A lesson Bill Ricker learned was to expect the unexpected and the effects of ocean acidification should not turn out to be a surprise.

In general, long-term research needs of all Pacific salmon research in the United States is to:

- identify specific mechanisms that cause marine mortality (starvation, predation, disease);
- continue monitoring prey abundance;
- identify predators and their distribution and determine the impact of predation on Pacific salmon;
- measure key prey abundance, production and energetic levels on temporal and spatial scales relevant to salmon populations;
- measure ocean growth rates and bioenergetic demands of juvenile and adult Pacific salmon;
- monitor lipid levels throughout the year;
- map the seasonal feeding areas, migration routes and the timing of movements with focus on the winter ecology of juvenile Pacific salmon;
- begin to study the impacts of diseases and parasites;
- develop archival and acoustic tags that can be applied to fish 10-15 cm in length and can sample multiple environmental parameters concurrently;
- begin to study the impacts of ocean acidification;
- fund complete life cycle studies;
- link ocean research to well-established freshwater research programs to study variation in productivity of the whole life history of salmon populations;
- conduct studies of both hatchery and wild fish;
- determine relative effects of ocean fishing vs. climate on adult salmon returns;
- communicate results to colleagues, clients and patrons;
- conduct international cooperative research including data sharing, standardized surveys and coordinated research programs;
- develop and disseminate International databases useful for research on ocean production of salmon;
- continue juvenile trawl surveys and the corresponding data series;
- evaluate the relative importance of coastal habitats (within 200 mile zones) compared to high seas habitats (beyond 200 mile zones) in the determination of ocean productivity in growth and survival;
- continue shipboard research and monitoring programs that provide a platform for process studies, as well as collection of long-term data on interannual variation in ocean growth, distribution, and run timing of key populations (e.g. BASIS, Wakatake maru survey in central North Pacific and Bering Sea);
- reinstate long-term surveys that have been terminated (e.g. Oshoro maru and Auke Bay Lab's Marine Ecosystem Stock Assessment program, BASIS group surveys in the Gulf of Alaska);
- expand US-Asia collaborations in DNA baselines of sockeye, chum and Chinook salmon;
- expand Pacific Rim single nucleotide polymorphism (SNP) baselines;
- develop new DNA and other technologies and international baselines for salmon stock identification;
- improve integration of stock composition and ecological data;
- continue scale and CWT programs.

The United States is developing an ecosystem approach to management to provide a comprehensive framework for living marine resource decision making. The ecological approach will consider a wide range of relevant ecological, environmental, and human factors bearing on societal choices regarding resource use. A key step in ecosystem approach to management is to develop integrated ecosystem assessments that provide a synthesis and quantitative analysis of information on relevant physical, chemical, ecological and human processes in relation to specified ecosystem management objectives. Integrated ecosystem assessments start by identifying human and natural factors affecting the ecosystem, selecting key ecosystem status indicators, link ecosystem status to climate and human factors, evaluate ecological and economical impacts of management options, and adaptively manage to reduce risk.

Six climate change issues involving ecological resources that are important for integrated ecosystem assessments include:

1) determining climate signals,(long term change versus natural variation) impacting ecosystems:

2) the impact of ocean warming on distribution and productivity of living marine resources;

3) the impacts of loss of sea ice on living marine resources;

4) ocean acidification impacts on marine biota;

5) freshwater supply and resource management; and

6) sea level rise.

The United States plans to work with international, regional and local partners to develop temporal and spatial scales for integrated ecosystem assessments and to determine the ecosystem indicators for monitoring climate and human induced impacts to these ecosystems. The BASIS project within the NPAFC is one example of a coordinated ecosystem assessment for living marine resources within the Bering Sea.

Conclusion

It is accepted that Pacific salmon are impacted by changes in climate occurring on both regional- and basin-scales, and in long-term trends and individual events. The purpose of this Long-term Research and Monitoring Plan is to ensure that the stewardship of Pacific salmon is well equipped with the knowledge needed to manage Pacific salmon. The NPAFC Science Sub-Committee should determine what would be required to implement the contents of this report, including planning of simultaneous trawl surveys in the winter. The timing, location, cost and expected outcomes of these surveys need to be determined. A proposal for an International Year of the Salmon should be prepared to emphasize the importance of this work.

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Special Appreciation

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Appendix

First LRMP meeting in Sokcho, Korea on April 7-9, 2008

Participants of 1st LRMP meeting (List of participants is Table 1)

Visiting Dr. Shuntov in TINRO Center, Vladivostok, Russia

Second LRMP meeting in Nanaimo, Canada from September 29 to October 2, 2008

Participants of 2nd LRMP meeting (List of participants is Table 2)

Participants of 2nd LRMP meeting

Final LRMP in Shogama, Japan on June 18-20, 2009

Participants of final LRMP meeting (List of participants is Table 3)

Appendix 1
List of Participants

Table 1 – Participants of LRMP meeting on April 7-9, 2008 in Sokcho, Korea.

CANADA	
Richard Beamish	Pacific Biological Station
Gerry Kristianson	Sport Fishing Institute
Krista Lange	Pacific Biological Station
Brian Riddell	Pacific Biological Station
Marc Trudel	Pacific Biological Station
JAPAN	
Tomonori Azumaya	Fisheries Research Agency
Hiroto Imai	Hokkaido National Fisheries Research Institute
Yukimasa Ishida	Tohoku National Fisheries Research Institute
Masahide Kaeriyama	Hokkaido University
Jiro Seki	National Salmon Resources Center
KOREA	
Sukyung Kang	National Fisheries Research and Development Institute
Suam Kim	Pukyong National University
Chae Sung Lee	National Fisheries Research and Development Institute
Ki Baik Seong	National Fisheries Research and Development Institute
RUSSIA	
Maxim Koval	Kamchatka Research Institute of Fisheries and Oceanography (KamchatNIRO)
Leonid Klyashtorin	Russian Federal Research Institute of Fisheries & Oceanography (VNIRO)
Igor Melnikov	Pacific Scientific Research Fisheries Center
Svetlana Naydenko	Pacific Scientific Research Fisheries Center
Victor Nazarov	Pacific Scientific Research Fisheries Center
Vladimir Radchenko	Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO)
Vladimir Volobuev	Magadan Research Institute of Fisheries and Oceanography (MagadanNIRO)
UNITED STATES	
Robert Emmett	National Marine Fisheries Service, Hatfield Marine Science Center
Edward Farley, Jr.	National Marine Fisheries Service, Auke Bay Laboratory, Ted Stevens Marine Research Institute
Loh-Lee Low	National Marine Fisheries Service, Alaska Fisheries Science Center
Jamal Moss	National Marine Fisheries Service, Auke Bay Laboratory, Ted Stevens Marine Research Institute
Phil Mundy	National Marine Fisheries Service, Auke Bay Laboratory, Ted Stevens Marine Research Institute
Katherine Myers	School of Aquatic and Fishery Sciences, University of Washington
Greg Ruggerone	National Resources Consultants, Inc.
Jim Seeb	School of Aquatic and Fishery Sciences, University of Washington
Gary Smith	Gary Smith Company
Bill Templin	Alaska Department of Fish and Game
Sewall Young	Washington Department of Fish and Wildlife
OBSERVERS	
Richard Lincoln	Wild Salmon Center
Michael Webster	Gordon and Betty Moore Foundation
SECRETARIAT	
Wakako Morris	North Pacific Anadromous Fish Commission
Shigehiko Urawa	North Pacific Anadromous Fish Commission

Table 2 – Participants of the LRMP meeting on September 29 to October 2, 2008 in Nanaimo, Canada.

CANADA	
Richard Beamish	Pacific Biological Station
Krista Lange	Pacific Biological Station
Brian Riddell	Pacific Biological Station
JAPAN	
Yukimasa Ishida	Tohoku National Fisheries Research Institute
Masahide Kaeriyama	Hokkaido University
Toru Nagasawa	Hokkaido National Fisheries Research Institute
KOREA	
Sukyung Kang	National Fisheries Research and Development Institute
Suam Kim	Pukyong National University
Ki Baik Seong	National Fisheries Research and Development Institute
RUSSIA	
Vladimir Radchenko	Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO)
Vladimir Sviridov	Pacific Scientific Research Fisheries Center (TINRO)
Olga Temnykh	Pacific Scientific Research Fisheries Center (TINRO)
UNITED STATES	
Richard Brodeur	National Marine Fisheries Service, Northwest Fisheries Science Center, Newport
Phil Mundy	National Marine Fisheries Service, Auke Bay Laboratory, Ted Stevens Marine Research Institute
Katherine Myers	School of Aquatic and Fishery Sciences, University of Washington
OBSERVERS	
Richard Lincoln	State of the Salmon
Michael Webster	Gordon and Betty Moore Foundation
SECRETARIAT	
Vladimir Fedorenko	North Pacific Anadromous Fish Commission
Wakako Morris	North Pacific Anadromous Fish Commission
Shigehiko Urawa	North Pacific Anadromous Fish Commission

Table 3 – Participants of the LRMP meeting on June 18-20, 2009 in Hon-Shiogama, Japan.

CANADA	
Richard Beamish	Pacific Biological Station
Krista Lange	Pacific Biological Station
JAPAN	
Yukimasa Ishida	Tohoku National Fisheries Research Institute
Toru Nagasawa	Hokkaido National Fisheries Research Institute
KOREA	
Sukyung Kang	National Fisheries Research and Development Institute
RUSSIA	
Olga Temnykh	Pacific Scientific Research Fisheries Center (TINRO)
UNITED STATES	
Edward Farley, Jr.	National Marine Fisheries Service, Auke Bay Laboratory, Ted Stevens Marine Research Institute
SECRETARIAT	
Shigehiko Urawa	North Pacific Anadromous Fish Commission

Appendix II
Current ocean research and monitoring on the high seas (NI indicates that no information was available)

COUNTRY	RESEARCH AND MONITORING ITEMS	STUDIES	TIME
CANADA	Continue collection of biological information on Pacific salmon	Biological fish data	All year
	Describe ambient oceanographic conditions	Ocean conditions	All year
	Quantify the biomass of zooplankton and describe the zooplankton species community composition	Zooplankton	All year
	Examination of trends in diet of all five species of Pacific salmon	Diet	Summer and fall
	Examine growth and condition of juvenile Pacific salmon in relation to climate indices	Growth	Summer and fall
	Determine causes for early marine mortality of juvenile coho and Chinook salmon	Early marine mortality	Spring, summer and fall
	Stock identification using DNA analysis and acoustic tag studies	Stock identification	Spring, summer and fall
JAPAN	Determine the seasonal distribution of chum salmon after they leave the coastal areas	Distribution	All year
	Understand the role of Pacific salmon in the surface waters of the subarctic Pacific	Ecosystem	NI
	Explore factors affecting the growth and survival of chum salmon in the first ocean year, particularly in the Okhotsk Sea	Growth and survival	NI
	Determine the climate and ocean effects on the primary production and prey resources in the coastal areas of Japan and the Okhotsk Sea	Prey resources	NI
	Examine the linkages between basin- and regional-scale climate and ocean indices and early marine growth of chum salmon	Growth and survival	NI
	Explore synchrony in the productivity of Japanese chum salmon and other hatchery and wild chum salmon stocks	Productivity	NI
	Determine adaptive strategies of chum salmon in the winter	Winter	NI
	Cooperative monitoring and reporting of standard biological and population parameters of chum salmon; including prey, size and age at maturity, fecundity, egg size, wintering and lipid levels	Monitoring	NI
	Cooperative sampling of chum salmon throughout their ocean distribution	Ocean	NI
	The concept of an International Year of the Salmon would have as a major goal, the mapping of stocks of all five species (or six if steelhead trout are included) in the winter and in the summer	NI	NI
KOREA	Improved ability to protect habitat and wild salmon	Habitat	NI
	Continue the data collection in coastal and open ocean surveys	NI	NI
	Improve the understanding of the effects of global warming on distribution and abundance	Distribution and abundance	NI
	Develop an ability to forecast climate-induced variation in marine survival	Survival	NI
	Explain and measure carrying capacity	Carrying capacity	NI
	Continue life history studies	Life history	NI
RUSSIA	Accurate escapement estimates including production of a database of average size, genetics, scale and morphological data of returning adults	Escapement estimates	All year
	An inventory of the potential of freshwater habitats that produce Pacific salmon	Freshwater habitats	All year

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Appendix II

COUNTRY	RESEARCH AND MONITORING ITEMS	STUDIES	TIME
RUSSIA	Mass marking of otoliths of hatchery fish	Otolith marking	All year
	Determination of the optimal ratio of hatchery and wild fish	Hatchery/ wild interactions	All year
	Improvement of the information on the "phenology" of the forage base that is available to the various stocks that continuously migrate into the nearshore areas. This is particularly important for areas where massive releases occur from hatcheries	Forage base	All year
	An assessment of carrying capacity in the North Pacific during all stages of the life cycle	Carrying capacity	All year
	Search for new ways to assess the mortality rates (rather than survival) of Pacific salmon, particularly from the effects of injuries, diseases and parasites. Organization of these data into a centralized regional database	Mortality	All year
	Continue the trawl studies in the ocean with an emphasis of autumn studies in the Okhotsk and Bering Seas, early summer studies in the northwest Pacific and western Bering Sea and summer studies in the northwest Pacific, western Bering Sea, Okhotsk Sea and adjacent waters	Trawl studies	All year
	Improvements to in-season forecasts of optimal catch	In-season forecasts	All year
	Improve the understanding of ocean effects on distribution	Distribution	All year
	Identify why there are wave-like patterns in coastal migrations? What controls the specific onshore migration times?	Coastal migrations	Spring/summer/ fall
	Improve the understanding of the scale and role of vertical migrations in the feeding habitats and forage base	Vertical migrations	All year
	Compare growth rates in the winter and any physiological changes with other seasons	Growth rates	All year
	Rapid publication of the results of all studies and international cooperation in future studies	Publication	All year
USA	The development of new technologies and international baselines for salmon stock identification	Stock identification	NI
	Shipboard research and monitoring programs that provide a platform for the process studies, as well as data on interannual variation in ocean growth, distribution, and run timing of key stocks	Ocean growth and distribution	NI
	The development and dissemination of international databases useful for research on ocean production of salmon	NI	NI
	The identification of specific mechanisms that affect salmon marine survival	NI	NI
	The continued sampling of zooplankton	NI	NI
	The measurement of prey abundance such as larval fishes and euphausiids	NI	NI
	The measurement of abundance and identification of feeding habits of predators	NI	NI
	The measurement of growth rates in the ocean	NI	NI
	The identification and mapping of critical ocean feeding habitats and migration routes	NI	NI
	The assessment of the effects of interactions among stocks (Asian and North American, hatchery and wild)	NI	NI
	Identify specific mechanisms that cause marine mortality	NI	NI
	Continue monitoring prey abundances	NI	NI
	Identify predators and determine the impacts of predation	NI	NI
	Measure ocean growth rates	NI	NI
	Monitor lipid levels throughout the year	NI	NI
	Map the seasonal feeding areas, with focus on the winter ecology of juvenile Salmonids	NI	NI

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Appendix II

COUNTRY	RESEARCH AND MONITORING ITEMS	STUDIES	TIME
USA	Begin to study the impacts of diseases and parasites	NI	NI
	Develop archival and acoustic tags that can be applied to fish 10-15 cm in length	NI	NI
	Begin to study the impacts of ocean acidification	NI	NI
	Fund whole life cycle studies	NI	NI
	Conduct studies of both hatchery and wild fish	NI	NI
	Communicate results to colleagues, clients and patrons	NI	NI
	International cooperative research including data sharing, standardized surveys and coordinated research programs	NI	NI
	Continue the juvenile trawl surveys and the corresponding data series	NI	NI
	Expansion of US-Asia collaborations in DNA baselines of sockeye, chum and Chinook salmon	NI	NI
	Expansion of Pacific Rim SNP baselines	NI	NI
	Improve integration of stock composition and ecological data	NI	NI
	Continue scale and CWT programs	NI	NI

Appendix III
Current ocean research on Pacific salmon in coastal areas (an X indicates research is conducted)

COUNTRY	REGION	RESEARCHERS	SPECIES	TIME AND GEAR	PHYSICAL	NUTRIENTS	CHLOROPHYLL	ZOOPLANKTON	DIET	GROWTH	MIGRATION	PREDATORS
	Vancouver Island, Strait of Georgia	Beamish, Sweeting	Coho, Chinook, sockeye, pink and chum salmon	July and September; 1997-2008; Surface and midwater trawl	X		X	X	X	X	X	X
	Westcoast Vancouver Island	Trudel, Welch, Morris	Sockeye, chum and coho salmon	July, October and February; 1998-2008; Surface trawl	X	X	X	X	X	X	X	
	Southeast Alaska	Trudel, Welch, Morris	Sockeye, chum and coho salmon	July, October and February; 1998-2008; Surface trawl	X	X	X	X	X	X	X	
JAPAN	Western Hokkaido	Ono, Takahashi	Chum salmon	March-July; 1998-2008; Surface trawl	X			X	X	X	X	
	Eastern Hokkaido	Ono, Takahashi	Chum salmon	March-July; 1996-2008; Surface trawl	X			X	X	X	X	
	Kushiro, Hokkaido	Abe, Takahashi	Chum salmon	March-July; 1998-2008; Surface trawl	X			X	X	X	X	
	Nemuro Strait, Hokkaido	Nagata, Takahashi	Chum and pink salmon	March-July; 1996-2008; Surface trawl	X			X	X	X	X	
	Abashiri, Hokkaido	Yoshimo, Takahashi, Kaga	Chum and pink salmon	March-July; 1998-2008; Surface trawl	X			X	X	X	X	
	Iwate Prefecture, East Honshu	Hasegawa	Chum salmon	March-July; 1996-2008; Surface trawl	X	X		X	X	X	X	
	Iwate Prefecture, East Honshu	Shimizu	Chum salmon	March-July; 1995-2008; Surface trawl	X			X	X	X	X	
KOREA	Korean Coast	Kang, Seong	Chum salmon	April and May; 2005-2008; Boat seine	X	X		X	X	X	X	
RUSSIA	Eastern Kamchatka (including deepwater part of the Bering sea)	Shuntov, Glebov, Erokhin, Karpenko	Pink, chum, sockeye, Chinook and coho salmon	September-October 1978, 1982, 1986-1989, 1991-2008 June-August 1991-1993, 1995 and 2002-2004, 2006-2008 Surface trawl	X			X	X	X	X	X

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COUNTRY	REGION	RESEARCHERS	SPECIES	TIME AND GEAR	PHYSICAL	NUTRIENTS	CHLOROPHYLL	ZOOPLANKTON	DIET	GROWTH	MIGRATION	PREDATORS
RUSSIA	Western Kamchatka	Erokhin, Karpenko	Pink, chum, sockeye, Chinook, coho salmon	September-October 1981, 1982, 1984, 1986, 1987, 1989, 1990, 1991, 1995, 1997, 1999, 2001-2003, 2005 Surface trawl	X			X	X	X	X	X
	Eastern Sakhalin	Shubin, Radchenko	Pink, chum and masu salmon	June-August; 1998-2008; Surface trawl	X			X	X	X	X	
	Primorye (including sea shelf and deepwater part)	Blagod'erov, Ilyinskiy	Pink, chum, masu salmon	April-May 1991, June-July 1985, November 2003 Surface trawl	X			X	X	X	X	X
	Southern part of Okhotsk sea	Shuntov, Lapko, Radchenko, Loboda	Pink, chum, sockeye,chinook, coho and masu salmon	October-November 1991,1993-1995, 1998-2008 June-August 1991-1997 Surface trawl	X			X	X	X	X	X
USA	California	McFarlane, Harding	Chinook salmon	March-October; 1995-2005; Surface trawl	X		X	X	X	X	X	
	California, Oregon	Brodeur, Emmett	Chinook and coho salmon	June and August; 2000, 2002; Surface trawl	X	X	X	X	X	X	X	X
	Oregon, Washington	Casillas, Brodeur	Coho and Chinook salmon	May, June, September; 1998-2008; Surface trawl	X	X	X	X	X	X	X	
	Oregon, Washington	Emmett	Coho and Chinook salmon	April- August; 1998-2008; Surface trawl	X		X	X	X		X	
	Southeast Alaska	Orsi	Pink and chum salmon	May-August; 1999-2008; Surface trawl	X		X	X	X	X	X	X
	Northern Gulf of Alaska	Helle, Farley, Moss	Pink and chum salmon	July and August; 1995-2002; Surface trawl	X	X	X	X	X	X	X	

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COUNTRY	REGION	RESEARCHERS	SPECIES	TIME AND GEAR	PHYSICAL	NUTRIENTS	CHLOROPHYLL	ZOOPLANKTON	DIET	GROWTH	MIGRATION	PREDATORS
USA	Prince William Sound	Willette, Cooney	Pink salmon	June-August; 1994-1999; Seine, Acoustic	X			X	X	X	X	X
	Northern Gulf of Alaska	Haldorson, Boldt, Beauchamp, Myers	Pink, chum and coho salmon	July and August; 2001 and 2004; Surface trawl	X			X	X	X	X	
	Northern Gulf of Alaska	Haldorson, Boldt	Pink, chum and sockeye salmon	1998-2001; Gill net	X	X	X	X	X	X	X	X
	Bering Sea	Farley, Moss, Eisner, Murphy	Sockeye, chum, pink and coho salmon	August-October; 2000-2008; Surface trawl	X	X	X	X	X	X	X	
	Chukchi Sea	Murphy, Eisner, Farley, Moss	Pink and chum salmon	August and September; 2003 and 2007; Surface trawl	X	X	X	X	X	X	X	X

NORTH PACIFIC ANADROMOUS FISH COMMISSION

A LONG-TERM RESEARCH AND MONITORING PLAN (LRMP) FOR PACIFIC SALMON *(ONCORHYNCHUS* SPP.*)* IN THE NORTH PACIFIC OCEAN

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