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Workshop Synopsis

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The intent of the workshop was to bring experts together and get as close as possible to identifying exactly why pink and chum salmon abundances and catches continue to increase. As with any important event, it is reasonable to ask how successful we were, recognizing that such an assessment can also be a function of individual expectations. A number of agencies provided financial and logistical support; some provided funds without being asked. This, surely, was an indication that the topic was important and timely and that agencies had confidence in the NPAFC and the participants. Every invited speaker agreed to participate, another indication that people considered the workshop necessary. The location was perfect, the breaks were long enough for meaningful discussion, and everyone seemed to be ready for some serious thinking.

Although we did not identify exactly why pink and chum salmon abundances continue to increase, we did consolidate interpretations. The synopsis is our summary of the workshop. We benefited from the excellent notes taken by Dawn Steele. To summarize interpretations, the first four sections of the synopsis are organized around the targets for the workshop: (1) identify pink and chum salmon production trends by region, (2) identify reasons for high production of pink and chum salmon and low production of other salmon species, (3) predict future production of salmon, and (4) identify key areas of future research. The latter two sections include advice for fisheries management and a summary of conclusions drawn from the workshop. References cited in the synopsis refer to the authors as they are listed in this technical report.

Pink and Chum Salmon Production Trends by Region

Since the 1980s, the patterns of pink salmon catch in the Russian Far East have shown increased variability, including unexpectedly high and low returns (Radchenko). Radchenko suggested the reason for increased production variability is complex. More dependency on finding prey in the winter may help explain why there has been increased variability in Russian catches of pink salmon and possibly all odd-year pink salmon catches. One of the determinants of change in stock abundance of Kamchatkan pink salmon is the relative contributions of northern subpopulations (Shevlyakov and Koval). Pink salmon catches of southern Chukotka have increased, particularly for odd-year runs. In 2011 pink catches were almost equal to chum salmon catches, which were the dominant run (Khokhlov).

Pink salmon populations returning to Hokkaido increased substantially from 1975 to 2000 (Iida et al.). Despite stable hatchery fry releases, recent pink salmon catches exhibit a biennial oscillation dominated by odd-year runs.

Total chum salmon production from the western Pacific (Korea, Japan and Russia) has increased since the 1970s, with catches reaching 350,000 metric tonnes in recent years (Kim et al.). Chum salmon traditionally contributed the majority (70–88%) of salmon production along the southern coastline of Chukotka from fish spawning in the Anadyr River watershed (Khokhlov). Since 1995, Anadyr chum salmon abundance has been increasing and abundance trends for these fish show fluctuations in the 40- to 50-year period. Since 2000, Kamchatka chum salmon catches along both coasts have increased threefold as compared to the previous decade (Zavarina).

The trend for total annual returns of Japanese chum salmon from 1965–2010 shows increases for Honshu and Hokkaido, followed by a decrease in Honshu since the late 1990s and in Hokkaido since the early 2000s (Qin and Kaeriyama). Fluctuations in returning Japanese chum salmon stocks have increased recently (Nagasawa and Azumaya). Freshwater survival is high because most Japanese chum salmon originate in hatcheries and managers expect consistent returns. However, large inter-annual fluctuation in rates of chum salmon returning to different areas of Hokkaido has been observed since the late 2000s (Miyakoshi and Nagata). Miyakoshi and Nagata observed recent returns of chum salmon are historically high in the Okhotsk Sea region, relatively low in the Sea of Japan region, and highly variable in the Pacific Ocean region of Hokkaido.

Pink and chum salmon are abundant in the Gulf of Alaska and the fish in this region originate from nine major production areas of Asia and North America (Heard and Wertheimer). Alaska commercial harvest (as a proxy for run strength) showed declines in the 1950s and 1970s. Since the start of hatchery programs in the 1970s, pink

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and chum salmon abundance have rebounded. The Pacific Decadal Oscillation (PDO) shifted at around this time, and likely had positive effects on pink and chum salmon survival (Heard and Wertheimer). With chum hatchery development in 1979, hatchery chum have become an increasingly large proportion of total chum salmon commercial harvest in Southeast Alaska and Prince William Sound. In Kodiak, the contribution of hatchery chum salmon is much lower (Heard and Wertheimer).

In Southeast Alaska, pink and chum salmon represent 93% of the total salmon harvest (Orsi et al.). Most of the pink harvest is wild production and most of the chum salmon harvest is hatchery production (Piston and Heinl). Piston and Heinl reported pink salmon harvests, which started increasing in the 1980s, have declined since 2000, with periodic shifts between odd- and even-year dominance. While remaining at high levels, pink salmon harvests have declined from an average of 49 million per year in the 1990s to an average of 40 million fish per year since 2001. Chum salmon catches began increasing in the 1990s, largely due to hatchery enhancement, and have also declined since 2000. Estimated harvests of wild chum did not rebound to the same degree as pink salmon and have recently declined to levels similar to those of the 1970s (Piston and Heinl).

Generally, pink salmon assessments show increasing productivity of Fraser River and Puget Sound populations over the long term, with odd-year runs doing better than even-year runs for fish from the same watershed (Irvine et al.). Total returns of Fraser River pink salmon increased after the 1977-78 regime shift, decreased after the 1989 regime shift, increased again after the 1998 regime shift, and were unusually high in 2010 and 2011 (Beamish). Beamish observed a weak relationship between Fraser River fry abundance and total returns for the same brood year, but no clear relationship between downstream fry counts and CPUE of juveniles in July and September surveys in the Strait of Georgia, or between total adult returns and CPUE in juvenile surveys. Average size of juvenile pink salmon has been larger in July, but no meaningful relationship was found between larger juvenile body size and total adults returns.

Surveys in the northern California Current catch juvenile pink and chum salmon at different periods (Weitkamp et al.). Pink salmon are caught only in September in the northern section off Washington State. These fish likely originate from Puget Sound and the Fraser River and enter the ocean around the southern end of Vancouver Island. Their survey results show little relationship between juvenile pink salmon abundance and adult returns from the same brood year. Chum salmon are more abundant in May and June, and by September are mostly gone from the northern survey section. These chum salmon likely originate from the many short coastal rivers and juveniles appear to grow rapidly through the summer. Sampling programs in the early 1980s indicated juvenile chum salmon were much larger than those sampled in recent years. The reasons for this may be increased size-selective mortality, less competition with Chinook salmon in the 1980s, or other unspecified reasons (Weitkamp et al.).

Population abundance of chum salmon originating in the Columbia River and southwards to Newport, Oregon, is highly variable and has fallen more than 80% from historic levels (Johnson et al.). Genetics and run-timing data show that Oregon coastal chum salmon are a single evolutionarily significant unit, and they have a narrower time window for spawning than other Northwest chum stocks. Chum salmon are resilient, but their need for access to rivers and estuaries necessitates preservation of lower river spawning habitats (Johnson et al.).

Reasons for High Production of Pink and Chum Salmon and Low Production of Other Salmon

At the workshop, explanations for the high production of pink and chum salmon fit into three general areas that are not exclusive, but may be working in combination to produce the current trends of salmon abundance. First, environmental factors provide opportunities for salmon to consume prey more frequently, thus allowing them to grow more quickly. Second, particular biological and life history characteristics of pink and chum salmon make them more responsive than other salmon species to favourable environmental conditions. Third, human activities, such as improved stock enhancement, reductions in harvest, and responsible fisheries management, contribute to increased production of pink and chum salmon.

Environmental factors contributing to high abundance of pink and chum salmon

There was convincing evidence given at the workshop that large-scale atmospheric processes can be used as an index of pink and chum production. Favourable ocean conditions for salmon production (at least in northern areas) may have increased ocean carrying capacity. Salmon prey production links climate variability to growth of individual salmon and that prey production appears to be increasing.

Wild pink salmon abundance increased in most regions of the North Pacific after the mid 1970s regime shift. The recent rise of abundance and biomass in Russian far eastern salmon stocks, and West Kamchatka pink salmon stocks in particular, could be related to the shift of dominant modes of sea surface temperature variability in the North

Pacific and North Atlantic in the second half of the 1990s (Krovnin and Klovach). These observations identify the importance of integrating the larger-scale hemispheric and possibly planetary influences into regional interpretations of climate effects and salmon production.

Agler et al. suggested the growth of western Alaska chum salmon and Bugaev and Tepnin mentioned catches of Asian pink and chum salmon were under the indirect influence of a complex of indicators for climate and of sea condition. Comparison of the PDO and Japanese chum salmon returns dating back to the 1960s shows high synchronicity since the early 1990s (Nagasawa and Azumaya). Recent increases in Hokkaido chum salmon returns may be due to favourable ocean conditions (Miyakoshi and Nagata). High abundance of Gulf of Alaska pink and chum salmon was attributed, at least in part, to favourable ocean conditions after the 1976/1977 regime shift that led to increased survival (Heard and Wertheimer). Abundance remained relatively high after the 1989 regime shift and in some regions of southeast and central Alaska (excluding Prince William Sound) further increases suggest environmental factors played a role (Ruggerone et al.). Large returns of pink salmon to the Fraser River and Puget Sound also point to pink salmon production increases due to favourable ocean conditions (Beamish). Productivity in the northern California Current is strongly driven by the PDO, with a negative PDO linked to good survival for juvenile salmon (Weitkamp et al.).

Evidence was presented indicating the depth and stability of the mixed layer depth in winter and spring was linked with climate. A mechanism was described for bottom-up control of pink salmon biomass (Chiba et al.). Change in climate produces a shallow mixed-layer depth in winter and weak water-column stratification in spring, which leads to an increase in spring-summer copepod abundance and greater pink salmon biomass.

It is the linkage between climate and prey production through ocean processes that appears to be the key to improving the ability to forecast more accurately. This makes sense; but exactly how can a large-scale climate state have such important impacts on the thousands of populations of pink and chum salmon in their early marine period throughout the Subarctic Pacific? Part of the explanation appears to be in the feeding strategy of pink and chum salmon. For northern salmon populations, increases in sea temperature (within limits) benefit fish growth, and this is likely a major factor for the high survival of Kamchatka salmon in recent decades (Karpenko and Koval). While there may not be a direct relationship between temperature and food, warmer sea temperatures could indicate increased production of preferred food items for salmon. Conversely, in spring with low sea surface temperatures in nearshore areas, the delay of juvenile chum salmon migration out of the littoral zone can adversely affect survival (Kasugai et al.).

Biological and life history characteristics contributing to high abundance of pink and chum salmon

Workshop attendees identified unique biological and life history characteristics of pink and chum salmon that enable them to preferentially benefit from current climate conditions. The life history of pink and chum salmon ensures they enter the ocean quickly after eggs hatch and enter early in the year, coinciding with earlier springs and earlier zooplankton prey availability (Ruggerone et al.).

Both pink and chum salmon spend the majority of their lives at sea. Vertical and horizontal migration at sea allows salmon to choose their preferred temperatures. This could mitigate (to some degree) the impact of warming environmental conditions (Morita). Species with long obligatory freshwater life phases in streams and rivers, such as masu, coho, and Chinook salmon, may experience lower survival rates because their movement is limited, making it harder for them to find preferred temperatures over the long term (Morita).

There was general agreement among workshop participants that brood year strength is determined early in the marine year for both pink and chum salmon. In particular, pink salmon abundance is formed in the early marine period (Shevlyakov and Koval), primarily by fry abundance (Kaev), number of spawning females (Beamish), and early marine survival (Beamish; Kaev; Orsi et al.). Pink salmon grow rapidly at sea and show a high risk/high reward life strategy with a higher survival rate per egg than other salmon (Ruggerone et al.). During coastal residency, juvenile salmon growth is strongly correlated to survival, however, external conditions such as zooplankton abundance has not yet been linked directly to salmon body size (Hasegawa et al.) Studies in both Russia and British Columbia suggest as few as 10% to 50% of juveniles survive their first month at sea. After this early phase, mortality may be low from this point on until return of adults (Orsi et al.). Rapid growth at sea likely contributes to higher overall survival.

Analysis of pink salmon scale growth patterns show that faster growing fish have higher survival and larger fish survive stressful winters better (Beamish). Several growth studies show pink salmon that survive the initial marine entry period have higher growth at sea (Ruggerone et al.). Early marine growth is known to be important to survival, while density dependent impacts are more apparent in later life (Radchenko; Ruggerone et al.).

Among Pacific salmon, species-specific feeding strategies have dramatic effects on survival and growth. Specific morphological and physiological features play a role in their feeding strategies and growth rates (Karpenko and Koval). Beamish suggested pink salmon may have different seasonal lipid storage patterns than other salmon that could enable them to be more responsive to fluctuations in ocean conditions. Pink salmon grow much faster than chum salmon over the marine winter, spring, and following summer because they consume more high- and average-caloric prey species (Karpenko and Koval). This plays a role in their readiness to spawn after one year at sea.

There may be different feeding strategies in the early marine period for odd- and even-year pink salmon. It is possible odd-year pink salmon store fewer lipids and continue to grow with the expectation that the energy needed in the winter can be found from improved prey production (Beamish). Different feeding and energy-use strategies could also explain why odd-year pink salmon tend to be larger than even-year pink salmon. From about the time of the 1977 regime shift, total catches of both odd- and even-year lines of pink salmon increased. However, it is relevant that in the past two decades it is the catch of odd-year pink salmon that has continued to increase. This suggests possible differences in food production and utilizations between the two broodlines in the past two decades. There are clear genetic differences between the odd- and even-year salmon (Seeb et al.).

Chum salmon consume the widest prey spectrum among Pacific salmon (Karpenko and Koval). Possessing an elongate digestive tract and high rate of digestion, chum salmon are uniquely adapted among the salmon species to digest gelatinous zooplankton having low energy content. Chum salmon survive because of less competition with other salmon for lower-caloric food (Karpenko and Koval). With a slower growth rate and variable maturity schedule, chum can remain at sea for a longer period than pink salmon.

Workshop participants presented several viewpoints on whether the large abundance of pink salmon, particularly in the Bering Sea and other locations, could negatively affect the abundance of chum and sockeye salmon. The mechanism suggested is food competition as there is diet overlap between pink, sockeye, and chum salmon. Cyclic changes in chum salmon lipid levels, diet, and returns to Hokkaido coincided with dominant odd-year run pink salmon (Kaga et al.; Saito et al.). Sockeye salmon responses to competition include reduced adult length at age at the end of the second year at sea, reduced sockeye smolt survival and abundance, and delayed maturation (Ruggerone et al.). However, there was no negative impact demonstrated between Asian pink salmon abundance and smolt-to-adult survival of Bristol Bay sockeye salmon (Wertheimer and Farley). The reason might be measurement error, or shifts in the distribution of Asian pink salmon in the ocean (Ruggerone et al.). Ruggerone et al. suggested shifts in ocean conditions may be the primary driver of species abundance, and competition may have a secondary effect that becomes more important when prey production is poor.

The importance of competition and density dependent interactions at sea in determining overall stock abundance will remain an open question until evidence clearly shows that shared prey resources are limited. Under present conditions, however, competitive interactions do not appear to stop abundances of pink and chum salmon from increasing.

Some participants expressed doubt there is limited forage supply for salmon in the North Pacific. Analysis of a long-term data series (1980–2011) of zooplankton sampling and salmon feeding conditions indicates there is sufficient food supply for salmon (Naydenko). Naydenko suggested that in the upper pelagic layer of the Russian far eastern seas and Northwest Pacific consumption of forage resources by salmon was insignificant and recent increases in salmon abundance would not cause significant changes to the trophic structure of the region. Declining body size at return for Anadyr chum salmon was associated with strong growth reduction after the first year of life in past decades in the Bering Sea and North Pacific (Zavolokin et al.). Negative correlations between temperature indices and Anadyr chum salmon growth after the first year indicate warming of the North Pacific, rather than density-dependent interactions, may adversely impact chum salmon growth after the early marine period of life (Zavolokin et al.). Russian studies continue to show it is unlikely the food supply for Pacific salmon is limiting once they arrive in the open ocean because salmon do not form schools at sea, which may explain continuing increases of pink and chum salmon.

Human activities contributing to high abundance of pink and chum salmon

Increased total catches of pink and chum salmon are related to management changes as well as climate changes. Hatchery production is the most important intervention, but reduced exploitation rates and the concern for the protection of freshwater habitats have also contributed to increased abundances. Recent increases in Hokkaido chum salmon adult returns result from improved hatchery techniques, particularly by increasing the size of fish at release and improving release timing to maximize smolt survival (Miyakoshi and Nagata). In the Magadan region, production is increased by annual release of artificially-reared chum into rivers that produce wild pink salmon (Safronenkov and Volobuev). These rivers do not support wild chum because they have no natural chum salmon spawning habitat. Because pink and chum salmon return at different times this procedure eliminates inter-specific ecological risks (Safronenkov and Volobuev). Elimination of the high seas fisheries for Pacific salmon in the North Pacific contributed to increases in pink and chum salmon abundance in the Gulf of Alaska (Heard and Wertheimer) and to total North Pacific production (Morita). By reducing fishing mortality for odd-year Fraser River pink salmon, responsible fisheries management largely explains increases in their adult returns in recent years (Irvine et al.). Better treatment of wild stocks and improved international coordination among North Pacific salmon producing countries through bilateral relationships and the NPAFC contributed to high abundance of salmon in the Gulf of Alaska (Heard and Wertheimer).

Future Production of Salmon

Workshop organizers requested participants speculate about what they thought was the likely future production of pink and chum salmon. Would it remain high, stable, or decrease through time? Most presenters suggested current high levels will likely decrease in the future. Krovnin and Klovach suggested salmon catches in the Russian Far East are likely to remain high for at least the next five years and may remain so through the end of the current warm phase of the Atlantic Multidecadal Oscillation (another 10 to 16 years). Based on a 60- to 65- year cyclic climate oscillation model, Klyashtorin and Klovach suggested a general decrease of Pacific salmon production in the 2010-2020s. According to the cyclic hypothesis, the change, when it occurs, will initiate a general declining trend in both pink and chum salmon, perhaps to levels that occurred before the mid 1970s. However, hatcheries, now a major producer of juveniles, make it difficult to relate impacts of future cyclic shifts back to the pre-1970s. In addition, there are decadal-scale climate changes within these longer 60-year cycles. These considerations aside, it remains important to recognize that large-scale climate events can affect abundance trends in pink and chum salmon.

Increasing pink salmon abundance in the Chukotka region was noted by Khokhlov, who speculated that areas previously dominated by chum salmon may be replaced by pink salmon as the principle catch. Kaev suggested abrupt changes in catches and synchronous declines of early-run pink salmon in the Sakhalin-Kuril area might indicate environmental instability and presage future abundance declines. If the forage base of the North Pacific is limited, Karpenko and Koval speculated future increases in Pacific salmon productivity will be limited and difficult to forecast. Strong density-dependent effects at high population levels could adversely affect salmon growth and future productivity (Agler et al.; Qin and Kaeriyama).

A continued warming climate will likely negatively affect species dependent on long freshwater life stages (Morita). Koshino et al. suggested decreased future abundance of naturally spawning fish will reduce transport of marine-derived nutrients to terrestrial ecosystems. The sea surface temperature warming trend predicted for the East Sea may cause Korean chum salmon to have trouble accessing the cool open waters of the North Pacific, significantly affecting ocean migration patterns (Kim et al.). Qin and Kaeriyama warned that continued global warming will decrease the ocean's carrying capacity by reducing the area of chum salmon distribution, and they predicted Hokkaido chum salmon could lose their migration route to the Okhotsk Sea by 2050 and suffer a population crash by 2100.

Key Areas for Future Research

Presenters made a number of suggestions for future research. These included addressing the appropriate scale in research questions; examining salmon food availability; studying conditions of salmon ocean growth, feeding, body condition, and fecundity; investigating salmon ocean migration and distribution; increasing capabilities for stock identification; and determining useful indicators for salmon run forecasting.

Several presenters emphasized the importance of choosing the appropriate scale of predictors and response indicators for salmon populations. Radchenko suggested future work focus on spatial differentiation of seasonal races and regional groupings because fish seem to be responding to local environmental differences at small scales. Heard and Wertheimer suggested if survival patterns correlate better at the meso-scale (100 km), it might be advantageous to find important environmental correlates at the same scale, rather than at larger scales. Comparison of marine growth patterns between close and more distantly located populations of British Columbia pink, chum, and sockeye salmon was proposed (Oka et al.). Orsi et al. suggested a large scale indicator was linked to chum harvest and survival rates, and both large and small scale indicators were linked to pink salmon harvest and survival in the Gulf of Alaska.

More extensive use of zooplankton data to evaluate salmon food availability and quality was suggested. Bevan et al. emphasized differences in nutritional quality of salmon prey, especially fatty acid composition, varies significantly between species and life history stages. Bevan et al. and Radchenko suggested future research focus on salmon productivity and prey availability at area and time scales relevant to salmon feeding. Analytical techniques for detecting stable nitrogen isotopes in amino acids could be used to improve estimation of salmon trophic level variation by eliminating the contaminating effects of isotope signals in phytoplankton and source water (Chiba et al.).

Suggestions were made to have future studies concentrate on investigations of salmon growth, feeding, body condition, and fecundity. Comparison of winter and spring growth on fish scales from spatially diverse populations of chum salmon could be used to estimate winter growth conditions (Zavolokin et al.). Diet differences between odd- and even-year juvenile pink salmon was proposed as a way to look at long-term consequences for salmon production (Kaev). Beamish advised future studies to determine if pink salmon have a unique seasonal pattern of lipid storage and utilization. Along similar lines, Radchenko suggested gathering data on salmon energy contents and physiology at sea to develop an index of optimal physiological conditions for each life phase with the goal of improving run forecasts. For future stock status assessments, Irvine et al. suggested examining fecundity in addition to spawner abundance to improve measurement of stock productivity.

Expanding investigations on salmon distribution and migration in the inshore zone and ocean wintering areas was suggested (Radchenko). Kim et al. indicated migration and distribution experiments are needed to monitor possible shifts in ocean distribution in response to changing environmental conditions. Future increases in otolith-marked releases of Japanese chum salmon and additional high-seas sampling will help to increase accuracy of forecasting returns to Japan (Urawa et al.). Shevlyakov and Koval suggested run forecasting of East Kamchatka stocks would be more informative if there were easy methods to differentiate stocks caught in mixed-stock aggregations. Orsi et al. suggested further refinement of geospatial migration models of major stock and age groups of Southeast Alaska salmon.

Several presentations proposed future research to enhance genetic techniques in providing information on stock distribution. There was a suggestion to expand the PacSNP baseline to include additional SNPs that would be useful for fine-scale local analysis of stock distribution (Templin et al.). Sato et al. speculated that maturing chum salmon caught in the Chukchi Sea surveys might be on their way to spawn in Arctic Rivers and suggested genetic baselines be expanded to include rivers from that region.

Future research directions are increasing the capabilities of salmon stock identification using genetic, scale pattern, and otolith analyses. Shpigalskaya et al. suggested Cytb/D-loop polymorphism of the mtDNA fragment is an informative marker for regional separation of pink salmon stocks in mixed-stock samples and Seeb et al. reported on progress in comparing even- and odd-year pink salmon DNA sequencing for widely divergent North American stocks. Future research on stock identification based on scale patterns of pink salmon will require more baseline information to characterize all pink salmon spawning regions (Savin et al.). Chistyakova et al. demonstrated sufficient variation and resolution to differentiate chum salmon stock origins at a regional level using otolith microstructure.

Identifying control mechanisms using ecosystem metrics and process studies for developing better forecast models was proposed (Orsi et al.). Process studies and development of models of ocean salmon survival (Shevlyakov and Koval) including salmon prey and salmon predators (Khokhlov), and models linking climate, salmon, and their prey (Bugaev and Tepnin) were suggested to better understand salmon population abundance and improve salmon run forecasting. Increased coordination and communications among researchers will help to identify promising ecosystem indicators and researchers might consider developing an annual ocean salmon assessment report (Orsi et al.).

Advice for Fisheries Management

Although suggesting advice for fisheries management was not a specific target of the workshop, several presenters made proposals. Fisheries managers were advised to prepare for greater future variability in salmon production. Initiating a discussion establishing international agreements for management of the common pool of ocean salmon prey resources was suggested to reduce competition among stocks (Peterman et al.). Conclusions from modeling current climate, ocean carrying capacity, market, and chum salmon stock conditions indicated that the present hatchery releases of about 1 billion Japanese chum salmon maximizes total income to fishermen (Kishi et al.). Hatchery managers might consider revising their practices to address future climate and habitat changes (Miyakoshi and Nagata). Careful hatchery operations are needed to protect genetic diversity and fitness of wild salmon (Yu et al.). Restoration efforts to improve freshwater environments and technical investments for protecting wetlands are crucial for management of salmon resources (Liu et al.). Kim et al. suggested experts from across different disciplines need to work together effectively and begin considering climate impacts on salmon behaviour, production, and economics in fishery management plans. If ocean salmon carrying capacity decreases in the future, the need for sustainable, adaptive Pacific salmon management plans that include powerful feedback control systems for climate, biological, and ecosystem factors will become paramount (Qin and Kaeriyama).

Conclusions

It appears we are closer to the explanation for the recent increase in chum and pink salmon abundance, but we still lack the understanding that will allow forecasts to be used in the long-term planning of fisheries and hatcheries. The short period in fresh water and the early ocean entry of pink and chum salmon fry are well synchronized to an apparent earlier production of prey in the nearshore area. The warmer ocean appears to be producing more prey for both pink and chum salmon. The feeding strategies of pink and chum salmon seem well matched to increased production of higher and lower caloric prey in the open ocean in the winter and spring. Odd-year pink salmon are more productive and grow larger than even-year pink salmon because they may eat more and use more of their energy for growth. However, if 60-year cycles affect plankton production, it is possible that within the next two decades there will be a reversal of the present trend. If Subarctic Pacific warming continues, salmon could begin to lose their migration route to ocean rearing areas and that could lead to loss of some stocks by the turn of this century.

Although the workshop did not answer the question, it did bring a better focus to the work that needs to be done. The solution will eventually appear and, like many things, it will appear simple. However, the solution may appear sooner rather than later, if the friendly and productive working relationships that were developed at the workshop are continued.