NPAFC
Doc. 491
Rev.

Japanese Salmon Research under the NPAFC Science Plan: A Review and Future Issues

Shigehiko Urawa[*1], Yukimasa Ishida[*2], and Masa-aki Fukuwaka[*2]

[*1]*National Salmon Resources Center, Fisheries Agency of Japan,*
2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan
[*2]*Hokkaido National Fisheries Research Institute, Fisheries Agency of Japan,*
116 Katsurakoi, Kushiro, Hokkaido 085-0802, Japan

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

JAPAN

October 2000

This paper may be cited in the following manner:
Urawa, S., Y. Ishida, and M. Fukuwaka. 2000. Japanese salmon research under the NPAFC science plan: a review and future issues (NPAFC Doc. 491) 12 p. Hokkaido National Fisheries Research Institute, Fisheries Agency of Japan, Katsurakoi, Kushiro, Hokkaido 085-0802, Japan.

Japanese Salmon Research under the NPAFC Science Plan: A Review and Future Issues

Shigehiko Urawa[*1], Yukimasa Ishida[*2], and Masa-aki Fukuwaka[*2]

[*1]*National Salmon Resources Center, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan*
[*2]*Hokkaido National Fisheries Research Institute, Fisheries Agency of Japan, 116 Katsurakoi, Kushiro, Hokkaido 085-0802, Japan*

Abstract

This paper provided a review of the results of Japanese salmon research conducted under the NPAFC Science Plan in 1993-2000, following several future research issues proposed for the sustainable stock management of Pacific salmon. Recent developments of stock identification techniques and high-seas salmon population surveys provided new information for the ocean distribution of chum salmon: Japanese chum salmon inhabit the Okhotsk Sea in the early ocean life, pass the first winter in the western North Pacific Ocean, and then migrate to the Bering Sea by the next summer. Coastal surveys suggested that major salmon mortalities occur in the early ocean life, but the causes of juvenile mortalities have not been well understood. Scale pattern analysis suggested that Japanese chum salmon suffer from growth reduction in the Bering Sea, resulting in increase of age at maturity. A long term biological monitoring in the subarctic North Pacific Ocean found a negative relationship between macrozooplankton and pink salmon biomass. A similar biological monitoring should be important in the Bering Sea. The extremely low lipid contents in the muscle of overwintering salmon indicated a great difficulty for them to survive in winter. Future research issues are (1) juvenile salmon studies in the Okhotsk Sea, (2) winter salmon studies in the North Pacific Ocean, (3) salmon ecology studies in the Bering Sea, and (4) monitoring of major salmon stocks. These issues may be incorporated into a new NPAFC Science Plan.

Introduction

The North Pacific Anadromous Fish Commission (NPAFC) was established under the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean, signed on February 11, 1992 and entered into force on February 16, 1993 by Canada, Japan, the Russian Federation and the United States. The primary objective of NPAFC is to promote the conservation of anadromous stocks in the North Pacific Ocean and adjacent waters.

At the 1993 NPAFC annual meeting, the Committee on Scientific Research and Statistics (CSRS) identified two critical issues for research by the parties: (1) factors affecting current trends in ocean productivity, and (2) factors affecting changes in biological characteristics such as growth, size and age at maturity, oceanic distribution, survival, and abundance of Pacific salmon. The CSRS developed the NPAFC Science Plan to address these two critical issues by three components: (1) life history of salmonids, (2) salmonid population dynamics, and (3) salmonid habitat and ecosystem. Each component has several items that identify questions relating to the two critical issues. Under the NPAFC Science Plan, the Parties make each research plan, cooperating in the scientific research.

At the 1998 NPAFC annual meeting, the Science Sub-committee (SSC) has decided that a substantial revision will be made for the present Science Plan after the 1999 NPAFC symposium based on NPAFC activities in the period of 1993-99. At the Research Planning and Coordinating Meeting held in March 2000, it is recommended that each Party will provide the Chairman of SSC with a review of research completed under the present Science

Plan.

Abstracts of the recent results by Japanese salmon research were compiled by Fisheries Agency of Japan (1997) and Urawa and Ishida (1998, 1999). The purposes of this paper are to review the results of Japanese salmon research related with the present Science Plan, and to propose future research for the appropriate conservation and utilization of Pacific salmon.

Review of Research

1. Life History of Salmonids

1.1 Spatial Distribution

Intensive high-seas tag releases showed approximate ocean distribution of Japanese chum salmon (*Oncorhynchus keta*) (see Ogura, 1994), but the ocean migration route was not been decided especially during the early ocean life period and winter season. Recent developments of stock identification techniques and salmon population surveys have provided new information for the ocean distribution of chum salmon (see a review by Urawa, 2000).

In coastal waters of northern Japan, juvenile chum salmon change their spatial distribution from inshore to offshore regions with their growth (Kaeriyama, 1986; Fukuwaka and Suzuki, 1998a). Juvenile chum salmon migrate from Japanese coasts to the Okhotsk Sea in the first summer, and reside there by late fall (Ueno, 1998; Urawa et al., 1998b). When the sea surface temperature (SST) decreased less than 5ºC in the Okhotsk Sea, juveniles migrated to the western North Pacific Ocean, where they overwintered with other Asian juvenile stocks (Urawa and Ueno, 1997, 1999; Urawa et al., 1998b). In summer, Japanese immature and maturing chum salmon were abundant in the Bering Sea, but rarely in the North Pacific waters (Urawa et al., 1997; Urawa, 2000). In the following winters, Japanese immature chum salmon were mainly distributed in the Gulf of Alaska (Urawa et al., 1997).

Seawater temperature should be an important factor to affect the ocean distribution of salmon, but favorite temperatures differ depending on fish species and season. In winter, most salmonids were captured in northern waters of the North Pacific Ocean at SST 4-8°C (Ueno et al., 1999). Planktophagous salmonids may have a survival strategy to stay in such cold waters in order to reduce their energetic consumption, because zooplankton as prey is not abundantly available in winter (Nagasawa, 2000).

In the Bering Sea, CPUE of pink salmon (*O. gorbuscha*) was extremely higher in odd years than in even years, while chum salmon showed opposite CPUE trends. Chum salmon shifted their distribution to southeastward in odd years. These results suggest that the spathial distribution of chum salmon may be affected by abundance of pink salmon (Azumaya et al., 1999).

Maturing salmon with depth-sensing ultrasonic transmitters moved in particular directions and maintained their ground speeds and directions during day and night (Ogura and Ishida, 1995; Ogura, 1999). Archival tags showed that maturing chum salmon dived into mid-waters (about 50 m in depth) and rose to surface waters very frequently at daytime, which might be related to location and orientation for their homing migration (Wada and Ueno, 1999). In the Pacific coasts of northern Honshu where SST was over 20ºC in fall, adult chum salmon frequently dived to depths exceeding 100 m before returning to the native river. Duration of deep dives tended to be prolonged as the thermal difference between sea surface and bottom water increased, indicating that salmon sought the coolest thermal refuge that they could exploit by vertical movement. Thermal refuge could be a way for salmon to minimize metabolic energy cost (Tanaka et al., 2000).

It is still unclear why Japanese chum salmon concentrate in the Okhotsk Sea at juvenile stage and in the Bering Sea at immature and maturing stages. Further studies are necessary to clarify relations between oceanographic conditions, productivity of food organisms, and salmonid distribution.

1.2 Growth and Maturity

Density dependence is one of possible causes for the recent increase of age and decrease of size at maturity for chum salmon in the North Pacific Ocean (Ishida et al., 1993, Kaeriyama, 1996a). Limited prey resources in the ocean may lead to density-dependent growth of Pacific salmon during rapidly growing season (Ishida et al., 1998). A scale pattern analysis showed that Japanese chum salmon suffered from growth reduction after the second year of ocean life (Kaeriyama, 1998). Urawa (2000) estimated that these growth reduction may occur in the Bering Sea, where chum salmon density increases in summer. A growth reduction of chum salmon in the third year of ocean life may be partly due to a requirement of immature age 0.2 fish chum salmon to consume a large amount of prey (Ishida and Davis, 1999).

Techniques to estimate somatic growth or age of chum and sockeye salmon (*O. nerka*) have been improved using otolith or scale patterns (Fukuwaka, 1996; Fukuwaka and Kaeriyama, 1997; Endo et al., 1998), while biochemical approach is also useful to assess somatic growth. Contents of nucleic acids or lipids suggested that strategies of resource allocation for somatic growth is different among Pacific salmon, and growth characteristics depend on life stages (Azuma et al., 1998). The total lipid content and lipid classes in the muscle and liver of pink and chum salmon were examined for estimating their trophic condition in the ocean (Nomura et al., 1999). The extremely low lipid contents in winter suggest that chum and pink salmon are confronted with a great difficulty to live during this season. Further studies of seasonal and spatial variation in lipid content among North Pacific salmonids may better estimate changes in trophic conditions experienced by salmon during their high seas residency.

Endocrinological studies found that homing migration relates closely to gonadal maturation of Pacific salmon (Fukaya et al., 1998; Kitahashi et al., 1998a, 1998b; Ueda, 1998). The fecundity of mature female chum and sockeye salmon was positively correlated with their fork length, but the egg size did not show any correlations with the body size (Ishida et al., 1995; Kaeriyama et al., 1995). However, it is not known how growth variations affect maturation and reproduction.

1.3 Feeding Ecology

In coastal waters, juvenile chum salmon fed more on large zooplankton such as copepods or polychaetes, when such organisms were abundant or when stomach fullness of fish was high (Suzuki and Fukuwaka, 1998). In inshore waters (5-15 m in depth) where juvenile chum salmon were distributed, prey zooplankton was less than at deeper layer (30 m) in offshore waters (Seki and Shimizu, 1998).

In the central North Pacific and the Bering Sea, age 0.1 chum salmon contained a relatively high proportion of amphipods as compared to the other age groups, while prey composition was similar among older chum salmon (age 0.2 to 0.5) (Ishida and Davis, 1999). In the same regions, chum salmon changed their dominant diet from gelatinous zooplankton (such as pteropods, appendicularians, or jellyfishes) in 1991, when pink salmon were abundant, to a diet of crustaceans (such as euphausiids, copepods, or amphipods) in 1992, when pink salmon were less abundant (Tadokoro et al., 1996). Local crustacean biomass had significant negative correlation with the CPUE of pink salmon in 1991 and that of chum salmon in 1992.

2. Salmonid Population Dynamics

2.1 Abundance, Monitoring, and Forecasting

The synchronous decreasing body size and increasing age at maturity of Hokkaido chum salmon occurred in face of rising marine survival rates and ocean conditions favorable for growth, suggesting that reduced growth and increasing age at maturity was due to density dependent intraspecific competition and high abundance of chum salmon in the North Pacific Ocean (Kaeriyama, 1996a, 1996b, 1998).

Every summer, salmon stock assessment researches were conducted in the North Pacific Ocean and Bering Sea. Abundance of salmon in offshore areas based on CPUE of research gillnet operations may be used to develop pre-season forecasts of Japanese chum salmon and Bristol Bay sockeye returns (Ishida and Ito, 1998).

2.2 Mortality

Fukuwaka and Suzuki (1998b) calculated that in the Sea of Japan the early ocean mortality of chum salmon accounted for 97.4% of their total ocean mortality. However, few studies clarified the causes of ocean mortalities in juvenile salmon.

Field and experimental studies showed that the ectoparasitic flagellate *Ichthyobodo necator* cause high mortalities among juvenile chum salmon soon after migrating into the coastal seawater (Urawa, 1993, 1996a, 1996b). Further studies should be conducted to evaluate other pathological organisms as the cause of natural mortalities of salmon.

Although over 90 fish species have been reported to occur with chum salmon juveniles, there is no evidence that fish predation has much impact on the number of returning adult chum salmon in Japan (Nagasawa and Kaeriyama, 1995; Nagasawa and Mayama, 1997; Nagasawa, 1998b). On the other hand, rhinoceros auklets (*Cerorhinca monocerata*) and black-tailed gulls (*Larus crassirostris*) have been recorded as predators of juvenile chum salmon. These seabirds abundantly breed in northern Japan, and the impact of their predation on chum salmon populations may be significant (Nagasawa et al., 1998b). More field and experimental works are necessary to assess the mortality of juvenile chum salmon caused by predation by fishes and seabirds.

Relatively high positive correlation coefficients were found between the survival rate of Russian pink salmon and SST in the Okhotsk Sea and the waters off the East Kamchatka during fry emigration period in August (Azumaya et al., 1998). The survival rate of Alaskan pink salmon was also positively related to SSTs in the waters along the west coast of North America in August. These results suggest that the survivals of pink salmon are affected by SST changes at a local level.

Salmon shark (*Lamna ditropis*) occupy the highest trophic level in the food web of subarctic waters, where salmonids are their major prey item. Nagasawa (1998a) estimated that salmon sharks consumed 73-146 x 10^6 salmonids from spring to autumn in 1989, which corresponded to 12.6-25.2% of the total annual run of Pacific salmon for that year. Salmon shark may highly cause the ocean mortality of immature and maturing salmon.

2.3 Stock Interaction

Kawamura et al. (1998) showed potential feeding interactions between chum salmon and fat greenling (*Hexagrammos otakii*) juveniles along the northern coast of Hokkaido. In the Okhotsk Sea, prey species (diet niche) overlap was highest between pink and chum salmon, but inter-specific competition might be lesser importance in their diets (Tamura et al., 1999).

Hiyama et al. (1999) suggested that there were density-dependent effects on the body size and spawning success of pink salmon in the Japan Sea. It is suggested that an interaction between pink and chum salmon changes the spatial distribution of chum salmon in the offshore waters (Azumaya et al., 1999).

2.4 Stock Identification

Scale characters of chum salmon collected in Japanese and Russian local stocks were compared to establish a stock identification technique and baseline data on scale characters (Niita and Ueno, 1999). These results demonstrated that scale characters used in this study were effective for stock identification of age 4 maturing fish and not sufficient for of age 3 maturing fish. Other new characters are necessary to identify the stock origin of chum salmon.

A genetic stock identification technique using allozyme variations has been well developed, and this technique is frequently applied for the stock identification of high-seas chum salmon (Urawa and Ueno, 1997, 1999; Urawa et al., 1997, 1998b, 2000a).

The continental origins of chinook salmon (*O. tshawytscha*) in the North Pacific Ocean and Bering Sea were successfully estimated by using two freshwater parasites (*Myxobolus arcticus* and *M. kisutchi*) as biological tags (Urawa et al., 1998a). However, parasite species useful as biological tags are limited.

Recently thermal otolith marking has been applied to hatchery-released juvenile salmon for their identification in the western coasts of North America. Many thermally marked chum and pink salmon were recaptured in the Gulf of Alaska (Kawana et al., 1999; Urawa et al., 2000a). Japan also started thermal mark releases in the spring of 1999. The initial aim of thermal mark programs is to provide information for the ocean migration and survival of each regional salmon stock in Japan. The number of thermal mark releases from Japanese hatcheries will increase year by year (Urawa et al., 2000b).

3. Salmon Habitat and Ecosystem

3.1 Physical-biological Interaction and Productivity

Year-to-year variations in biomass of phytoplankton and macrozooplankton, and abundance of pink salmon were examined in summer from 1985 to 1994 in the subarctic North Pacific Ocean. After 1989, phytoplankton biomass and pink salmon abundance showed corresponding yearly patterns, whereas the pattern shown by macrozooplankton biomass was always the inverse of that shown by phytoplankton and salmon. These patterns suggest that macrozooplankton biomass remained low when pink salmon were abundant due to the intense feeding impact of pink salmon, which in turn allowed phytoplankton biomass to remain high as a result of the lesser grazing effect of macrozooplankton (Shiomoto et al., 1997). Similar relationships among phytoplankton, macrozooplankton, and salmonid biomass were observed along the north-south transect in the North Pacific Ocean and Bering Sea in the summers of 1992 and 1993 (Nagasawa et al., 1999).

East-west distributions of total and size-fractionated chlorophyll a concentration and primary productivity were determined at the surface in the subarctic North Pacific during November and December 1992. It is suggested that more turbulent water column conditions induced by high wind velocity was an advantageous factor for survival of large phytoplankton in the surface layer, and hence the high total chlorophyll a concentration and primary productivity were achieved in the western and central subarctic North Pacific (Shiomoto et al., 1999).

3.2 Climate Change Effects

During the period from the mid-1970s to the late 1980s, the Aleutian Low Pressure Index (ALPI) was high, but both sea surface temperature and zooplankton biomass in the Oyashio region remained low. Although the annual catch of pink salmon along the east coast of Sakhalin gradually increased from the 1960s to 1977, it declined from 1978 to 1984 despite decreasing catches by the Japanese high-seas salmon fishery. The coastal catch trend was similar to long-term changes in zooplankton biomass in the Oyashio region, suggesting that east Sakhalin pink salmon production is affected by climate and zooplankton production in this region (Nagasawa, 1998c, Nagasawa et al., 1999). Pink salmon catch on the east coast of Sakhalin declined from mid-1970s to the late 1980s but sharply increased in 1989. Catch of pink salmon on the Hokkaido coast showed a similar trend and dramatically increased 1991. Pink salmon from these regions stay as juveniles in the Okhotsk Sea. The low catch for the mid-1970s through the 1980s was closely related to increased sea-ice cover in the southern

Okhotsk Sea in response to intensifying of the ALPI. The 1989-1991 sharp increase in catch was in accordance with decreased sea-ice cover in the southern Okhotsk Sea corresponding to weakening of the ALPI (Nagasawa et al., 2000). Return rates of Japanese chum salmon did not indicate a significant relation with the ALPI. However, carrying capacity estimated for odd-year pink salmon in the North Pacific Ocean indicated a significant relation with the ALPI (Kaeriyama, 1997). Because the impact of the ALPI differs between regions in North America and Asia, and also among salmon species, research on climate change and ocean production is needed on both regional and whole North Pacific scales (Nagasawa, 1998c).

Future Salmon Research

Several questions identified in the NPAFC Science Plan have been resolved in cooperation with scientists of Canada, Russia and the United States, while others are not yet settled (Table 1). The major purpose of Japanese salmon research is to accomplish sustainable fisheries, balancing the conservation and use of salmon stocks in the North Pacific ecosystem. Recent studies are showing the main ocean distribution of Japanese chum salmon. They inhabit in the Okhotsk Sea in the first summer and fall, overwinter in the western North Pacific Ocean, and migrate to the Bering Sea by the next summer. Immature chum salmon migrate to the Gulf of Alaska for overwinter after intensive feeding in the Bering Sea. In accordance with these seasonal migration, we should concentrate future salmon studies to population dynamics and ocean ecosystems in specific waters. These research are (1) juvenile salmon studies in the Okhotsk Sea, (2) winter salmon studies in the North Pacific Ocean, (3) salmon ecology studies in the Bering Sea, and (4) monitoring of major salmon stocks. These issues may be incorporated into a revised new NPAFC Science Plan.

Juvenile Salmon Studies in the Okhotsk Sea

The previous studies indicated that Asian salmon stocks inhabit in the Okhotsk Sea during summer and fall in the first year of ocean life. The early ocean life in Pacific salmon may be the most critical period. In order to develop the demography of juvenile salmon, we should concentrate the following research items:

Seasonal distribution and migration of juvenile salmon
Population size and survival estimates of juvenile salmon
Feeding competition and growth change of juvenile salmon
Primary production and food animals

Winter Salmon Studies in the North Pacific Ocean

Recent winter salmon studies indicate that Japanese chum salmon stay in the western North Pacific Ocean during the first winter, while in the Gulf of Alaska during the following winters. Biochemical analysis suggests that winter is one of the critical periods for salmon population. To elucidate impacts of winter ocean environments on salmon survivals, future research issues are:

Winter distribution of salmon
Population size and survival estimates of overwintering salmon
Survival strategies of salmon in winter

Salmon Ecology Studies in the Bering Sea

Recently, the depression of ocean growth was observed in salmon stocks originating both the Asian and American coasts. Current studies suggest that salmon growth reduction may occur in the Bering Sea, when many salmon migrate in the waters for their feeding and growth in summer. To clarify relations between the growth and mortality of salmon and the carrying capacity in the Bering Sea, we focus the following research items:

Climate change and primary production
Production of food animals

Population size and distribution of major salmon stocks
Feeding competition and growth change of salmon

Monitoring of Major Salmon Stocks

A monitoring program should be continued to assess the status of major salmon stocks for their proper management.

Annual changes in the number of adult returns
Annual changes in body size and age at maturity, and fecundity
Genetic monitoring for stock conservation

References

Azuma, T., T. Yada, Y. Ueno, and M. Iwata. 1998. Biochemical approach to assessing growth characteristics in salmonids. N. Pac. Anadr. Fish. Comm. Bull., 1: 103-111.

Azumaya, T., Y. Ishida, and Y. Ueno. 1999. The long-term mean spatial and temporal distribution of CPUE for pink salmon (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*) in the North Pacific Ocean. Salmon Report Series 47: 129-136.

Azumaya, T., Y. Ishida, Y. Ueno, and K. Watanabe. 1998. Long-term and spatial correlations between survival rates of pink salmon (*Oncorhynchus gorbuscha*) and sea surface temperatures in the North Pacific Ocean. NPAFC Technical Report. pp. 16-17.

Endo, Y., O. Watarai, and M. Igarashi. 1998. Age determination off salmon using scale pattern analysis. J. School Marine Sci. Tech. Tokai Univ. 46: 1-15.

Fisheries Agency of Japan. 1997. A summary of research results by Japan related to the NPAFC Science Plan for 1992 to 1997. (NPAFC Doc. 286) National Research Institute of Far Seas Fisheries, Fisheries Agency of Japan, Shimizu, Japan.

Fukaya, M., H. Ueda, A. Sato, M. Kaeriyama, H. Ando, Y. Zohar, A. Urano, and K. Yamauchi. 1998. Acceleration of gonadal maturation in anadromous maturing sockeye salmon by gonadotropin-releasing hormone analog implantation. Fish. Sci. 64: 948-951.

Fukuwaka, M. 1996. Allometric back-calculation of individual growth for chum salmon otolith during early life. Sci. Rep. Hokkaido Salmon Hatchery 50: 113-116.

Fukuwaka, M., and M. Kaeriyama. 1997. Scale analyses to estimate somatic growth in sockeye salmon, *Oncorhynchus nerka*. Can. J. Fish. Aquat. Sci., 54: 631-636.

Fukuwaka, M., and T. Suzuki. 1998a. Role of a riverine plume as a nursery area for chum salmon *Oncorhynchus keta*. Mar. Ecol. Prog. Ser., 173: 289-297.

Fukuwaka, M., and T. Suzuki. 1998b. Early sea mortality of chum salmon juveniles in the Japan Sea coast. (NPAFC Doc. 335) 6 p. National Salmon Resources Center, Fisheries Agency of Japan, 2-2 Nakanoshima, Toyohira-ku, Sapporo 062-0922, Japan.

Hiyama, Y., S. Hasegawa, and F. Kato. 1999. Density-dependent effects on body weight of the pink salmon in the Japan Sea. Bull. Japan Sea Natl. Fish. Res. Inst., 48: 17-25.

Ishida, Y., and N. D. Davis. 1999. Chum salmon feeding habits in relation to growth reduction. Salmon Report Series, 47: 103-110.

Ishida, Y., and S. Ito. 1998. Salmon abundance in offshore waters of the North Pacific Ocean and its relationship to coastal salmon returns. N. Pac. Anadr. Fish Comm. Bull., 1: 334-339.

Ishida, Y., S. Ito, Y. Ueno, and J. Sakai. 1998. Seasonal growth patterns of Pacific salmon (*Oncorhynchus* spp.) in offshore waters of the North Pacific Ocean. N. Pac. Anadr. Fish. Comm. Bull., 1: 66-80.

Ishida, Y., S. Ito, M. Kaeriyama, S. McKinnell, and K. Nagasawa. 1993. Recent changes in age and size of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean and possible causes. Can. J. Fish. Aquat. Sci., 50: 290-295.

Ishida, Y., D. W. Welch, and M. Ogura. 1995. Potential influence of North Pacific sea-surface temperatures on increased production of chum salmon (*Oncorhynchus keta*) from Japan. p.271-275. In R.J. Beamish[ed.] Climate change and northern fish populations. Can. Spec.

Publl. Fish. Aquat. Sci. 121.
Kaeriyama, M. 1986. Ecological study on early life of the chum salmon *Oncorhynchus keta* (Walbaum). Sci. Rep. Hokkaido Salmon Hatchery, 40: 31-92. (In Japanese with English summary.)
Kaeriyama, M. 1996a. Population dynamics and stock management of hatchery-reared salmon in Japan. Bull. Natl. Res. Inst. Aquaculture, Suppl. 2: 11-15.
Kaeriyama, M. 1996b. Effects of population density and habitat environment on life history strategy and migration of juvenile sockeye (*Oncorhynchus nerka*) and chum salmon (*O. keta*). Sci. Rep. Hokkaido Salmon Hatchery, 50: 101-111.
Kaeriyama, M. 1997. Biomass of Pacific salmon and climate change in the North Pacific Ocean. Bull. Jpn. Soc. Fish. Oceanogr., 61: 75-77. (In Japanese.)
Kaeriyama, M. 1998. Dynamics of chum salmon, *Oncorhynchus keta*, populations released from Hokkaido, Japan. N. Pac. Anadr. Fish Comm. Bull., 1: 90-102.
Kaeriyama, M., S. Urawa, and M. Fukuwaka. 1995. Variation in body size, fecundity and egg size and kokanee salmon *Oncorhynchus nerka*, released from hatchery. Sci. Rep. Hokkaido Salmon Hatchery, 49: 1-9.
Kawamura, H., M. Miyamoto. M. Nagata, and K. Hirano. 1998. Interaction between chum salmon and fat greenling juveniles in the coastal Sea of Japan off northern Hokkaido. N. Pac. Anadr. Fish Comm. Bull., 1: 412-418.
Kawana, M., S. Urawa, G. Anma, Y. Kamei, T. Shoji, M. Fukuwaka, K. Munk, K. W. Myers, and E. V. Farley, Jr. 1999. Recoveries of thermally marked maturing pink salmon in the Gulf of Alaska in the summer of 1998. Bull. National Salmon Resources Center, 2: 1-9.
Kitahashi, T., D. Alok, H. Ando, M. Kaeriyama, Y. Zohar, H. Ueda, and A. Urano. 1998a. GnRH analog stimulates gonadotropin II gene expression in maturing sockeye salmon. Zool. Sci., 15: 761-765.
Kitahashi, T., H. Ando, M. Ban, H. Ueda, and A. Urano. 1998b. Changes in the levels of gonadotropin subunit mRNAs in the pituitary of pre-spawning chum salmon. Zool. Sci., 15: 753-760.
Nagasawa, K. 1998a. Predation by salmon sharks (*Lamna ditropis*) on Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean. N. Pac. Anadr. Fish Comm. Bull., 1: 419-433.
Nagasawa, K. 1998b. Fish and seabird predation on Juvenile chum salmon (*Oncorhynchus keta*) in Japanese coastal waters, and an evaluation of the impact. N. Pac. Anadr. Fish Comm. Bull., 1: 480-495.
Nagasawa, K. 1998c. Long-term changes in climate, zooplankton biomass in the western North Pacific, and abundance and size of east Sakhalin pink salmon. NPAFC Technical Report. p. 35.
Nagasawa, K. 2000. Winter zooplankton biomass in the Subarctic North Pacific, with a discussion on the overwintering survival strategy of Pacific salmon (*Oncorhynchus* spp.). N. Pac. Anadr. Fish Comm. Bull., 2. (In press.)
Nagasawa, K., Y. Ishida, and M. Hirai. 2000. Long-term changes in abundance of Pacific herring (*Clupea pallasi*) and pink salmon (*Oncorhynchus gorbuscha*). Beyond El Nino: A Conference on Pacific Climate Variability and Marine Ecosystem Impacts, from the Tropics to the Arctic. Program and Abstracts Book. p. 70.
Nagasawa, K., and M. Kaeriyama. 1995. Predation by fishes and seabirds on juvenile chum salmon (*Oncorhynchus keta*) in coastal waters of Japan: a review. Sci. Rep. Hokkaido Salmon Hatchery, 49: 41-53. (In Japanese with English summary.)
Nagasawa, K., and H. Mayama. 1997. Additional fish predators of juvenile chum salmon (*Oncorhynchus keta*) in coastal waters of Japan, with a note on the importance as predators of juvenile masu salmon (*O. masou*). Tech. Rep. Hokkaido Salmon Hatchery, 166: 29-33. (In Japanese.)
Nagasawa, K., A. Shiomoto, K. Tadokoro, and Y. Ishida. 1999. Latitudinal variations in abundance of phytoplankton, macrozooplankton, salmonids, and other epipelagic fishes in the northern North Pacific Ocean and Bering Sea in summer. Bull. Nat. Res. Inst. Far Seas

Fish., 36: 61-68.
Niita, A., and Y. Ueno. 1999. Stock identification of chum salmon, *Oncorhynchus keta*, based on scale character analysis. Salmon Report Series, 47: 94-101.
Nomura, T., H. R. Carlson, S. Urawa, H. Mayama, M. Fukuwaka, Y. Ueno, and Y. Ishida. 1999. Variations in lipid content of high-seas chum and pink salmon. (NPAFC Doc. 423) 9 p. National Salmon Resources Center, Fisheries Agency of Japan, Toyohira-ku, Sapporo 062-0922, Japan.
Ogura, M. 1994. Migratory behavior of Pacific salmon (*Oncorhynchus* spp.) in the open sea. Bull. Nat. Res. Inst. Far Seas Fish., 31: 1-139. (In Japanese with English summary.)
Ogura, M. 1999. Rapid dives and ascents of sockeye salmon *Oncorhynchus nerka* observed by ultrasonic telemetry in the open sea. Fish. Sci., 65: 659-660.
Ogura, M., and Y. Ishida. 1995. Homing behavior and vertical movements of four species of Pacific salmon (*Oncorhynchus* spp.) in the central Bering Sea. Can. J. Fish. Aquat. Sci., 52: 532-540.
Seki, J., and I. Shimizu. 1998. Diel migration of zooplankton and feeding behavior of juvenile chum salmon in the central Pacific coast of Hokkaido. Bull. Natl. Salmon Resources Center, 1: 13-27.
Shiomoto, A., K. Tadokoro, K. Nagasawa, and Y. Ishida. 1997. Trophic relations in the subarctic North Pacific ecosystem: possible feeding effect from pink salmon. Mar. Ecol. Prog. Ser., 150: 75-85.
Shiomoto, A., M. Nanba, K. Nagasawa, and Y. Ueno. 1999. East-west distributions of chlorophyll a, primary productivity and their size compositions in the early winter subarctic North Pacific. La mer, 37: 67-79.
Suzuki, T., and M. Fukuwaka. 1998. Variation in prey size selectivity of fingerling chum salmon (*Oncorhynchus keta*) in sea life: Effects of stomach fullness and prey abundance. N. Pac. Anadr. Fish. Comm. Bull., 1: 138-145.
Tadokoro, K., Y. Ishida, N. D. Davis, S. Ueyanagi, and T. Sugimoto. 1996. Change in chum salmon (*Oncorhynchus keta*) stomach contents associated with fluctuation of pink salmon (*O. gorbuscha*) abundance in the central subarctic Pacific and Bering Sea. Fish. Oceanogr., 5: 89-99.
Tamura, R., K. Shimazaki, and Y. Ishida. 1999. Trophic relations of juvenile salmon (genus *Oncorhynchus*) in the Okhotsk Sea and Pacific waters off the Kuril Islands. Salmon Report Series, 47: 138-168.
Tanaka, H., Y. Takagi, and Y. Naito. 2000. Behavioural thermoreguation of chum salmon during homing migration in coastal waters. J. Exp. Biol., 203:1825-1836.
Ueda, H. 1998. Correlations between homing, migration and reproduction of chum salmon. N. Pac. Anadr. Fish. Comm. Bull., 1: 112-117.
Ueno, Y. 1998. Distribution, migration, and abundance estimation of Asian juvenile salmon. Salmon Report Series, 45: 83-103.
Ueno, Y., Y. Ishida, K. Nagasawa, and T. Watanabe. 1999. Winter distribution and migration of Pacific salmon. Salmon Report Series, 48: 60-79.
Urawa, S. 1993. Effects of *Ichthyobodo necator* infections on seawater survival of juvenile chum salmon (*Oncorhynchus keta*). Aquaculture, 110: 101-110.
Urawa, S. 1996a. Improvement of marine survival of chum salmon by the control of protozoan parasites. Bull. Natl. Inst. Aquaculture, Spec. Vol. 2: 3-6.
Urawa, S. 1996b. The pathobiology of ectoparasitic protozoans on hatchery-reared Pacific salmon. Sci. Rep. Hokkaido Salmon Hatchery, 50: 1-99.
Urawa, S. 2000. Ocean migration route of Japanese chum salmon with a reference to future salmon research. National Salmon Resources Center Newsletter, 5: 3-9. (In Japanese.)
Urawa, S. and Y. Ishida. 1998. Abstracts of 1997/98 Japanese research results related to the NPAFC science plan. (NPAFC Doc. 337) National Salmon Resources Center, Fisheries Agency of Japan, Toyohira-ku, Sapporo 062-0922, Japan. 17 p.
Urawa, S. and Y. Ishida. 1999. Abstracts of 1998/99 Japanese research results related to the NPAFC science plan. (NPAFC Doc. 427) National Salmon Resources Center, Fisheries

Agency of Japan, Toyohira-ku, Sapporo 062-0922, Japan. 21 p.

Urawa, S., Y. Ishida, Y. Ueno, S. Takagi, G. Winans, and N. Davis. 1997. Genetic stock identification of chum salmon in the North Pacific Ocean and Bering Sea during the winter and summer if 1996. (NPAFC Doc. 259) National Salmon Resources Center, Fisheries Agency of Japan, Toyohira-ku, Sapporo 062-0922, Japan. 11 p.

Urawa, S., M. Kawana, G. Anma, Y. Kamei, T. Shoji, M. Fukuwaka, K. M. Munk, K. W. Myers, and E. V. Farley, Jr. 2000a. Geographical origin of high-seas chum salmon determined by genetic and thermal otolith markers. N. Pac. Anadr. Fish. Comm. Bull., 2. (In press.)

Urawa, S., M. Kawana, and T. Ishiguro. 2000b. Releases of thermally marked salmon from Japan in 1999 and 2000 with a thermal mark plan for 2000 brood year stocks. (NPAFC Doc. 461) 7 p. National Salmon Resources Center, Fisheries Agency of Japan, Toyohira-ku, Sapporo 062-0922, Japan.

Urawa, S., K. Nagasawa, L. Margolis, and A. Moles. 1998a. Stock identification of chinook salmon (*Oncorhynchus tshawytscha*) in the North Pacific Ocean and Bering Sea by parasite tags. N. Pac. Anadr. Fish Comm. Bull., 1: 199-204.

Urawa, S., and Y. Ueno. 1997. Genetic stock identification of chum salmon (*Oncorhynchus keta*) in the North Pacific Ocean in the winter of 1996. Salmon Report Series, 43: 97-104.

Urawa, S., and Y. Ueno. 1999. The geographical origin of chum salmon (*Oncorhynchus keta*) caught in the western and central North Pacific Ocean in the winter of 1998. Salmon Report Series, 48: 52-58.

Urawa, S., Y. Ueno, Y. Ishida, S. Takagi, G. Winans, and N. Davis. 1998b. Genetic stock identification of young chum salmon in the North Pacific Ocean and adjacent seas. (NPAFC Doc. 336) National Salmon Resources Center, Fisheries Agency of Japan. 9 p.

Wada, K., and Y. Ueno. 1999. Homing behavior of chum salmon determined by an archival tag. (NPAFC Doc. 425) Hokkaido National Fisheries Research Institute. 29 p.

Table 1. A contribution of Japanese salmon research to clarify questions identified in the NPAFC Science Plan.

Questions	Reference
1. Life History of Salmonids	
1.1 Spatial Distribution	
When and where do salmon concentrate in highest density?	Azumaya et al., 1999; Urawa, 2000
Does sea surface temperature regulate salmon distribution?	Ueno, 1998
Does interaction between different species and different stocks affect the distribution?	Azumaya et al., 1999
Are juvenile salmon distributed in oceanographically protected waters?	Ueno, 1998
Is salmon distribution related to distribution of predators or competitors?	Azumaya et al., 1999
Do oceanographic conditions and productivity of food organisms affect salmonid distribution, and is there a trend in this influence at various periods during their life history?	
1.2 Growth and Maturity	
When and where does growth variation of salmon occur?	Ishida et al., 1993, 1998; Kaeriyama, 1998
Which life history stage is the most important for determining growth variation (juvenile, immature, maturing, or returning adult)?	Kaeriyama, 1998
What factors (salmon density, sea temperature, food resources, competitors, predators) affect growth variation?	Kaeriyama, 1998
How does growth variation affect maturation and reproduction?	
1.3 Feeding Ecology (Diet)	
Is salmon diet species-specific?	Ishida and Davis, 1999
Is the composition of food specific to salmon species?	
Does salmon diet change by salmon density?	Tadokoro et al., 1996
Does salmon diet reflect the abundance of food items?	Suzuki and Fukuwaka, 1998
Does salmon diet affect salmon growth, and survival?	
Does salmon diet relate to salmon distribution and population numbers?	
Does salmon abundance regulate food supply or does food supply regulate salmon abundance?	Shiomoto et al., 1999
2. Population Dynamics	
2.1 Abundance, Monitoring, and Forecasting	
Does salmon abundance on the high seas provide a good estimate of adult returns? Where and When?	Ishida and Ito, 1998
What are the most important and effective monitoring items?	
How can carrying capacity be estimated?	
What determines changes in carrying capacity of salmon?	
How can a strategy of forecasting be determined for the commercial returns in various populations?	
What factors are related to changes in carrying capacity?	Ishida et al., 1995

Table 1 (continued).

Questions	Reference
Do changes in carrying capacity alter salmon abundance and production?	
What are the environmental variables that control carrying capacity?	
Does carrying capacity change with changing climate? If so, by what mechanism?	
Can the Ricker model be used to estimate the carrying capacity of salmon?	
2.2 Mortality	
What factors are related to salmon survival (return rate)?	Azumaya et al., 1998
Do predators and/or competitors affect salmon survival?	Nagasawa, 1998a, 1998b
What is the relationship among starvation, disease, temperature, and mortality?	Urawa, 1996; Nomura et al., 1999
Does over-wintering affect mortality?	Nomura et al., 1999; Nagasawa, 2000
Which period is critical for determining the abundance of the various species, populations, and age-groups?	Fukuwaka and Suzuki, 1998b
2.3 Stock Interaction	
Does stock interaction affect growth, distribution, diet, and reproduction?	Kawamura et al., 1998; Tamura et al., 1999
2.4 Stock Identification	
Are baseline data (genetic, parasite, etc.) stable?	Urawa et al., 1998a
What salmon stocks are identifiable with each of the various techniques?	Urawa et al., 2000a
How accurate and precise are the stock identification estimates?	Niita and Ueno, 1999; Urawa et al., 2000a
3. Salmon Habitat and Ecosystem	
3.1 Physical-biological Interaction and Productivity	
Does the Aleutian Low affect production?	Kaeriyama, 1997
Does salmon abundance affect productivity?	Shiomoto et al., 1997
Is productivity in the western, central, and eastern North Pacific different?	Shiomoto et al., 1999; Nagasawa, 2000
3.2 Climate Change Effects	
Does sea ice affect salmon production?	Nagasawa et al., 2000
What are the effects on southern distribution limits of salmon?	Ueno et al., 1999
What are the effects on food supply and predators of salmon?	Nagasawa, 1998c
In what way do meteorological changes affect productivity? Is there a trend?	
3.3 Regime Effects (Temporal and Spatial)	
How can regime shifts be detected?	
Are ancient salmon otoliths and scales available for retrospective analyses?	
Are regime shifts reflected in hard parts (scales, otoliths, etc.)?	
Are there other indicators (parameters) that permit tracking the changes?	