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Japanese Bibliography in 2012-2014 for NPAFC Science Plan

by

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ABSTRACT: This bibliography listed original papers and documents published in 2012-2014 by Japanese scientists and their collaborators in order to review Japanese national researches for the 2011-2015 NPAFC Science Plan. The bibliography includes 39 articles with abstracts, corresponding to five research components of the NPAFC Science Plan.

BACKGROUND

In 2010, the Science Sub-Committee (SSC) of the North Pacific Anadromous Fish Commission (NPAFC) developed a new five-year Science Plan (2011-2015) (Anonymous 2010). The SSC identified an overarching research theme “Forecast of Pacific Salmon Production in the Ocean Ecosystems under Changing Climate” and five research components: 1) Migration and survival mechanisms of juvenile salmon in the ocean ecosystems; 2) Climate impacts on Pacific salmon production in the Bering Sea (BASIS) and adjacent waters; 3) Winter survival of Pacific salmon in the North Pacific Ocean; 4) Biological monitoring of key salmon populations; and 5) Development and application of stock identification methods and models for management of Pacific salmon.

The national research plan by Japan was established in March 2011 to correspond to the new NPAFC Science Plan (Fisheries Agency of Japan 2011). The primary goal is to accomplish sustainable salmon fisheries with the conservation of wild and hatchery stocks in the North Pacific ecosystems. To review Japanese national researches for the NPAFC Science Plan, the previous bibliography listed original papers and documents published in 2010-2011 and 2011-2012 by Japanese scientists and/or their collaborators (Sato et al. 2011, 2012). The current issue supplemented 39 articles published in 2012-2014. The bibliography includes abstracts for all articles.

Anonymous. 2010. North Pacific Anadromous Fish Commission Science Plan 2011-2015. NPAFC Doc. 1255. 34 pp. (Available at www.npafc.org).

Fisheries Agency of Japan. 2011. Japanese salmon research under the NPAFC Science Plan 2011-2015. NPAFC Doc. 1311. 3 pp. (Available at www.npafc.org).

Sato, S., T. Nagasawa, and S. Urawa. 2011. Japanese bibliography in 2010-2011 for NPAFC Science Plan. NPAFC Doc. 1346. 14 pp. (Available at www.npafc.org).

Sato, S., T. Nagasawa, and S. Urawa. 2012. Japanese bibliography in 2011-2012 for NPAFC Science Plan. NPAFC Doc. 1417. 16 pp. (Available at www.npafc.org).

BIBLIOGRAPHY

Component 1: Migration and Survival Mechanisms of Juvenile Salmon in the Ocean Ecosystems

Hasegawa, K., and S. Takahashi. 2013. Microscale environments along the seaward migration route of stocked chum salmon fry. Transactions of the American Fisheries Society 142 (5): 1232-1237.

The microscale environment (e.g., current velocity) along the migratory route of aquatic organisms may directly affect their performance (e.g., migration speed or survival). We used minnow traps to evaluate how stocked Chum Salmon Oncorhynchus keta fry use stream velocity to optimize seaward migration. We found that fry were primarily captured at night and the number of fry collected was higher in traps with faster velocity water at the entrance to the trap. We interpreted this to mean that the fry were optimizing their migration efficiency by using faster velocity areas, which promote more rapid downstream migration.

Hasegawa, K., T. Sato, and K. Sasaki. 2013. Distinguishing local growth from immigration-based size shifts for juvenile chum salmon communities in coastal Hokkaido, northern Japan. Fisheries Science 79 (4): 611-616.

The body size of juvenile fish is often used as an index of growth rate, which in turn is influenced by local habitat conditions. We evaluated the size and origin of juvenile Chum salmon *Oncorhynchus keta* in the coastal areas of three regions (Atsuta, Shari, and Konbumori) of Hokkaido, northern Japan. The origin of the individuals in these communities differed between Konbumori and the other two regions. The former contained juveniles that originated from both the nearest stocked river and other rivers that were outside the area of interest. Conversely, the communities in Atsuta and Shari consisted exclusively of fish from the nearest stocked river. Moreover, the juveniles in Konbumori were larger than those in Atsuta and Shari. The results of our otolith analysis suggest that the larger size of the fish in Konbumori was due to the immigration of large individuals from natal rivers at distant locations. Thus, immigrants were likely to enlarge their body size composition in the area of interest. In summary, if the distance from a natal river is adjusted and daily growth is taken into account, body size can be used as an indicator of growth performance in coastal juvenile chum salmon.

Kasugai, K., K. Takeuchi, Y. Miyakoshi, and M. Nagata. 2014. Estimation of number of downstream migrating chum salmon fry in the Nishibetsu River in 2006. Scientific Reports of Hokkaido Fisheries Research Institute 85: 37-40 (In Japanese with English abstract).

Marked chum salmon *Oncorhynchus keta* fry (n = 104,200) with a clipped right pelvic fin were released in the upper reaches on 28 April, and were recaptured with a rotary screw trap in the lower reaches of the Nishibetsu River, eastern Hokkaido, northern Japan in 2006. A total of 23 marked fish were recaptured between 5 and 26 days after release. To assess the trap efficiency, chum salmon fry clipped upper the lobe of the caudal fin (n = 5,970) were released at 2 km upper the trap, and seven fish were recaptured; trap efficiency was estimated at 0.13%. Right pelvic fin clipped chum salmon fry that passed the trap site were estimated at 17,167; the rate of recaptured fish against released fish was estimated at 16.5%.

Kasugai, K., M. Torao, M. Nagata and J. R. Irvine. 2013. The relationship between migration speed and release date for chum salmon *Oncorhynchus keta* fry exiting a 110-km northern Japanese river. Fisheries Science 79 (4): 569-577.

The relationship between release date and migration speed was examined for hatchery chum salmon *Oncorhynchus keta* fry exiting the Nishibetsu River in eastern Hokkaido, northern Japan so that future releases might be scheduled so that fry arrive at the ocean during periods favoring high survival. Separate marked groups of chum salmon released in early April, mid-April, and early May in 2008, late March and mid-April in 2009, and mid-April in 2010 were recaptured with a rotary screw trap 12 km above the river mouth. Chum salmon in later release groups tended to migrate downstream faster than fish in earlier release groups. Those released after mid-April arrived in the lower river on average 9 days after release, while those released before mid-April arrived on average 26-28 days after release. Most marked fish arrived in the lower river during late April to mid-May. These results suggest that chum salmon are adapted to adjust their migratory speed so as to arrive at the ocean during a relatively discrete period, presumably during a time of high productivity favoring good survival.

Miyakoshi, Y., M. Nagata, D. Ando, M. Fujiwara, and T. Aoyama. 2013. Fish predators of juvenile chum and pink salmon in coastal waters of Abashiri region, eastern Hokkaido. Scientific Reports of Hokkaido Fisheries Research Institute 83: 41-44 (In Japanese with English abstract).

Stomach contents of fish captured by gillnet, angling, and trawl in the coastal waters of Abashiri region were examined for the presence of juvenile chum salmon *Oncorhynchus keta* or pink salmon *O. gorbuscha* in May-June 2003-2005. The following 4 species were recognized as fish predators of juvenile chum and pink salmon in the coastal waters of Abashiri region; masu salmon *O. masou*, pointhead flounder *Hippoglossoides pinetorum*, kurosoi rockfish *Sebastes schlegelii*, and saffron cod *Eleginus gracilis*. In a review paper (Nagasawa, 1998), 9 species were listed as fish predators of chum salmon in Japanese coastal waters, but the latest 3 species were not included. In this paper, we newly add the 3 species, i.e. pointhead flounder, kurosoi rockfish, and saffron cod, as fish predators of juvenile chum or pink salmon.

Miyakoshi, Y., D. Ando, M. Fujiwara, H. Hayano, and M. Nagata. 2012. Downstream migration of chum salmon released in the Abashiri River. Scientific Reports of Hokkaido Fisheries Research Institute 82: 19-26 (In Japanese with English abstract).

To investigate the downstream migration of chum salmon *Oncorhynchus keta* in the Abashiri River, eastern Hokkaido, three groups of otolith-marked juveniles were released and sampled using cast nets in the lower reach of the river in 2004 and 2005. Marked chum salmon were recaptured within 2 weeks of release, and thereafter the numbers of fish recaptured quickly decreased. Our study indicates that most of chum salmon juveniles (over 0.8g in weight) released in the Abashiri River in May migrated seaward immediately after release. Only a few of the marked fish released at the end of May were recaptured and the river water temperature exceeded 20 °C in mid-June, indicating the survival of chum salmon released at that timing would be low unless they migrate immediately after release. The release timing in each river should be considered by examining the river and coastal water temperature around the release timing.

Mizuno, S., H. Urabe, T. Aoyama, H. Omori, A. Iijima, K. Kasugai, M. Torao, N. Misaka, N. Koide, and H. Ueda. 2012. Changes in activity and transcript level of liver and gill metabolic enzymes during smoltification in wild and hatchery-reared masu salmon (*Oncorhynchus masou*). Aquaculture 362: 109-120.

It is important for the success of the masu salmon, *Oncorhynchus masou*, stock enhancement program in Hokkaido (northern Japan) to demonstrate physiological problems in

hatchery-reared (hatchery) smolt for artificial release. The present study examined changes in liver and gill metabolic parameters in wild and hatchery masu salmon during smoltification and elucidated differences in hepatic and gill metabolism between wild and hatchery fish. As reference to freshwater-adapted wild and hatchery smolt in this study, metabolic parameters of coastal smolt were studied. Yearling wild and hatchery smolting fish were collected from the Ken-ichi River and the Donan Research Branch, which used Ken-ichi river water for fish culture, at the same time every month from March through May 2008. Coastal smolts were caught from Nemuro Bay of Hokkaido in June. Decreased hepatic glycogen content during smoltification, which was observed in wild fish and revealed activation of glycogenolysis, was not found in hatchery fish. Hatchery fish demonstrated a positive change in hepatic ATP content during smoltification, while wild fish showed negative change in the content, which reflected activated consumption of hepatic ATP stores during smoltification. Increases in gill pyruvate kinase activity during smoltification, which were found in wild fish and indicated activation of glycolysis, were not detected in hatchery fish. There was a difference in increased timing of hepatic citrate synthase activity during smoltification between hatchery and wild fish. Increased gill citrate synthase activity during smoltification, which was observed in wild fish and reflected enhancement of the citric acid cycle, was not found in hatchery fish. Hatchery smolt revealed lower liver cytochrome c oxidase activity and transcript levels of some respiratory chain enzymes compared to wild smolt in May, which suggested lower respiratory chain capacity in hatchery fish at mid-smolt stage. On the other hand, there were no remarkable differences in hepatic and gill 3-hydroxyacyl-coenzyme A dehydrogenase related to lipolysis and creatine kinase activities, which operate in resolution of creatine phosphate, during smoltification between hatchery and wild fish. These results suggested hatchery masu salmon had some metabolic problems with carbohydrate metabolism, the citric acid cycle, and the respiratory chain. Our study will give valuable information to improve physiological quality of hatchery smolt for artificial release.

Saito, T., K. Watanabe, K. Sasaki, and F. Takahashi. 2013. The dispersal pattern of juvenile chum salmon in the Pacific ocean off the coast of Hokkaido, Japan. NPAFC Technical Report 9: 21-22.

Coastal residency of juvenile chum salmon, *Oncorhynchus keta*, is thought to be the period that mass mortality takes place, which often influences their brood-year strength. Predation and/or oceanic conditions may be the main factors generating mortality, but detailed mortality processes are still unclear. Their widespread dispersal after sea entry and, if juvenile salmon were captured in the sea, unknown origin of the fish have impeded us from further understanding the mortality processes. Otolith thermal marking is a useful tool for judging the origin of juvenile salmon after their release. In eastern Hokkaido, otolith-marked juvenile chum salmon have been released into two rivers, the Kushiro River and the Tokachi River, since 2003 and 2005, respectively. Every year, these fish are recaptured in juvenile salmon surveys carried out in coastal waters near the Shiraoi and Konbumori coasts more than 300 km apart. The recapture of marked fish revealed that juvenile salmon out-migrating from rivers in eastern Hokkaido extend their coastal distribution toward the west to near the Shiraoi, which is the opposite direction of their migration route to what was expected. Comparing the otolith-marked juveniles that had the same origins (i.e., Kushiro or Tokachi river stocks) but that were recaptured in the two distant coastal areas (i.e., Shiraoi or Konbumori) would provide a new insight on the dispersal pattern of juvenile salmon during early ocean life and its consequences. In this study, we examine recapture data of otolith-marked juvenile chum salmon collected in coastal waters of the Shiraoi and Konbumori coasts in May-July of 2005-2010. In particular, the timing and body size at sea entry of chum salmon are individually estimated by their otolith daily growth increments. Based on these analyses, we

will demonstrate how the difference in migration history, such as timing and size at sea entry, affects their dispersal locations and discuss inter-annual variability in dispersal patterns.

Sasaki, K., K. Watanabe, F. Takahashi, and T. Saito. 2013. Coastal residence of juvenile chum salmon and their adult returns to the Ishikari River, Hokkaido. NPAFC Technical Report 9: 216.

Recent numbers of chum salmon returning to the Sea of Japan (SJ) region of Hokkaido fluctuate at low levels, as compared with those in other regions of Hokkaido. The Ishikari River stock is one of the largest stocks in the SJ region: approximately 30 million otolith-marked chum salmon juveniles are annually released from the Chitose Hatchery. To improve adult returns in the SJ region, an effective strategy is needed for recovering salmon stocks in the region. Early marine residence is considered a critical period for juvenile salmon survival. Identifying factors that affect juvenile survival during coastal residence is essential to improve the techniques of salmon propagation for better survival of released fish. In this study, we analyzed data from surface trawl surveys of juvenile chum salmon conducted at Atsuta, in the coastal area of the Ishikari River, in March-July of 2003-2008. We found that catch per unit of effort of otolith-marked juveniles was positively correlated with the return rates of adult salmon to the Ishikari River. This suggested that the abundance of marked fish recaptured at Atsuta was an indicator of survival during their early marine residence. Based on the results of these surveys, we will discuss factors affecting the survival of juvenile chum salmon, such as juvenile growth and environmental conditions.

Sato, T., K. Sasaki, M. Takahashi, and T. Nagasawa. 2013. Interannual variation in prey resources during the early ocean life of juvenile chum salmon in four coastal areas around Hokkaido, northern Japan. NPAFC Technical Report 9: 91.

The early ocean life of juvenile chum salmon is a critical phase in their life history. It is thought that high mortality occurs in this initial phase, which may be an important determinant of subsequent salmon population size. Previous studies suggested the survival of juvenile chum salmon is affected by both physical factors (e.g., temperature) and biological factors (e.g., prey environment). The state of the prey environment, such as zooplankton abundance and species composition, is important for the growth and survival of juvenile chum salmon during their early ocean life. In order to evaluate the prey environment during the early ocean life of juvenile chum salmon in the period between March and July, 1998-2010, we sampled zooplankton in four coastal areas: Atsuta along the Japan Sea coast, Shiraoi along the western Pacific coast, Konbumori along the eastern Pacific coast, and Shari along the Okhotsk Sea coast of Hokkaido. Zooplankton samples were collected with vertical tows by a NORPAC net (0.45 m mouth diameter, 0.33 mm mesh) during daytime. In addition, we examined the stomach contents of juvenile chum salmon caught by tow nets in each coastal area. Zooplankton commonly observed in all survey areas were hydrozoans, cladocerans, copepods, euphausiids, chaetognaths and appendicularians, and occasionally included meroplanktonic larvae (organisms that are planktonic for only a part of their life cycle) such as gastropods, polychaetes, decapods and echinoderms. Trends in interannual variation of zooplankton abundance and species composition were different among the coastal areas. We will identify the main prey organisms of juvenile chum salmon in each coastal area and evaluate how fluctuations in their abundance affect juvenile chum salmon during their early ocean life.

Urawa, S. 2013. Control of the parasitic flagellate *Ichthyobodo salmonis*, a causative agent of marine mortalities of juvenile chum salmon. NPAFC Technical

Report 9: 214-215.

Survival of juvenile salmon in the ocean is affected by various factors including diseases caused by infectious organisms. *Ichthyobodo salmonis* is an ectoparasitic flagellate infecting the skin and gills of salmonid fishes, such as chum salmon and Atlantic salmon. Infection experiments have indicated that heavy parasite infections cause severe erosion in the skin epidermis of juvenile chum salmon, resulting in high mortality of anadromous hosts due to osmoregulatory failure when they migrate into the coastal ocean. The parasite infections commonly occur at salmon hatcheries. A bath with dilute formalin solution is the most effective way to treat infected fish. In Japan, however, the use of formalin for hatchery fish is restricted since revision of the Pharmaceutical Affairs Law in 2003. Alternative effective treatment methods are currently not available for hatchery salmon, and some hatchery managers believe that the recent decrease of chum salmon returns in Japan might be partly caused by parasite infections. The present study aimed to develop a safe method to control *I. salmonis* infections of juvenile chum salmon. Various concentrations of salt and vinegar solutions were tested on juvenile chum salmon heavily infected with *I. salmonis*. A 10-min bath with a high concentration (5%) of salt water decreased the parasite density, but it also had a high risk of killing the juvenile fish because the parasite infections reduced the fish's tolerance to salt water. When *I. salmonis* is attached to anadromous salmon it can survive in sea water, so low concentrations of salt water were not effective to control the parasite infections. A bath containing 0.4-1.0% corn vinegar could control the parasite, but exposure to a 1% corn vinegar (pH 3.9) bath over 15 minutes weakened or killed the treated fish. The present treatment study suggested that exposure to a one-hour bath with a low concentration (0.4%, pH 4.5) of corn vinegar is a safe method to control *I. salmonis* infections on juvenile chum salmon at hatcheries.

Component 2: Climate Impacts of Pacific Salmon Production in the Bering Sea (BASIS) and Adjacent Waters

Kaga, T., S. Sato, T. Azumaya, N. D. Davis, and M. Fukuwaka. 2013. Lipid content of chum salmon *Oncorhynchus keta* affected by pink salmon *O. gorbuscha* abundance in the central Bering Sea. Marine Ecology Progress Series 478: 211-221.

To assess effects of intra- and inter-specific interactions on chum salmon in the central Bering Sea, chum salmon lipid content was analyzed as a proxy for body condition. We measured the lipid contents of 466 immature individuals collected during summer from 2002 to 2007. Individual variation in log-transformed lipid content was tested using multiple regression analysis with biological and environmental variables. A regression model that included chum salmon fork length and pink salmon CPUE (number of fish caught per 1500 m of gillnet) was the most effective in describing variation in lipid content. Path analysis showed that the negative effect of pink salmon CPUE was stronger than the effect of chum salmon CPUE on chum salmon lipid content. Stomach content analysis of 283 chum salmon indicated non-crustacean zooplankton (appendicularian, chaetognath, cnidarian, ctenophore, polychaete, and pteropod) was higher under conditions of high pink salmon CPUE. Increased consumption of non-crustacean zooplankton containing a low lipid level could lower the lipid content of chum salmon. Thus, chum salmon lipid content could be affected directly by their shift in prey items and indirectly by interspecific competition with pink salmon.

Ohwada, M., K. Sakaoka, N. Hoshi, T. Abe, K. Imai, and S. Takagi. 2014. Results of 2013 salmon research by the *Oshoro-maru*. NPAFC Doc. 1514. 11 pp.

In order to accumulate oceanographic and biological data (including salmonids) and to

clarify the oceanic structure and marine ecosystem, the T/V *Oshoro maru* conducted oceanographic observations and fishing surveys in the western North Pacific (along the 155°E longitude line) and Bering Sea. The survey was conducted during the Cruise #254 in May, and the Cruise #255 in June 2013. Six oceanographic observations and three drift gillnet surveys were conducted along the 155°E during the Cruise #254 in May. The Polar Front was observed in the vicinity of 43°N which were similar to the location in previous years. A total of 673 salmonids was caught by gillnet surveys, including 95 chum and 573 pink salmon. Pink salmon was dominant species at 43°-14'N and 42°-56'N. Chum salmon was abundant at 44°-20'N. The fork lengths (F.L.) of chum salmon collected by C-gear gillnet ranged between 484-608 mm F.L., and those of pink salmon ranged between 375-524 mm F.L.. All chum salmon caught along 155°E were mature fish. To collect salmonid samples extensively and to collect fresh salmon blood and various tissues, two surface long-line and four hook-and-line gear samplings were conducted during the Cruise #254. One sockeye, five chum and 297 pink salmon were collected. During the Cruise #255-Leg1, three hook-and-line gear samplings were conducted. A total of nine sockeye and 11 chum salmon were collected in south of the Bering Sea.

Ohwada, M., K. Sakaoka, N. Hoshi, T. Abe, K. Imai, and S. Takagi. 2013. Results of 2012 Salmon Research by the *Oshoro-maru*. NPAFC Doc. 1461. 18 pp.

In order to accumulate oceanographic and biological data (including salmonids) and to clarify the oceanic structure and marine ecosystem, the T/V *Oshoro maru* conducted oceanographic observations and fishing surveys in the western North Pacific (along the 155°E longitude line) and eastern North Pacific (along the 150°W longitude line). The survey was conducted during the Cruise #242 in May, and the Cruise #243-Leg2 July 2012. Nine oceanographic observations and three drift gillnet surveys were conducted along the 155°E during the Cruise #242 in May. The Polar Front was observed in the vicinity of 43°N. The Subarctic Boundary observed in surface (0-100 db) at nearby 39°-30'N. Pink salmon was dominant species at 43°-16.0'N and 42°-57.4'N. Chum salmon was collected at 43°-16.0'N and 42°-57.4'N. A few salmon were caught at 39°-25.2'N. The fork lengths (F.L.) of chum salmon collected by C-gear gillnet ranged between 420-640 mm, and those of pink salmon ranged between 300-510 mm, 86.9% of chum salmon were adult fish. A total of 64 Chum and 690 Pink salmon were collected. Seven oceanographic observations and three drift gillnet surveys were conducted along the 150°W during the Cruise #243-Leg2 in July. Seasonal thermal stratification observed until 100 db, thereunder Alaskan gyre were observed in the vicinity of 51°N. At 42°-49.9'N, no salmons collected, but at other two stations total of 14 Sockeye, 38 Chum, four Pink, 10 Coho salmon and one Steelhead were collected by C-gear gillnet. F.L. of Chum salmon ranged between 360-550 mm, 5.3% of chum salmon were adult fish. F.L. of Coho salmon ranged between 490-660 mm, and all Coho salmon were adult fish. F.L. of Sockeye salmon ranged between 330-600 mm, 21.4% of Sockeye salmon were adult fish. To collect salmon samples extensively and to collect fresh salmon blood and various tissues, two surface long-line and three hook-and-line gear samplings were conducted during the Cruise #242 and #243-Leg2.

Sato, S., T. Sato, T. Ohkubo, S. Nakamura, and M. Kagaya. 2014. The summer 2013 Japanese salmon research cruise of the R/V *Hokko maru*. NPAFC Doc. 1518. 18 pp.

A summer high-seas research cruise to investigate the biology of Pacific salmon was conducted from July 20 to August 10 in the Bering Sea aboard the Japanese research vessel *Hokko maru*. Research cruise activities included the collection of data on oceanography, zooplankton, micronekton, salmonids, and other organisms. In addition, seawater samples were collected for environmental DNA analysis. A total of 3,443 salmonids were caught by

trawls and angling. Chum salmon was the most abundant species (87.5%), followed by sockeye salmon (8.9%), Chinook salmon (3.5%), coho salmon (0.09%), and pink salmon (0.06%). Salmonids were measured with respect to fork length and body and gonad weights by sex, and the scales were removed for age determination. Isotope, genetic, otolith, stomach, muscle of chum and Chinook salmon, brain and pituitary of chum and sockeye salmon, and seawater samples were obtained for future study. There were 116 chum salmon and one sockeye salmon tagged with disk tags and released in the Bering Sea. Among tagged fish, 19 small and seven large chum salmon were released with DST micro and DST magnetic tags, respectively. Age-specific catch per a surface trawl (CPUE), scale mass index of chum salmon from at 17 fixed sampling stations from 2007 to 2013, and estimated stock composition and abundance of chum salmon in 2013 are documented in this report.

Sato, S., T. Sato, K. Ohmoto, and F. Takahashi. 2012. The summer 2012 Japanese salmon research cruise of the R/V *Hokko maru*. NPAFC Doc. 1419. 14 pp.

A summer high-seas research cruise to investigate the biology of Pacific salmon was conducted from July 20 to August 9 in the Bering Sea aboard the Japanese research vessel *Hokko maru*. Research cruise activities included the collection of data on oceanography, zooplankton, micronekton, salmonid fishes, and other organisms. A total of 3,694 salmonids were caught by trawls and angling. Chum salmon was the most abundant species (91.4%), followed by sockeye salmon (5.4%), Chinook salmon (3.1%), pink salmon (0.1%), and coho salmon (0.05%). Salmonids were measured with respect to fork length and body and gonad weights, they were sexed, and the scales were removed for age determination. Isotope, genetic, otolith, and radioactive monitoring samples were obtained for future study. There were 70 chum salmon tagged with disk tags and released in the Bering Sea. From among fish released with disk-tags, 28 small and 12 large chum salmon were released carrying DST milli-F and DST magnetic tags, respectively. Age-specific catch per surface trawl (CPUE) and scale mass index of chum salmon from 17 fixed fishing stations from 2007 to 2012 are documented here.

Component 3: Winter Survival of Pacific Salmon in the North Pacific Ocean Ecosystem

No publication

Component 4: Biological Monitoring of Key Salmon Population

Hasegawa, K., K. Morita, Y. Okamoto, and K. Ohkuma. 2013. Comparisons of age and size at maturity between wild and hatchery chum salmon *Oncorhynchus keta* from three rivers in Hokkaido. Nippon Suisan Gakkaishi 79 (4): 657-665 (In Japanese with English abstract).

Until recently, it was thought that Japanese populations of chum salmon *Oncorhynchus keta* consisted entirely of hatchery fish. However, the presence of a significant proportion of wild fish has now been documented in some populations. To allow for differential management of both wild and hatchery salmon, it is important to understand the differences and similarities that exist in a number of measurable biological traits. We compared age and body size at maturity of wild and hatchery fish collected from three rivers in which the otoliths of all hatchery-origin fry were thermally marked. The difference between wild and hatchery fish varied among rivers. In one river, wild fish were older and larger than hatchery fish. In the second river, there was no difference between hatchery and wild fish, whereas in the third

river, the age-related increase in body size of wild fish was smaller than that of hatchery fish.

Hasegawa, K., C. Yamazaki, K. Ohkuma, and M. Ban. 2012. Evidence that an ontogenetic niche shift by native masu salmon facilitates invasion by nonnative brown trout. Biological Invasions 14 (10): 2049-2056.

The mechanisms underlying successful invasions by a competitively subordinate species are poorly understood. In Japan, nonnative brown trout *Salmo trutta* L. have successfully invaded a number of streams that contain native masu salmon *Oncorhynchus masou* Brevoort, even though young of the year (YOY) brown trout are thought to be competitively subordinate to YOY masu salmon because of their smaller body size due to later emergence time. We conducted a laboratory experiment and field observations to evaluate whether ontogenetic habitat shifts could explain the success of brown trout. In a laboratory experiment, smaller YOY brown trout were competitively inferior to YOY masu salmon. Our field observations suggest that YOY masu salmon shift to deeper and faster velocity habitat before the emergence of brown trout fry. Thus, there is separation of habitat use between the two species. Taken together, our results suggest an ontogenetic niche shift by competitively dominant native masu salmon may reduce niche overlap and the opportunity for competitive interactions, and thus facilitate invasion by a nonnative brown trout.

Hatakeyama, M., N. Misaka, S. Mizuno, and N. Koide. 2013. Genotyping of *Flavobacterium psychrophilum* isolated from Chum Salmon *Oncorhynchus keta* in Hokkaido, Japan. Fish Pathology 48 (4): 135-138.

We examined matured female chum salmon *Oncorhynchus keta* returning to a river, at a hatchery three times a year between 2006 and 2008, and chum salmon fry suffering from bacterial coldwater disease at the same hatchery in 2008 for *Flavobacterium psychrophilum* isolation. The isolates were genotyped by plasmid and RAPD analyses. In adults, the frequency distribution of genotypes varied among different years but was seemingly similar among different sampling opportunities within the same years. The RAPD genotype of the isolates from fry was one of major genotypes isolated from their parental group, which suggests vertical transmission of the bacterium.

Koshino, Y., H. Kudo, and M. Kaeriyama. 2013. Stable isotope evidence indicates the incorporation into Japanese catchments of marine-derived nutrients transported by spawning Pacific Salmon. Freshwater Biology 58 (9): 1864-1877.

1. Pacific salmon (*Oncorhynchus* spp.) transport marine-derived nutrients (MDN) and organic matter to freshwater ecosystems, which enhances the productivity of North Pacific ecosystems. Relatively few studies, however, have evaluated the MDN subsidy to both the aquatic system and the terrestrial catchment simultaneously. Using stable isotope analysis, we tested how the dynamics of MDN differed between the river and adjacent riparian forest in rivers of the Shiretoko World Natural Heritage Site in eastern Hokkaido (Japan). In addition, we accounted for temporal and spatial variations in the stable isotope signatures of freshwater organisms due to the presence or absence of spawning salmon.
2. We analyzed carbon and nitrogen stable isotopes (C-13 and N-15) of biofilm, invertebrates, fish, riparian plants and brown bear (*Ursus arctos*) in the Rusha River during the pre-spawning and spawning periods and in the Akai River (where there are no salmon). Willow leaves were collected along the 50-m transects to evaluate how far MDN are incorporated within the riparian area. We counted the number of pink salmon (*O. gorbuscha*) carcasses in riparian areas and categorized their mode of transport. In addition, we examined the stomach contents of Dolly Varden (*Salvelinus malma*).
3. The C-13 and N-15 of aquatic organisms increased by 1-4 parts per thousand and 1-6 parts

per thousand, respectively, with the arrival of salmon spawners. Aquatic organisms incorporated 23% of their nitrogen from salmon (range: 7-46%). The diet of Dolly Varden switched from aquatic invertebrates to salmon eggs during the salmon spawning run.

4. More salmon carcasses were transported from the stream to riparian areas by flooding than by brown bears. The C-13 and N-15 of blowflies (*Calliphora* spp.) and brown bears increased significantly during the spawning run. Riparian vegetation, with the exception of Manchurian alder (*Alnus hirsuta*), incorporated 25% of its nitrogen from salmon. The N-15 values of riparian willow (*Salix* spp.) were correlated negatively with distance from the stream.
5. The proportion of MDN incorporated in the freshwater biota was lower than that reported for North American rivers, potentially due to the influence of dams and modification of the river environment in this Japanese example. The riparian forest incorporated a relatively high fraction of MDN, however, mainly due to the transport of salmon carcasses from the channel by brown bears and, particularly, flooding. The dynamics of salmon-derived nutrients thus differed between river and adjacent riparian zones. These results suggested the importance of linkages between freshwater and riparian ecosystems for the extent of the marine nutrient subsidy.

Misaka, N., M. Hatakeyama, N. Koide, and K. Suzuki. 2013. The variation in virulence among *Flavobacterium psychrophilum* strains isolated from chum salmon *Oncorhynchus keta*. Fish Pathology 48 (1): 17-20.

We investigated virulence and elastin-degrading activity in ten strains of *Flavobacterium psychrophilum* isolated from chum salmon *Oncorhynchus keta* in Hokkaido, Japan through 2004 to 2006. Intraperitoneal injection of these strains to chum salmon fry revealed that 50% lethal doses (LD50) of the strains were from 2.6 x 10^5 to 4.7 x 10^7 CFU/g. No clear relationship between elastin-degrading activity and virulence in these strains was found. These results indicate that the virulence of *F. psychrophilum* isolated from chum salmon varies considerably among strains, and is not clearly related to elastin-degrading activity.

Miyakoshi, Y. 2014. Age-9 chum salmon caught in eastern Hokkaido. Scientific Reports of Hokkaido Fisheries Research Institute 85: 33-35 (In Japanese with English abstract).

Chum salmon *Oncorhynchus keta* usually mature at two to six years of age (i.e., age 0.1-0.5 in the European system), and recently the existence of age-7 and age-8 chum salmon has been reported. For management of fisheries and enhancement of this species, the Salmon and Freshwater Fisheries Research Institute examines the age of chum salmon returned to rivers and coastal areas of Hokkaido. An age-9 chum salmon was found in fish caught in the set-net fishery in the Utoro area, eastern Hokkaido, on 12 September 2012. The fish was male, and scales were only sampled but the body size was not measured. From the scale length, fork length of the fish was estimated at 67.5 cm (95% confidence interval: 66.8-68.2 cm). This is the first record of age-9 (age 0.8) chum salmon in Japan.

Miyakoshi, Y., M. Nagata, S. Kitada, and M. Kaeriyama. 2013. Historical and current hatchery programs and management of chum salmon in Hokkaido, northern Japan. Reviews in Fisheries Science 21 (3-4): 469-479.

The hatchery program for chum salmon in Hokkaido, northern Japan, constitutes one of the largest salmon hatchery programs in the world. The hatchery program has been conducted for over 120years, and returns of chum salmon rapidly increased during the last quarter of the 20th century. Since the 1990s, chum salmon returns to Hokkaido have remained at a historically high level, although different fluctuation trends have been observed among regions within Hokkaido. Although such intensive hatchery programs have been conducted

for more than 25 generations, there has been no evidence indicating any decline of genetic diversity. The hatchery program for chum salmon in Hokkaido is successful in increasing commercial catches and will likely be the main management tool in future. However, information on naturally spawning chum salmon in Hokkaido remains scarce. Assessment of naturally spawning populations recently commenced, and it has been revealed that naturally spawning chum salmon populations remain in many rivers in Hokkaido. For future management, monitoring chum salmon of both hatchery and natural origin is important, and a novel strategy that accounts for the enhancement of commercial stocks and the coexistence of hatchery programs and wild populations should be established in Japan.

Miyakoshi, Y., D. Ando, M. Fujiwara, M. Torao, H. Hayano, and H. Urabe. 2013. Characteristics of body size of chum salmon returning to Okhotsk rivers in Hokkaido. Scientific Reports of Hokkaido Fisheries Research Institute 84: 21-29 (In Japanese with English abstract).

Fork length, body weight, and age of chum salmon *Oncorhynchus keta* returning to 7 rivers in the Okhotsk Sea region were measured, 2010-2012. Mean fork lengths of chum salmon were larger in the western region than those in the central or the eastern regions. Also, in many rivers, fork lengths were different among run timings; larger for fish captured in earlier timing (August and September) and smaller for fish captured in the later timing (November and December). When fork lengths of chum salmon of the same ages (age-4 and age-5) captured in October were compared, the difference of fork lengths among rivers was smaller, but was significant. In 2012, body sizes of chum salmon returning to Hokkaido were small, and the differences of fork lengths among rivers were not significant for all ages and sexes. When body sizes of chum salmon returning to rivers were compared, age and run timing should be taken into account.

Morita, K., S. Takahashi, K. Ohkuma, and T. Nagasawa. 2013. Estimation of the proportion of wild chum salmon *Oncorhynchus keta* in Japanese hatchery rivers. Nippon Suisan Gakkaishi 79 (2): 206-213.

It is widely assumed that almost all chum salmon *Oncorhynchus keta* in Japan originate in hatcheries, but there are no studies that actually show the contribution of naturally-spawned fish (wild fish) to total production. In this study, we estimated the contribution of wild chum to the total chum salmon catch in rivers where chum salmon hatcheries are located and hatchery-reared chum salmon are released. The catch of wild and hatchery chum salmon was estimated at weirs located on eight rivers in Hokkaido, northern Japan, by identifying the ratio of otolith thermal-marked hatchery fish and unmarked wild fish. In total, the contribution of wild fish to the total catch in these rivers was estimated to be 28.3±1.2% (15.9±0.6% for rivers where the percentage of marked fry released was 100%), but the value varied considerably among rivers and years (range: 0 to 50%). This study showed that the contribution of wild chum salmon is not negligible; rather, it is large enough to constitute fishery production.

Morita, K., Y. Hirama, Y. Miyauchi, S. Takahashi, T. Ohnuki, and K. Ohkuma. 2013. Efficiency of natural reproduction of chum salmon in the Chitose River, Hokkaido, Japan. Nippon Suisan Gakkaishi 79 (4): 718-720 (In Japanese, no abstract).

Saneyoshi, H., Y. Miyakoshi, S. Kudo, and H. Kawamura. 2013. Body size of juveniles released and its effect on the return rate of chum salmon in Shokanbetsu River, Hokkaido, Japan. Scientific Reports of Hokkaido Fisheries Research Institute 84: 21-29 (In Japanese with English abstract).

To investigate the effect of release size of chum salmon *Oncorhynchus keta* juvenile on the return rate in Shokanbetsu River, northern Hokkaido, small and large body size groups of otolith-marked juveniles were released in 1996 and 1997. The mean fork length and body weight of small and large size groups at release were 49.0 mm, 0.95 g and 54.0 mm, 1.32 g in 1996, and were 46.0 mm, 0.77 g and 51.0 mm, 1.09 g in 1997, respectively. The return rates were calculated by cumulative numbers of 3-5 age fish returned to Shokanbetsu River from 1998 to 2001 divided by numbers of fish released. The return rates of small and large size groups released in 1996 were 0.105% and 0.097%, and those released in 1997 were 0.109% and 0.138%, respectively. These results suggest large body size at release is not always effective to increase the return rate of chum salmon.

Ueda, H. 2014. Homing ability and migration success in Pacific salmon: mechanistic insights from biotelemetry, endocrinology, and neurophysiology. Marine Ecology Progress Series 496: 219-232.

Salmon have precise abilities to migrate long distances from the ocean to their natal streams for reproduction. Using chum salmon *Oncorhynchus keta* in the North Pacific Ocean as well as sockeye salmon *O. nerka* and masu salmon *O. masou* in Lake Toya and Lake Shikotsu (Hokkaido, Japan), mechanisms of homing ability and migration success were investigated using 3 different approaches: biotelemetry studies of behavior, endocrinology studies on the brain-pituitary-gonadal (BPG) axis, and neurophysiological studies on olfactory function. Physiological biotelemetry techniques were used to compare homing behavior of adult chum salmon from the Bering Sea to Hokkaido with lacustrine sockeye and masu salmon within Lake Toya, demon strating that salmon can navigate in open water using different sensory systems. Hormone profiles in the BPG axis were analyzed in both chum salmon and sockeye salmon during their homing migration, and showed that salmon gonadotropin-releasing hormone is an important factor facilitating homing during migration. The olfactory functions of salmon were investigated using electrophysiological, behavioral, and biochemical techniques, suggesting that dissolved free amino acid compositions in natal streams are crucial for olfactory imprinting and homing. These topics are discussed in terms of mechanisms of homing ability in Pacific salmon with special reference to navigation abilities in open water, hormonal controlling mechanisms during homing migration, and olfactory discriminating abilities of natal stream odors-all necessary to successfully reach spawning grounds.

Ueda, H. 2012. Physiological mechanisms of imprinting and homing migration in Pacific salmon *Oncorhynchus* spp. Journal of Fish Biology 81 (2): 543-558.

After several years of feeding at sea, salmonids have an amazing ability to migrate long distances from the open ocean to their natal stream to spawn. Three different research approaches from behavioral to molecular biological studies have been used to elucidate the physiological mechanisms underpinning salmonid imprinting and homing migration. The study was based on four anadromous Pacific salmon *Oncorhynchus* spp., pink salmon *Oncorhynchus gorbuscha*, chum salmon *Oncorhynchus keta*, sockeye salmon *Oncorhynchus nerka* and masu salmon *Oncorhynchus masou*, migrating from the North Pacific Ocean to the coast of Hokkaido, Japan, as well as lacustrine *O. nerka* and *O. masou* in Lake Toya, Hokkaido, where the lake serves as the model oceanic system. Behavioral studies using biotelemetry techniques showed swimming profiles from the Bering Sea to the coast of Hokkaido in *O. keta* as well as homing behaviors of lacustrine *O. nerka* and *O. masou* in Lake Toya. Endocrinological studies on hormone profiles in the brainpituitary gonad axis of *O. keta*, and lacustrine *O. nerka* identified the hormonal changes during homing migration. Neurophysiological studies revealed crucial roles of olfactory functions on imprinting and

homing during downstream and upstream migration, respectively. These findings are discussed in relation to the physiological mechanisms of imprinting and homing migration in anadromous and lacustrine salmonids.

Qin, Y. X., A. Nagai, H. Kudo, and M. Kaeriyama. 2013. Stable isotope comparison between presumably wild and hatchery chum salmon *Oncorhynchus keta* in the Yurappu River, Hokkaido, Japan. Nippon Suisan Gakkaishi 79 (5): 872-874 (In Japanese, no abstract).

Yamamoto, T. and S. Kitanishi. 2014. Reduced oceanic growth of growth hormone pseudogene-positive female masu salmon *Oncorhynchus masou*. Journal of Fish Biology 84 (1): 256-262.
This study compared the growth rates of female masu salmon *Oncorhynchus masou*, who possessed a male-specific gene marker, the growth hormone pseudogene (GHp), and normal females, as estimated from their scale growth. There was a difference between the growth rates of GHp-positive females and those of normal females of the same age during the ocean period, although their growth rates during the river period were similar. These results suggest that GHp-positive salmonid females exhibit male-like characteristics such as reduced feeding activity during the ocean period, which depresses their growth.

Component 5: Development and Applications of Stock Identification Methods and Models for Management of Pacific Salmon

Beacham, T. D., J.C. Candy, S. Sato, and S. Urawa. 2014. Microsatellite identification of sockeye salmon rearing in the Bering Sea during 2009-2013. NPAFC Doc. 1511. 18 pp.
Stock composition of sockeye salmon (*Oncorhynchus nerka*) caught in the southern central Bering Sea during Japanese research cruises in the summers of 2009, 2011, 2012, and 2013 was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for immature sockeye salmon, and a 404-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Alaskan-origin sockeye salmon were the most abundant in the catch, comprising 86.1% of all sockeye salmon caught (United States total 86.1%), with the catch dominated by sockeye salmon of Bristol Bay origin. Russian-origin salmon accounted for an average of 10.6% of the annual catch, while Canadian-origin sockeye salmon accounted for 3.4% of the annual catch.

Beacham, T. D, J.C. Candy, S. Sato, and S. Urawa. 2012. Microsatellite identification of sockeye salmon rearing in the Bering Sea 2011. NPAFC Doc. 1389. 9 pp.
Stock composition of sockeye salmon (*Oncorhynchus nerka*) caught in the southern central Bering Sea during a Japanese research cruise in the summer of 2011 was estimated through an analysis of microsatellite variation. Variation at 14 microsatellites was analyzed for 177 immature sockeye salmon, and a 387-population baseline spanning Japan, Russia, Alaska, Canada, and Washington State was used to determine the stock composition of the fish sampled. Alaskan-origin sockeye salmon were the most abundant in the catch, comprising 86.1% of all sockeye salmon caught (United States total 86.7%), with the catch dominated by sockeye salmon of Bristol Bay origin. Russian-origin salmon accounted for 12.1% of the catch, while Canadian-origin sockeye salmon accounted for 1.2% of the catch.

Nagai, A., A. Yamada, Y. Qin, R. R. Edpalina, H. Kudo, S. Abe, and M. Kaeriyama. 2012. Genetic influence of hatchery program on chum salmon (*Oncorhynchus keta*)

populations in the Japan Sea coast, Honshu Island of Japan, inferred from mitochondrial DNA sequence variation. Fish Genetics and Breeding Science 42 (1): 33-40 (In Japanese with English abstract).

We examined the genetic population structure of chum salmon *Oncorhynchus keta* in Tedori and Gakko Rivers of Japan Sea coast, Honshu Island, using mitochondrial DNA (mtDNA) analysis, and evaluated genetic variability and relationships among populations in Japan based on previous studies. Tedori and Gakko River populations displayed 5 and 2 haplotypes of the 481 bp 5' variable portion of the mtDNA control region, respectively. Pairwise FST showed no genetic differentiation between Tedori early population and all Hokkaido populations, and between Gakko River November population and all populations in Honshu Island except for the early Tedori and Kawabukuro River populations. UPGMA tree among chum salmon populations in Japan resulted that Tedori and Gakko River populations were closely related with Chitose and Tokachi River populations in Hokkaido Island and populations of Pacific coast in Honshu Island, respectively. These results show that a part of Tedori and Gakko River chum salmon populations receive gene flow and disturbance following artificial transplantation of massive eyed-eggs from other river populations in Japan.

Sato, S., K. Hirasawa, and S. Urawa. 2013. Stock origins of juvenile chum salmon migrating along the eastern Pacific coast of Hokkaido during early summer. NPAFC Technical Report 9: 23-24.

Origins of juvenile chum salmon migrating along the eastern Pacific coast of Hokkaido were estimated by otolith thermal marking and genetic stock identification (GSI) using single nucleotide polymorphism (SNP) markers. Surveys were conducted on the Kombumori coast (42° 57'N, 144° 31'E) almost weekly from early June to mid July of 2011 and 2012. Fish samples were collected from several stations (0.4- 12.0 km from the coast) by a seine net towed by two boats. Otolith and tissue samples were collected from each juvenile chum salmon after recording fork length (FL) and body weight. Tissue samples were assayed for 45 SNP loci and their stock contributions (Hokkaido, Pacific coast of Honshu (Honshu-PO), and Japan Sea coast of Honshu (Honshu-JS)) were estimated by a conditional maximum likelihood algorithm using a SNP baseline dataset from 48 Japanese populations. A total of 622 and 385 juvenile chum salmon were collected in 2011 and 2012, respectively. The mean FL of juvenile chum salmon collected in 2011 (7.7±1.6 cm) was significantly smaller than fish collected in 2012 (10.3±1.7 cm). In 2011, otolith marks were detected in 70 out of 622 juvenile chum salmon. All the otolith-marked juveniles (5.6-11.4 cm in FL) originated from hatcheries along the Nemuro Strait and Pacific coast of Hokkaido. In 2012, 43 out of 385 samples were otolith-marked fish, of which 31 fish (6.3-11.0 cm in FL) were released from Hokkaido hatcheries and 12 fish (9.9-12.5 cm in FL) were from Honshu-PO hatcheries. GSI-estimated stock composition of small juveniles (less than 10 cm in FL) caught in 2011 was 96.7% Hokkaido and 3.3% Honshu-PO stocks, and that of large fish (more than 10 cm in FL) was 56.9% Hokkaido, 17.7% Honshu-PO, and 25.4% Honshu-JS stocks. In 2012, the estimated stock composition was 72.4% Hokkaido, 22.0% Honshu-PO, and 5.6% Honshu-JS stocks for small fish, and 32.1% Hokkaido, 60.9% Honshu-PO, and 7.1% Honshu-JS stocks for large fish. The results suggest that juvenile chum salmon released from Honshu-PO hatcheries migrate along the eastern Pacific coast of Hokkaido between mid-June and early July, heading for the Okhotsk Sea. Abundance of 2011 juvenile chum salmon from Honshu-PO hatcheries might have been reduced by the March 11, 2011, earthquake and tsunami.

Yamada, A., Y. Koshino, H. Kudo, S. Abe, K. Arai, and M. Kaeriyama. 2012. Genetic

comparison between odd- and even-year populations of pink salmon *Oncorhynchus gorbuscha* based on mitochondrial DNA analysis. Nippon Suisan Gakkaishi 78 (5): 973-975 (In Japanese, no abstract).

Yamamoto, S., T. Kurokawa, M. Sekino, M. Yasuike, and K. Saitoh. 2013. Tetra-repeat microsatellite markers for the masu salmon (*Oncorhynchus masou masou*) and its application in cross-subspecies. International Journal of Molecular Sciences 14 (11): 23153-23159.

We developed tetranucleotide-repeat microsatellite markers for the masu salmon (*Oncorhynchus masou*) complex. 454 pyrosequencing was used to discover repeat motifs, and seven polymorphic microsatellite-primer sets were identified. The number of alleles detected at each locus ranged from four to 24 and the expected heterozygosity varied from 0.57 to 0.92. Cross-subspecies amplification for *O. m. masou, O. m. ishikawae* and *O. m.* subsp. was successful. These microsatellites can be utilized in studies of genetic structure, genetic diversity, and intra- and inter-subspecific hybridization, making a contribution to conservation and management of the *Oncorhynchus masou* complex.

Yoon, M., S. Abe, J. K. Kim, and K. E. Hong. 2013. Population structuring of chum salmon, *Oncorhynchus keta,* populations in far east Asia. NPAFC Technical Report 9: 144-145.

As previous investigations have shown, the significant genetic differentiation of chum salmon among regions of the Pacific Rim reflects contemporary restrictions on gene flow. However, the historical events and processes leading to the genetic structure of chum salmon populations in the Northwest Pacific remain unclear. In the present study, microsatellite and mitochondrial DNA analyses were used to estimate the genetic structure of chum salmon populations in Far East Asia. Our analyses provide differentiation between two regions for effective population size, genetic bottleneck signature, and gene flow. Our findings carefully suggest that long-term historical events, such as postglacial decolonization from different glacial refuges, may influence genetic population structure. Pleistocene ice-ages may have considerably influenced not only the historical demographic evidence, glacial population extinctions, and interglacial colonization, but also the contemporary populations of phylogroups of chum salmon in Far East Asia.

Watanabe, K., K. Morita, and T. Saito. 2013. Verification of the immature ratio at age of chum salmon in the Bering Sea and central North Pacific Ocean, 1971–2010. NPAFC Technical Report 9: 228.

The mean age at return of Japanese chum salmon populations, as with other Pacific salmon, increased from the 1970s–2000s, which could be associated with variability of the immature ratio (IMR) at age. Nominal IMRs calculated from Japanese offshore surveys and returns at age given by fishery data will be subject to uncertainty due to biases. To estimate reliable annual IMRs of Japanese chum salmon, we evaluated the IMRs at ages 3-4 by using fishery independent and fishery dependent data separately: (*i*) Japanese experimental chum salmon survey data (sex, age, gonad weight, and fork length) collected in the Bering Sea and central North Pacific Ocean, July-August, 1971–2010, and (*ii*) Japanese chum salmon return at age. For data (*i*) examined using generalized linear mixed models (GLMM), annual means of male and female IMR at age 4 ranged from 0.2–0.8 and 0.1–0.9, respectively, fluctuated in parallel, and increased on a long-term basis. For data (*ii*) investigated by virtual population analysis (VPA), the sex–combined IMR at age 4 ranged from 0.1–0.5, i.e., was relatively low compared to the GLMM–IMR. All correlations among the VPA– and GLMM–IMRs were positive and significant, thereby supporting the reliability of both the types of relative IMR.

As a result of testing factors on IMR variability, the growth rate of immature ages 2–3 chum salmon and the mean sea surface temperature in the Bering Sea were significant indices common to VPA– and GLMM– IMRs. We provide a probable cause whereby the immature ratio of age 4 chum is affected mainly by the growth rate of ages 2–3 chum salmon and environmental conditions.