Biological Monitoring of a Key Korean Salmon Population: Namdae River Chum Salmon

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Brief history of South Korea's chum salmon enhancement program

In 1913, the artificial enhancement program of chum salmon (*Oncorhynchus keta*) was initiated in Hamkyung-do in what is now North Korea, and in 1967 hatcheries were built in Gangwon, Gyeongnam, and Gyeongbuk provinces in South Korea.

In 1984, the Yangyang Inland Hatchery, which was renamed the Yangyang Salmon Station (FIRA) in 2012, began releasing salmon in the Namdae River. The Namdae River in Yangyang city is an important location for Korean chum salmon production and it has been the primary producer of chum salmon in South Korea since the hatchery was built. The river is located between the northeastern city of Sokcho and the southeastern city of Gangneung in Gangwon-do on the east coast of South Korea.

Currently there is a total of 18 chum salmon streams where chum salmon fingerlings are released along the eastern and southern coast of Korean Peninsula (Fig. 1).

Prior to 1984, the number of hatchery releases was less than 3 million chum salmon. This total increased dramatically from approximately 5 million to over 25 million chum salmon after the Yangyang hatchery began releasing chum salmon fingerlings into the Namdae River (Fig. 2). In both 2010 and 2011 South Korea released more than 15 million chum salmon fingerlings. The 21 million released in 2011 was the second highest record of releases since 2000. The percentage of the total hatchery releases in South Korea that originated from the Yangyang hatchery ranges from 40 to 79 percent, averaging 65 percent. However, return rates of chum to Korean hatcheries are low. For example the return rate of salmon in the Namdae River has been less than 0.6 percent since the late 1980s (Suam Kim, Pukyong National University, personal communication).

Catches of chum salmon have followed a similar trend (Fig. 3). Before 1983, catches remained less than 10 metric tons (MT) per year and after the Yangyang hatchery started releasing fingerlings, total catches in South Korea increased to a peak of around 500 MT fish in the late-1990s, likely

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Kwan Eui Hong was born in Gangneung, Gangwon-do, Republic of Korea. After obtaining a Bachelor's and Master's degrees, he completed a PhD in the field of Aquaculture. Kwan Eui currently serves as the Director of the Yangyang Salmon Station of the Korea Fisheries Resources Agency (FIRA). Throughout his career, he has endeavored to recover and enhance inland fish and chum and masu salmon resources in the area of Korea's east coast. Kwan Eui is a member of the Committee on Scientific Research and Statistics and serves on several working groups.

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due to favorable oceanic conditions and the successful enhancement program during that time period. Total chum salmon catches have decreased to an average of 128 MT since 2000 (www.npafc.org/new/science_statistics.html). Researchers have hypothesized that warmer sea water temperatures along the east coast of the Korean Peninsula negatively affect the survival rate of Korean chum salmon during their first year of ocean life (Suam Kim, pers. comm.).

The number of chum salmon returning to the Namdae River represents a high proportion of the total number of chum salmon caught in the rivers in South Korea. High numbers of hatchery releases from the Yangyang hatchery in 2010 and 2011 (Fig. 2) are associated with a large 45-year record number of chum salmon returning to the Namdae River in 2013 (Fig. 4).

Current artificial enhancement program

Namdae River chum salmon life stages are monitored from maturing fish captured in set-net fisheries to release of fry into the river (Fig. 5). Generally females mature and return to the river at three to five years of age (total age) (Fig. 6) and the males return at 2 to 4 years of age (Fig. 7). The males can mature at a younger age than the females and the percentage of males maturing at age 2 (after spending one winter at sea) can represent a significant proportion of the fish sampled in the river. There has been some discussion that age 2 fish may actually represent a mixture of maturing and immature fish (Suam Kim, pers. comm.). This interesting variation in the life history of male chum salmon maturing early as jacks, or even returning to freshwater in an immature state clearly deserves further clarification.

Temporal changes in life-history traits of Namdae River chum salmon have been reported (Seo et al. 2006, Urbach et al. 2012). Researchers have shown that the 1988-1989 regime shift was a major factor affecting changes in chum salmon growth and maturation. Age at maturity in male chum salmon declined prior to 1989 and significantly increased in response to the 1988-1989 regime shift. Similarly, body length at maturity increased both in females and males after 1989 (Urbach et al. 2012).

From mid-September to mid-December, most adult chum salmon are captured by commercial set-net fisheries operated

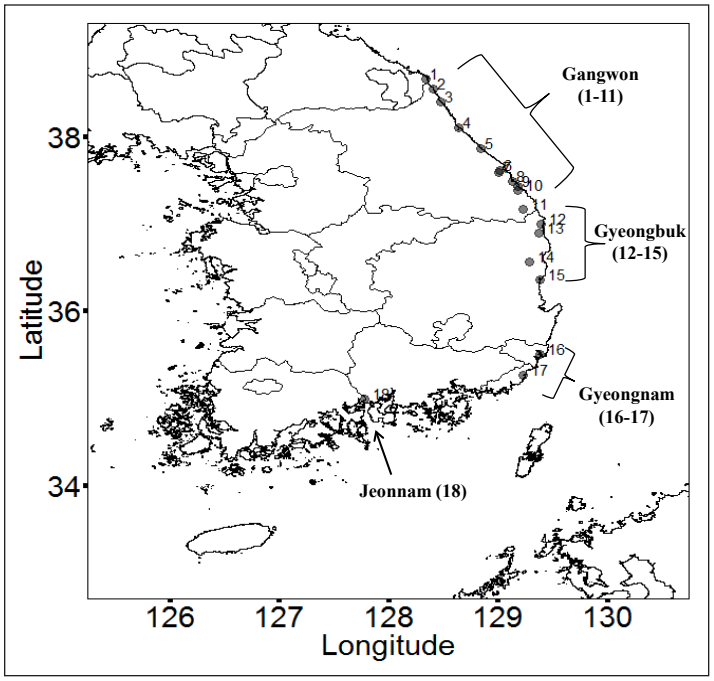

Fig. 1. Map showing 18 streams and rivers in South Korea where chum salmon migrate into the ocean, grouped by NPAFC statistical reporting areas. Please note the terms of "gang" and "cheon" mean river and stream, respectively. Reporting area I (Gangwon Province): Nam-gang (1), Myeongpa-cheon (2), Buk-cheon (3), Namdae-cheon in Yangyang (4), Yeongok-cheon (5), Nakpung-cheon (6), Jusu-cheon (7), Jeon-cheon (8), Osip-cheon in Samcheok (9), Maeup-cheon (10), Gagok-cheon (11). Reporting area II (Gyeongbuk Province): Namdae-cheon in Uljin (12), Wangpi-cheon (13), Songcheon-cheon (14), Osip-cheon in Yeongdeok (15). Reporting area III (Gyeongnam Province for hatchery releases and Ulsan for commercial catch): Taehwa-gang in Ulsan (16), Ilgwang-cheon (17). Reporting area VI (Jeonnam Province): Seomjin-gang (18).

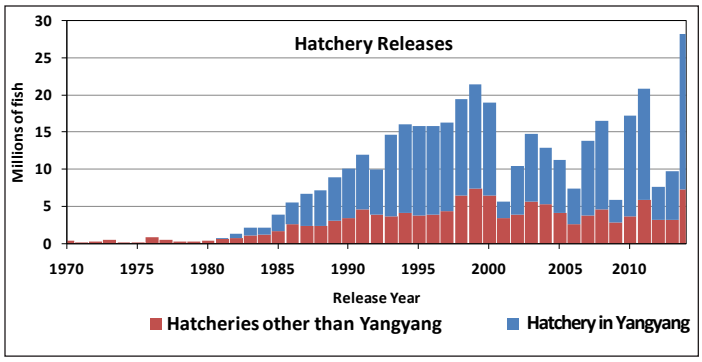

Fig. 2. Chum salmon hatchery enhancement in millions of fish released in South Korea from 1970 to 2014. Yangyang hatchery is the primary hatchery in South Korea.

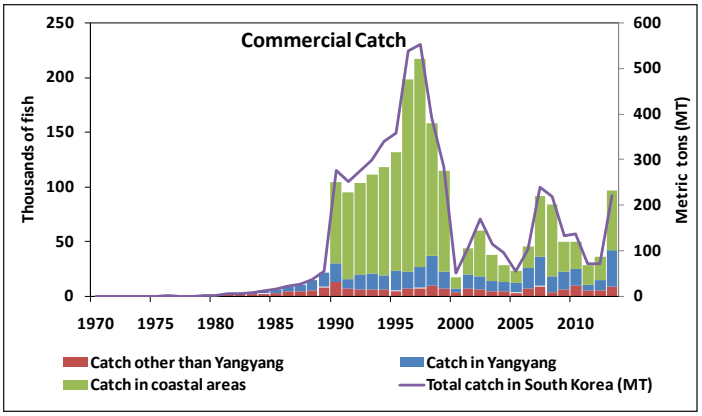

Fig. 3. River and coastal catch (bar graphs, numbers) and total catch (blue line, metric tons) in South Korea from 1970 to 2013. Yangyang city comprises four rivers where salmon are caught. The Namdae River is the primary location for catch of chum salmon.

near the east coast of South Korea, catching from 43.7 to 88.9 percent of the total run. Permit holders for commercial fisheries are prohibited from conducting their fishing operations in the coastal area from October 1 to November 30 and in all freshwater areas from October 11 to November 30.

Almost all fish that escape from set-net fisheries are captured by weirs set across the upper reaches of rivers or streams. There may be opportunities for chum salmon to escape set-net fisheries and weirs in the Namdae River to spawn naturally, but further studies are required to investigate if this occurs.

Adult chum salmon usually enter streams (or rivers) when water temperatures fall below 15°C, and most upstream migration occurs between late-October and early-November when water temperature ranges from 11 to 13°C. When chum salmon have reached maturity during the peak of the run, they are transferred to the hatchery for spawning. Eggs and milt are collected, the eggs are fertilized, and then the fertilized eggs are placed in trays for incubation.

Before hatching, eyed eggs are exposed to a series of timed intervals that expose the eggs to a 4°C temperature change and places a specific thermal mark code on the otolith. From 2006 to 2014, 41.6 million chum salmon were otolith-marked at the Yangyang and Uljin hatcheries and released into the Namdae and/or Wangpi Rivers. South

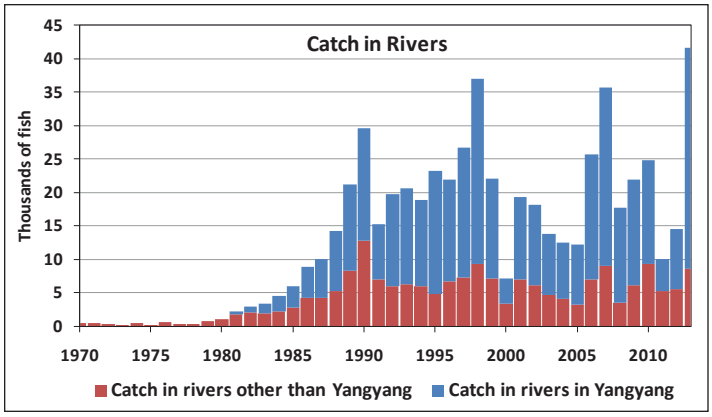

Fig. 4. Catch in rivers in South Korea from 1970 to 2013. Yangyang city comprises four rivers where salmon are caught. The Namdae River is the primary location for catch of chum salmon.

Korea uses three different hatchery codes to identify its chum salmon. The mark codes are 3,3nH, 3,1,2H, and 3,2,1H based on the RBr notation modified by Hagen (1999).

After hatching, the alevins absorb nutrients from their yolk sac over a two or three week period. After the yolk is absorbed, they are fed dry pellets for two or three months (Fig. 5). Just prior to release, the fingerlings range from 5.0 to 6.0 cm fork length and from 0.8 to 1.0 g body weight.

Fig. 5. Timeline showing major events related to the capture of chum salmon in commercial fisheries and production of chum salmon at the Yangyang hatchery in South Korea. Photo credits: Kwan Eui Hong and Ju Kyoung Kim.

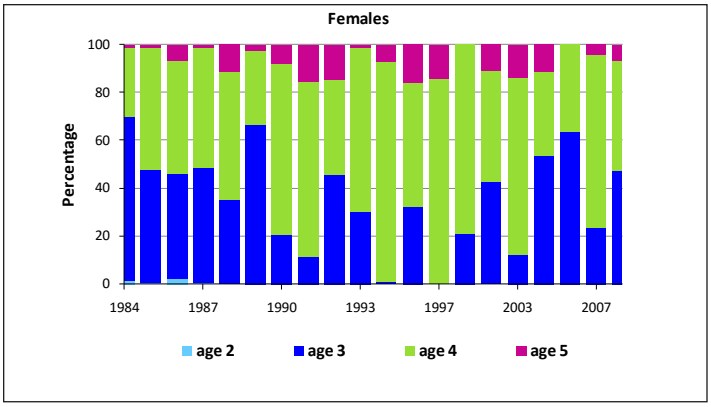

Fig. 6. The age (total age) composition (percent) of mature female chum salmon returning each year to the Namdae River, 1984-2008.

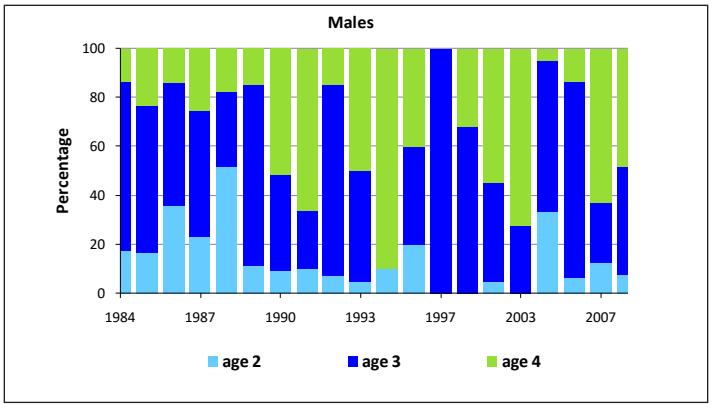

Fig. 7. The age (total age) composition (percent) of mature male chum salmon returning each year to the Namdae River, 1984-2008.

The juveniles are generally released into the river between March and April when the freshwater temperatures are above 2°C. Some of the fingerlings reared in the Yangyang hatchery are released into the Namdae River directly, and some are transported to other rivers for release.

A coded-wire tag (CWT) program was initially conducted by the Cold-water Fish Research Center at National Fisheries Research and Development Institute (NFRDI) during the 2003-2009 period, but the program has not been operated continuously since then. The program was subsequently transferred to the Yangyang Salmon Station, but due to budget restrictions it was not continued in 2010 and 2011. CWTs were placed in juvenile chum in 2012, but thereafter the CWT tagging program has been discontinued. During the program, a total of 100,000 juvenile chum salmon with CWTs and clipped adipose fins was been released in the Namdae River.

Coastal monitoring

Monitoring the abundance and distribution of chum salmon caught in the coastal area began in the early 2000s. The purpose was to determine the mechanisms of mortality and growth of juvenile chum salmon during their early marine life stages and to reveal the pattern of migration along the eastern coast of South Korea.

Recoveries of coded-wire tagged chum salmon at the hatchery helped to provide knowledge of smolt-to-adult survival rates and age at maturity. CWT recoveries of known age fish provided the evidence that some mature males

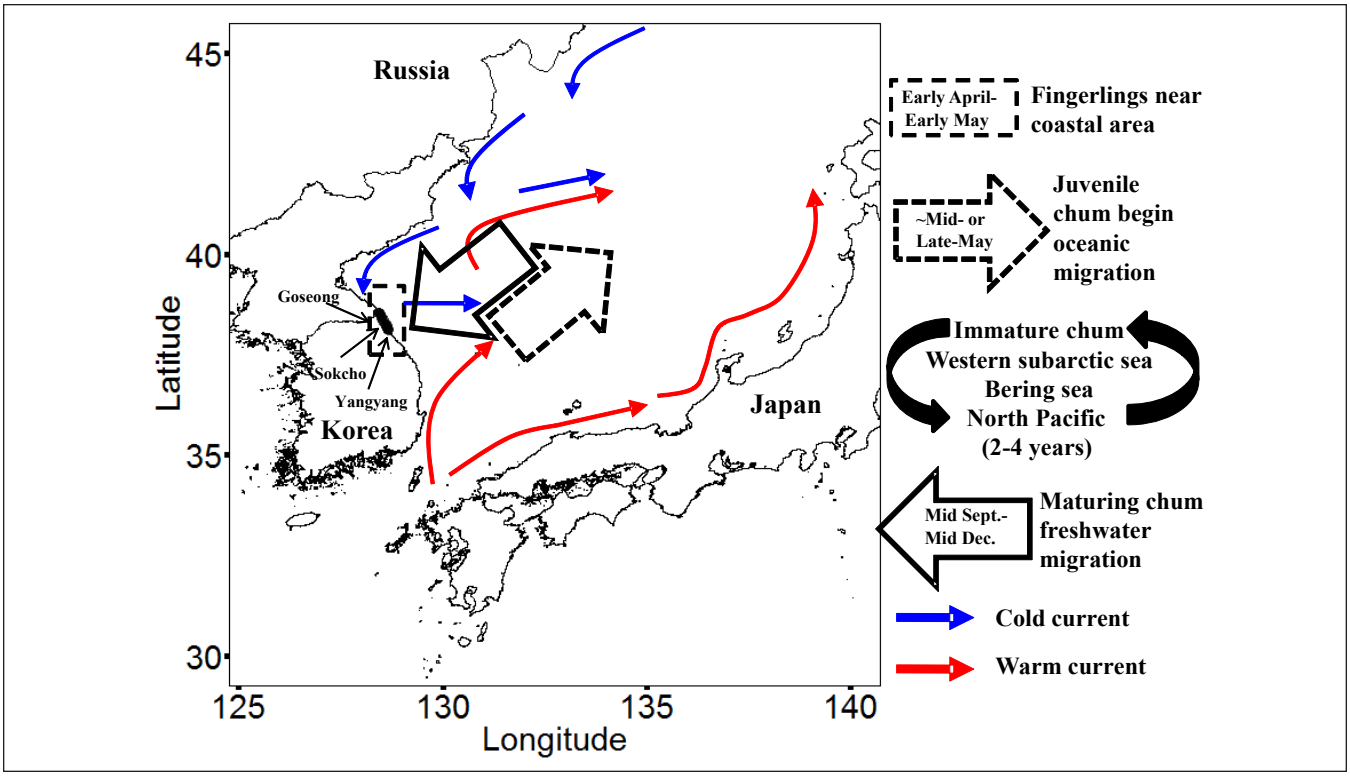

Fig. 8. A schematic map showing the time periods when juvenile and adult chum salmon are present near the east coast in South Korea. Information on juvenile migration timing from Hong et al. 2012. The strength of cold (blue arrows) and warm (red arrows) currents varies spatially and temporally. Further information on the monthly currents in this area is available at the website (sms.khoa.go.kr/koofs/eng/observation/obs_real_map.asp)

returned to the hatchery after only one year at sea (Salmon Research Team 2006).

In 2010 and 2011, juveniles released from hatcheries were sampled at the northern end of the coastline (38°06'-38°32'N, 128°24'-128°39'E) in early April to early June using a paired surface trawl (Hong et al. 2012) (Fig. 8). Sea surface temperatures ranged from 7.5 to 17.1°C during the survey. Stomach contents analysis was conducted and predominant juvenile chum salmon prey items were amphipods and copepods (Kim et al. 2013). Stomach contents also contained a small proportion of euphausia and small-size fish. Based on these surveys, juvenile chum salmon seem to stay near the coastal areas (Yangyang, Sokcho, and Goseong) between early-April and early-May and begin their impressive migration toward the open ocean after mid- or late-May (Fig. 8).

Oceanic distribution

The known ocean range of Korean chum salmon has been reported based on a few recoveries of marks and tags. Thus far, a total of two otolith-marked Korean chum salmon were

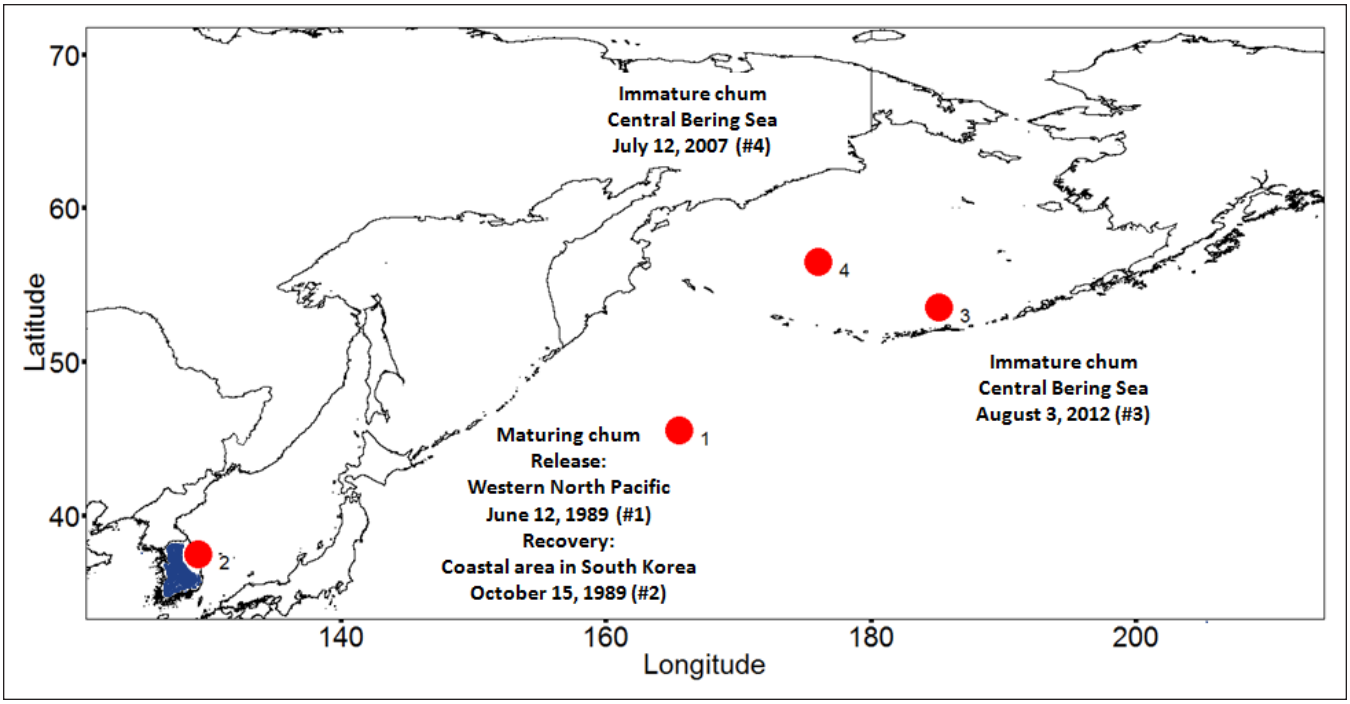

Fig. 9. Known ocean range of immature Korean chum in the central Bering Sea and maturing Korean chum salmon in the northwestern North Pacific as determined from detection of otolith thermal marks (n=2) and recovery of a high seas disk tag (n=1).

Table 1. Information for immature Korean chum salmon found in the central Bering Sea by recovery of thermally-marked otoliths. Hatchery source code: KR = Country (Korea), XX = Brood year (2010 and 2005), -X = hatchery code (Yangyang hatchery).

Species	Chum salmon	Chum salmon
Mark type	3,2,1H	3,3nH
Hatchery source	KR10-1	KR05-1
Recovery Date	August 3, 2012	July 12, 2007
Recovery Location	53°30'N 174°53'W	56°30'N 176°00'E
Recovery Area	Central Bering Sea	Central Bering Sea
Age	0.1	0.1
Sex	Male	Male
Maturity	Immature	Immature
Fork length (mm)	363	334
Body weight (g)	650	390
Gonad weight (g)	0.4	1.0
Research Vessel	*Hokko maru*	*Wakatake maru*
Data source	Shunpei Sato pers. comm.	Sato et al. 2009

Table 2. Information for maturing Korean chum salmon found in the northwestern North Pacific Ocean by recovery of a high-seas disk tag.

Species	Chum salmon
Release date	June 12, 1989
Location at release	45°30'N 165°30'E
Release area	Western North Pacific
Recapture date	October 15, 1989
Location at recapture	37°26'N, 129°11'E
Recapture area	Coastal area near Yangyang
Sex	Male
Maturity	Mature
Fish origin	South Korea
Data source	INPFC/NPAFC High-seas salmonid tag-recovery database

obtained from immature fish caught in the central Bering Sea in summer, one in 2007 and another in 2012, by researchers conducting Japanese ocean salmon surveys (Sato et al. 2009, Shunpei Sato, Hokkaido National Fisheries Research Institute, pers. comm.; Table 1, Fig 9). In addition, one high-seas disk tag was recovered from a maturing Korean chum salmon tagged in the northwestern North Pacific that was released in June 1989 and recovered in October 1989 in the coastal area in the vicinity of Yangyang city (NPAFC 2013) (Table 2, Fig. 9). These recoveries show the known ocean range of immature Korean chum salmon extends to the central Bering Sea in summer and maturing fish are present in the northwestern Pacific in the summer.

Researchers have not determined the migration route of Korean chum salmon in the ocean partially because there have been no research cruises yet dedicated to this purpose. Genetic stock identification (GSI) studies have often included genetic information from chum salmon collected in the Namdae River to represent Korean chum salmon in the GSI baseline. But present techniques indicate Korean and Japanese chum salmon are genetically indistinguishable based on several studies of genetic diversity and population structure of chum salmon in the North Pacific (Sato et al. 2004, Kim et al. 2007, Yoon et al. 2008). Based on genetic and geographic proximity, there is speculation that Korean chum salmon have a similar (but not identical) migration route as Japanese chum salmon (Seo et al. 2006). Juvenile Korean chum salmon might migrate from their natal rivers along the coast into the Sea of Okhotsk (summer and fall), then over-winter in the Western Subarctic Gyre (winter and spring), and then move into the Bering Sea (summer and fall). Male chum salmon that mature after one year at sea may not have such an extensive ocean migration route.

If we were to speculate on the migration of juvenile Korean chum, we suggest that the juveniles could (1) move with the warm current along the western coast of Honshu and pass into the Okhotsk Sea via the Soya Strait, or (2) move against the cold current northwards along the coast of North Korea and Russia and travel into the Okhotsk Sea via the Tatar Strait.

Directed marine research surveys are necessary to collect the information required to determine Korean chum salmon migration corridors and evaluate how future climate change might affect this stock.

"Canary in a coal mine"

Even as Korean salmon products have recently become more important in local markets, the levels of commercial catches in South Korea are much lower than those in the other NPAFC-member countries. For example, using chum commercial catch as an index of production, during the period 1969-2013, total production of Korean chum accounted for only 0.02 percent (5,577 MT) of the total chum salmon production from all NPAFC countries (23.7 million MT).

Will chum salmon continue to return to the Namdae River in the future? It is possible that Korean chum salmon are the canary in the coal mine, meaning that these fish might function as sentinels of environmental conditions (and potential hazards). Because Korean chum salmon reside at the southern end of both freshwater and marine habitats of chum salmon in general, this may place Korean chum salmon at special risk earlier than others.

Acknowledgements

We would like to express our special thanks to Dr. Shunpei Sato (Hokkaido National Fisheries Research Institute), Dr. Suam Kim (Pukyong National University), and Dr. Nancy Davis (NPAFC Secretariat) for their valuable comments. We appreciate the crews of R/V *Wakatake maru* and R/V *Hokko maru* for their ocean sampling efforts and the researchers who painstakingly place otolith marks on salmon and detect and report finding these marks.

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INTERNSHIP ANNOUNCEMENT

Announcement: 2016 NPAFC Internship Program

APPLICATION DEADLINE: March 16, 2016

The North Pacific Anadromous Fish Commission (NPAFC) invites citizens from its member countries (Canada, Japan, Republic of Korea, Russian Federation, and USA) to apply for the NPAFC Internship Program. One intern will be accepted upon approval of the Commission. The intern will work at the NPAFC Secretariat office in Vancouver, BC, Canada.

The intern will gain experience and knowledge in operations of the NPAFC and will have the opportunity to test their interest in international governmental organizations, management, fisheries, biology, ecology, and fisheries enforcement. The intern will work under the supervision of the Executive Director and/or his designate. In general, the intern will assist in a variety of tasks, including:

- plan, develop, and complete an individual project in communication, scientific or administrative areas
- prepare information for and provide support to special projects
- assist organizing and editing various NPAFC publications
- coordinate international cooperative programs and assist Secretariat activities

Internship period: Starts on or about September 1, 2016, for a period up to a maximum of 6 months. The intern is expected to perform his/her tasks at the Secretariat office on a daily basis, Monday-Friday, 7.5 hours per day.

Qualifications: Applicants must be a citizen of a NPAFC member country, have a university degree, the ability to read, write, and speak English, the ability to use computers and the internet; and demonstrated personal initiative. Applicants must currently be a part of the government or academic sector, a recent graduate, or currently enrolled in school for an advanced degree.

Financial support: NPAFC will provide a stipend of $2,500 CDN per month. Travel cost to and from the intern's place of residence and the location of the Secretariat office and cost of medical insurance will be at the intern's own expense or by home country support. Travel expenses associated with the Intern's work in the Secretariat will be covered by NPAFC.

Applications: Completed applications must include all of the following:

- cover letter describing the applicant's interests and qualifications
- resume showing academic and/or work experience
- three professional letters of reference

Email the completed application to secretariat@npafc.org by March 16, 2016.

For complete information please visit www.npafc.org.

POSITION ANNOUNCEMENT

Position Announcement for NPAFC Deputy Director

APPLICATION DEADLINE: April 30, 2016

Responsibilities of the Position

The Deputy Director, reporting to Executive Director, is the Commission's second chief executive officer and shall assist the Executive Director in performance of his/her duties and responsibilities as provided in Rules of Procedure, #19 (see www.npafc.org/new/about_rules.html). The Deputy Director is responsible for coordinating the compilation of information for publication of catch and hatchery release statistics concerning anadromous stocks, and other publications, provides liaison and advice to the Commission, conducts special studies on the Commission's subject of interest, and performs other duties in accordance with the duties and responsibilities delegated to him/her by the Executive Director.

If the position of Executive Director shall become vacant or if the Executive Director is unable to act, his/her powers and duties shall be assumed by the Deputy Director until such time as a successor is appointed or the Executive Director is able to act.

Qualifications and Essential Experience

Applicants must be a citizen of one of the NPAFC member countries at the time of assuming office. Applicants must have a university degree or its equivalent, excellent interpersonal skills, and good working knowledge and ability in both spoken and written English.

Applicants should have good working knowledge of or experience in the following activities:

- fisheries in the North Pacific Ocean including international arrangements for fisheries management and enforcement
- coordinating and participating in national and international fisheries management and/or scientific research programs
- basic biology of salmon and other living marine resources
- compiling and processing of fisheries statistical data
- providing secretarial support to committees and groups
- operating within the framework of intergovernmental organizations
- organizing large and small meetings
- managing production and contents of bulletins, technical reports, and newsletters, and editing meeting proceedings
- developing website content

The successful candidate will be notified in August 2016.

For complete information please visit www.npafc.org.