Biological Monitoring of Key Salmon Populations: Japanese Chum Salmon

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Background
Chum salmon is one of the important fish resources for Japanese commercial fisheries. Salmon catches generally occupy a position within the first ten species-groups of the most harvested fish in the whole country, accounting for about 5% in 2013 (Fig 1). Of the total salmon catch, chum salmon represents about 95% and pink salmon about 4%. Chum salmon are mainly captured from late August to December in the coastal waters of northern Japan, when adult salmon migrate toward their natal rivers to spawn. In some regions, commercial chum catches continue through January or February.

Management of the salmon fishery falls under provincial jurisdiction. For example, in Hokkaido (the highest salmon producing area in Japan) the Governor granted more than 900 set-net licenses in 2014. Set-nets are commonly used for salmon fishing, and they are anchored along the shore to capture migrating adults. These licenses, which are effective for five years, almost entirely encompass the island coastline of Hokkaido (Fig 2).

Although a large portion of chum salmon are harvested in coastal waters due to high fishing pressure, fish that escape the coastal fishery are captured in their natal rivers (Fig. 3). These in-river catches help to supply eggs for hatcheries and provide incomes to hatchery organizations and freshwater fishermen’s cooperatives. At present, about 250 salmon hatcheries produce about 1.6-1.9 billion chum salmon fry every year in northern Japan. This is nearly 40% of the annual releases from hatcheries around the Pacific Rim.

To maintain chum salmon resources for commercial fisheries in Japan, it is important to achieve the annual planned number of chum releases in each river system (i.e., by each hatchery). At the same time, however, it cannot be denied that such mass hatchery releases may cause risks to the sustainability of this species from a long-term viewpoint. To evade or minimize the risks accompanied with hatchery releases, biological monitoring is indispensable for Japanese chum salmon.

Monitoring unit
Hatchery releases of chum salmon contribute to maintaining the fisheries resources of this species in Japan. In all rivers where salmon production is enhanced, data about adult chum catches, eggs taken for hatcheries, chum fry production, time and average...
size at release, and the numbers of chum fry released are recorded. This information is first collected at each hatchery organization or fishermen’s cooperative, then gathered at the prefectural level, and finally assembled for the whole country by three National Institutes of the Fishery Research Agency (Hokkaido National Fisheries Research Institute, HNFRI; Tohoku National Fisheries Research Institute, TNFRI; and Japan Sea National Fisheries Research Institute, JSNFRI).

Recent studies on the genetic structure of Japanese chum salmon suggest that seven regional groups exist in Japan. Five of these groups are in Hokkaido and two are in Honshu (4, 5; Fig. 4). Based on these regional groups, HNFRI, TNFRI, and JSNFRI monitor biological characteristics of returning adult chum salmon in several rivers with enhanced salmon production in each regional group. Data on body size (fork length and weight) and age (determined from scales) are fundamental biological characteristics and they are routinely obtained from about 100 fish collected at 10-day intervals throughout the upriver migration. At rivers where chum fry are released with thermal marks, the otoliths are collected for detection of the marks. Data on fecundity and egg size of female chum salmon and fish pathogens are occasionally surveyed in some rivers. These surveys, particularly for fecundity and egg size information, have not been always been carried out for the same river populations, but they are conducted on populations within each regional group every year. In 2013, for example, body size information and scales samples were collected from more than 40,000 fish from 47 production-enhanced rivers, otoliths were obtained from more than 10,000 fish from 10 rivers, and data on fecundity and egg size were acquired from about 1,200 fish from 12 rivers.

Furthermore, genetic samples from adult chum salmon are collected from some major rivers, with the populations varying each year. The objective of genetic monitoring is to maintain surveillance of the genetic structure and diversity of each of the regional groups.

Although the intensity of surveys (i.e., sample size and sampling frequency) has changed over time, some of the data series, such as body size and fish age, have been monitored as far back as the 1940s, or even earlier for some populations. But large portions of the earlier monitoring data remain as handwritten texts, and scale samples kept as acetate cards are often damaged. An intensive archiving process will be necessary in the future to preserve and provide access to this historical data.
The current monitoring scheme evolved gradually in the early 1990s, and some collected data for the years 1994-2005 were published in the Salmon DataBase. For enhanced user convenience, the Salmon DataBase is available in electronic format starting from the 2006 survey year. Access to the electronic data is limited to data users/providers, such as provincial governments or provincial research institutes. Due to the East Japan Earthquake on March 11, 2011, there are some gaps in the data, or data authorization may be delayed in some provinces, which consequently makes it difficult to compile monitoring data for the whole country.

Utilization of monitoring data

Firstly, the current year’s data are used to evaluate the status of returning chum salmon. Through the fishery season each year, the number of chum salmon caught in coastal fisheries, in rivers, and the amount of fish used for hatchery egg collection are compiled as a monthly flash report by each province or by smaller regional-scale jurisdictions in northern Japan. The monthly report is available on the HNFRI web page. In addition, some short reports on the status of chum salmon, such as age composition and body size, are also available monthly on the HNFRI web page.

Next, the data collected through the whole season are used to develop a forecast for the next year’s chum salmon returns. A sibling method is commonly used to forecast the chum salmon run. The sibling method is one in which the expected number of fish returning at age \( t \) in year \( i \) is calculated from the actual number of fish returning at age \( t-1 \) last year \( i-1 \) (from the same year-class or brood year) based on a regression between the number of fish returning at age \( t-1 \) and age \( t \) for the particular region. In some provinces, forecasts are produced on a provincial scale. HNFRI provides a forecast at larger regional scales, such as Okhotsk coast, Pacific coast, and Sea of Japan coast.

As a final step, all the monitoring data, particularly the amount of coastal and in-river catches, the quantity of fish used for egg-taking, and hatchery fry release data, are aggregated and authorized by the relevant provinces. After authorization the information is placed in the Salmon DataBase, where it can be utilized for a variety of salmon research investigations.

Recently, 1994-2008 chum salmon biological data obtained from the Salmon DataBase, such as the timing of peak upriver migration, body size, age at maturity, egg size, and fecundity, were compared among the seven regional groups that are recognized to be genetically different (6). Results showed that regional differences were statistically detected for almost all the...
Recent biological characteristics are not always the same as those previously observed. Machidori (7) investigated the timing of chum salmon upriver migration for stocks along the Sea of Japan coast of Honshu during 1970 and 1974. He reported that chum stocks from the Ira River to the Nezugaséki River appeared to have the most delayed timing of upriver migration compared to more northerly or southerly stocks (Fig. 6). His observations are similar to the latitudinal change observed in stocks along the Pacific coast of Honshu today (Fig 5). The recent data demonstrate the timing of upriver migration is earlier in many stocks as compared with the early 1970s and any latitudinal variance in run timing that existed previously has since disappeared (Fig. 6).
Examples of various types of weirs used in Japan to capture adult chum salmon in rivers. They are made of nets (weir 1), wood and bamboo (weir 2), steel (weir 3), and a fish wheel (weir 4).

Photo credits: Weir 1, 2, and 4 FRA (HNFRI), Weir 3 T. Saito Machidori (7) observed that the latitudinal change in run timing existed along both the Sea of Japan and Pacific coasts of Honshu. However, the latitudinal component in the variation in run timing is now reduced in Honshu stocks located along the Sea of Japan due to changes in the run timing of populations from that area. In this region, early-run chum salmon were transplanted from Hokkaido during the 1970s and 1980s to increase salmon production. Artificial manipulation is considered to be a principal cause of the change in run timing. To conserve regional stocks of chum salmon, long-distance transplants are now restrained. But the results of past alterations of population structures often remain in present and future generations.

Sea water temperatures are higher along the Honshu coast of the Sea of Japan than other regions where chum inhabit, such as the Okhotsk and Pacific coasts. Advanced run timing may expose adult chum salmon returning to the Sea of Japan to higher water temperatures, particularly in the future as global warming becomes more serious. To see the signs of potentially harmful changes in chum stocks, monitoring of today’s biological characteristics and comparing this to data from the past is indispensable.
**Marine monitoring**

The HNFRI conducts two types of the marine monitoring for chum salmon—one is coastal and the other is offshore.

**Coastal monitoring**

Today’s coastal monitoring program began in the late 1990s (about 1997), when previous research studies for juvenile salmon were coalesced. There are two coastal monitoring areas off Hokkaido.

One monitoring area is near the town of Atsuta (43°23’55”N, 141°25’57”E), located on Ishikari Bay. At Ishikari Bay, the Ishikari River, the longest river in Hokkaido (268 km), discharges into the Sea of Japan. This river is well known as the most important river for salmon enhancement along the Sea of Japan coast of Hokkaido. A tributary of the Ishikari River is the Chitose River, where HNFRI’s salmon hatchery and Chitose Field Station (CFS) are located. At the hatchery, about 30 million chum salmon juveniles are produced annually, and all the fish are released with otolith thermal marks. Because the CFS is the only salmon hatchery in the Ishikari River system, many of juvenile salmon collected in the coastal waters off Atsuta in April through June originate from the CFS. Recently, a relationship between juvenile CPUE (catch per unit effort) in the coastal area off Atsuta and the number of their adult returns to the Chitose River was discovered (8). This suggests that the brood-year strength of Chitose River fish is determined during the period of time between release from the hatchery and the first few months after sea entry. The monitoring data collected at Atsuta serves to understand the mortality processes of juvenile salmon during their early ocean life.

The second coastal monitoring area is near the town of Konbumori (42°57’10”N, 144°31’51”E), located on the Pacific coast of eastern Hokkaido. Juvenile chum salmon are collected from mid-June to mid-July every year with a two-boat surface trawl. At Atsuta the body size of chum juveniles are mainly < 70 mm fork length (FL), but at Konbumori juvenile body size ranges from 70 to 100 mm FL, or more. This indicates that juvenile chum salmon caught off Konbumori are survivors of the mass mortality phase of early ocean life and they are migrating toward the Sea of Okhotsk, which is the nursery area of Japanese chum salmon after leaving coastal waters. A variety of otolith thermally-marked juveniles originating from rivers on Hokkaido, the Pacific coast of Honshu, and even those migrating from the Honshu’s Sea of Japan coast are recaptured in the coastal waters off Konbumori. The monitoring program and related research have discovered that juvenile chum salmon originating from the rivers on the Sea of Japan coast of Honshu migrate toward the Sea of Okhotsk by moving through the Tsugaru Strait and traveling along Hokkaido’s Pacific coast. Thus, the coastal waters off Konbumori are now regarded as an important migration corridor for Japanese chum salmon. Monitoring juveniles at Konbumori enables us to observe migration timing of fish originating from several regions of northern Japan.

The juvenile chum salmon are densely distributed close to shore, and the monitoring surveys at Atsuta and Konbumori are conducted in a very narrow zone within 10 km of shore. Because of the surveys’ proximity to the shoreline, they overlap with coastal fishing areas for set-nets, gill nets, octopus pots, etc. Therefore monitoring surveys are conducted with the assistance of fishermen who have expert local knowledge. Their assistance is crucial to the past and future success of the monitoring surveys.
Offshore monitoring

The Bering Sea is a well-known rearing area for immature chum salmon (age 0.1 and older) originating from both Asia and North America. Ecosystem dynamics, including physical oceanography (such as water temperature), biological changes (such as feeding conditions), and interactions with other species, all play an important role in determining the growth and survival of chum salmon in the Bering Sea.

Japanese research vessels have monitored the condition of Pacific salmon stocks since 1952, and HNFRI started a new offshore monitoring program in the Bering Sea in 2007 using the R/V Hokko maru (902 gross tons). The offshore monitoring survey is carried out in July and August every year at 17 stations in the central Bering Sea (Fig. 7). At each station, data on physical oceanography (vertical profiles of temperature and salinity) and samples of macrozooplankton, salmonids, and other pelagic fish are collected. Fish samples are collected during daytime with a surface trawl that is towed for one hour at a speed of approximately 5 knots. The trawl net collects fish from the surface to about 30 m depth. For salmonids, basic information is collected on body size (fork length and weight), sex, and gonad weight, and scales are removed for age-determination. In addition, samples of body tissues are collected for genetic stock identification, and otoliths of chum salmon are obtained for detection of thermal marks. Occasionally, stomach samples are also collected.

Fig. 7. The location of offshore monitoring trawl survey stations for salmonids in the central Bering Sea. These operations have been conducted in July-August by the Japanese research vessel Hokko maru since 2007.

Fig. 8. Scaled mass index (grams) of chum salmon obtained from central Bering Sea surveys, 2007-2009 and 2011-2013. The index is based on body weight standardized to 400 mm fork length. Error bars indicate 95% confidence intervals. Significant differences (p<0.05) among years are indicated with unique single letters. Figure modified from Fig. 5 (9).
The offshore monitoring program has revealed new information about chum salmon in the Bering Sea. For example, genetics analyses have demonstrated that Russian stocks of chum salmon were dominant in the survey area in 2007 and 2009-2012 (9), which likely reflects the relative abundance of this species among the surrounding countries in recent years. In addition, the program has indicated a decreasing trend in chum salmon body condition based on a scaled mass index, a measurement of size based on body weight standardized to 400 mm FL (Fig. 8). The index shows chum salmon body size was smaller in 2011-2013 compared to 2007-2009, and the lowest value was observed in 2013. This result implies the growth of chum salmon in 2011-2013 in the Bering Sea has declined.

Conclusion

Japanese chum salmon fisheries are largely supported by salmon hatchery production, which annually release 1.6-1.9 billion fry. The annual number of chum salmon fry released has been almost constant since the early 1980s, but the adult returns have fluctuated widely and the decline has been particularly evident since 2008. Collection of data by the salmon monitoring programs has been profoundly useful in clarifying the reasons for the recent decline in returns, and possibly in reducing the decline. This continues as the top priority for scientific investigations of Japanese chum salmon today.

Recent analyses demonstrated that Japanese chum salmon stocks have regionally distinguishable biological characteristics, which appear to reflect the genetic differences among regional groups, despite the releases of large numbers of hatchery fish that have continued for a long time and the country-wide transplantation of fish. However, some characteristics, such as run timing of adult salmon, have changed over time due, at least in part, to hatchery manipulations. Changes in biological traits may pose risks to the sustainability of Japanese chum stocks in the future. To minimize the risks, biological monitoring is required in order to develop a time-based data series by which the past and present status of salmon can be assessed.
Research on wild salmon has revealed that the contribution of wild chum salmon is far from negligible in Japan (10). Conservation of wild chum salmon serves to increase the long-term sustainability of this species and contributes to the stability of salmon hatchery programs and salmon fisheries. At present, the monitoring program for wild salmon is not well developed and establishing it on a strong footing is an important priority.

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References