Japanese Wild Salmon Research: Toward a Reconciliation Between Hatchery and Wild Salmon Management

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Introduction

It has been widely assumed that almost all Pacific salmon (*Oncorhynchus* spp.) in Japan originate in hatcheries (*1*, *2*). One reason for this widespread belief is that there have been no quantitative studies that actually examined the contribution of hatchery or naturally-spawned fish (wild fish) to total production. However, recent studies examining the contribution of hatchery/wild fish by mass marking of hatchery fish have shown the contribution of wild salmon is far from negligible. Rather, it is large enough to constitute a substantial portion of fishery production (Fig. 1).

Fig. 1. Recent estimates of the relative contribution of hatchery and wild salmon to total production in Hokkaido, Japan.

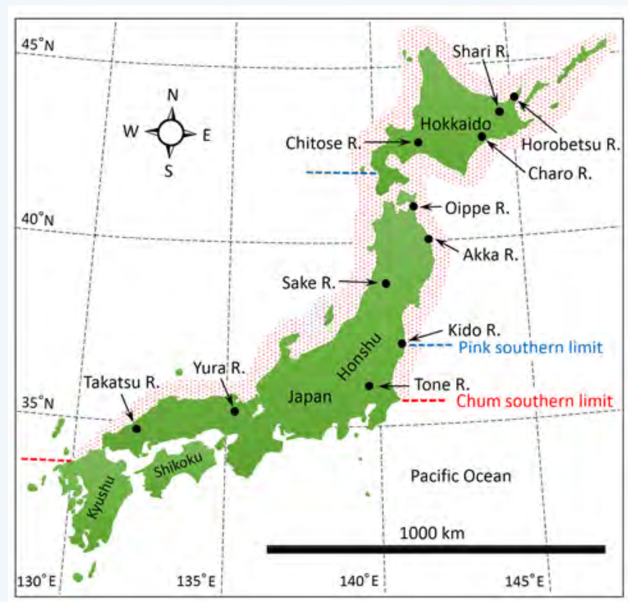
Most of the important information regarding wild salmon in Japan has been written in Japanese because the primary group interested in salmon fisheries management is domestic personnel. English is still unfamiliar in the fisheries field in Japan, where writing in Japanese is the best way to disseminate important information to fisheries managers. As a result, the vast majority of Japanese wild salmon data is almost completely unknown to the non-Japanese speaking fisheries scientific community.

In this article I review reports, especially those written in Japanese for the benefit of the non-Japanese reading audience interested in wild salmon in Japan. I also discuss future wild salmon management strategies for the sustainable use of both wild and hatchery salmon in Japan.

What is the ratio of wild and hatchery salmon in Hokkaido?

About Hokkaido

Hokkaido, the northernmost island of the Japanese archipelago, is Japan's largest salmon producing area (see review in *3*). Approximately 200 rivers on Hokkaido have salmon populations, and native anadromous *Oncorhynchus* spp. include chum (*O. keta*), pink (*O. gorbuscha*), and masu salmon (*O. masou*).



Light stippling indicates range of chum salmon producing rivers. Red and blue dashed lines indicate southern limit of chum and pink salmon distribution in Japan.

For ease of characterization, rivers in Hokkaido have been divided into four categories (*4*, *5*).

Category I: non-enhanced rivers; hatchery-reared fish have never been stocked.

Category II: non-enhanced rivers; hatchery-reared fish have been stocked historically but are not stocked presently.

Category III: enhanced rivers; hatchery-reared fish are stocked but returning adults are not captured for hatchery broodstock.

Category IV: enhanced rivers; hatchery-reared fish are stocked and returning adults are captured for hatchery broodstock.

Chum salmon
Miyakoshi *et al.* (*4*, *5*) found that natural spawning occurred in 38–41 category I rivers, 12-18 category II rivers, and 39-45 category III rivers. They also indicated there were 76-84 category IV rivers, but they did not note the number of rivers in this category containing naturally spawning fish.

For category IV rivers, Morita *et al.* (*6*) estimated the contribution of wild fish to total chum salmon catch in eight rivers by identifying the ratio of otolith thermal-marked hatchery fish to un-marked wild fish (*7*). The contribution of wild fish to the total catch in category IV rivers was estimated to be 28.3% (±1.2%), but the value varied considerably among rivers and years (ranging 0% to 50%). For example, about 38% of chum salmon captured in the Shari River were estimated to be wild fish. In fact, there are good spawning grounds in the Shari River system.

This September 2013 photo shows chum salmon spawning in the Satturu River (approximately 15 km in length), a tributary of the Shari River. There is no hatchery located on the Satturu River, but many chum salmon have been observed migrating into the river. *Photo credit: K. Morita.*

In contrast, the estimated contribution of wild fish was 0% in the Yurappu River, despite observations of many naturally-spawning chum salmon in the river (*8*). The number of spawning wild salmon in the Yurappu may be substantially higher than originally estimated because most redds are located downstream of the hatchery weir and the estimate was based on wild fish captured at the weir (*9*).

Two other studies estimated the proportion of wild chum salmon in category III rivers, including ALC otolith-marked hatchery fish identified in the Uebetsu River (*10*) and adipose fin-clipped hatchery fish identified in the Toyohira River (*11*, *12*). Both of these studies estimated about 70% of adult chum salmon were naturally-spawned fish. In the Toyohira River, the proportion of fish straying from other hatcheries was also measured, but this was found to be negligible (1.6%). The redd count of naturally-spawned chum salmon in the Toyohira River has been surveyed since 1985 (*13*), making it the longest time series census of wild salmon in Japan.

Although the number of category I and II rivers is substantial, these rivers are generally small. Historically, hatchery programs targeted larger rivers producing substantial numbers of salmon. From a quantitative perspective, perhaps production of wild salmon from category I and II rivers is small, but these rivers may produce genetically important wild populations.

So far, nobody has estimated the contribution of wild chum salmon to coastal commercial catches, which account for about 90% of the total commercial salmon catch in Japan. Hokkaido National Fisheries Research Institute (HNFRI) investigators are currently working to estimate the contribution of wild chum salmon to commercial fisheries.

Pink salmon observed in the Horobetsu River (category I river) in October 2005. There are no historical records describing hatchery releases of pink salmon in this river. *Photo credit: K. Morita.*

Pink salmon

In recent years, there have been many in-river observations of natural spawning pink salmon and the presence of naturally-spawned fry and adult pink salmon (*14-17*). Natural spawning of pink salmon is very common in rivers of Hokkaido's Okhotsk Sea coast. In fact, at the age of 18, I bicycled around northeastern Hokkaido and during that trip I saw a lot of pink salmon in the rivers of that area.

Using a population model Morita *et al.* (*18*) estimated the contribution of hatchery pink salmon to commercial catches was 17.5% during the period from 1994 to 2003 and the balance was wild pink salmon. By identifying the ratio of otolith thermal-marked hatchery pink salmon in random samples from the commercial fishery, Ohnuki *et al*. (*19*) estimated the contribution of hatchery fish to coastal catches of pink salmon to be 16.6% and 22.6% in 2011 and 2012, respectively. Pink salmon population trends correlate with climatic variables related to the reproduction of naturally-spawning pink salmon, namely rainfall and river discharge during fall of the two previous years (*20*).

Earlier studies reported relatively high return rates of hatchery pink salmon (>10% in some years) by assuming all returns were hatchery fish (*1, 2*). However, these estimates appear to be exaggerated because most commercial catches are naturally-spawned wild fish, not hatchery fish.

Masu salmon

Miyakoshi (*21*) estimated the contribution of hatchery fish to coastal catches of masu salmon based on tagging data in 1994-2003. He estimated the contribution of hatchery fish to the total coastal catch was 14-26%. Recently, Urabe *et al.* (*22*) found masu salmon parr densities were significantly lower for stocked rivers than for non-stocked rivers, even though recreational fishing is often prohibited in stocked rivers. This suggests the need to consider the potentially negative effects of hatchery releases on wild production of masu salmon.

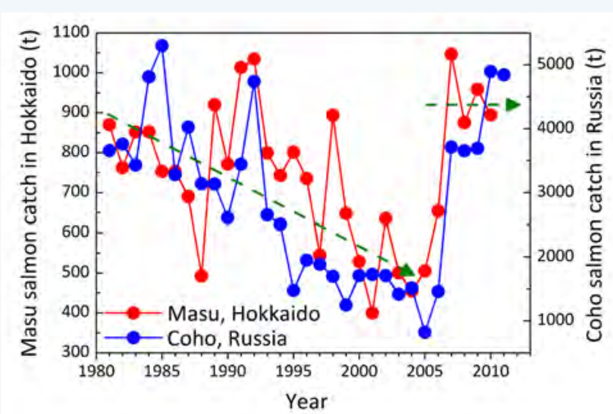


Fig. 2. Changes in masu salmon catch in Hokkaido (red circles) and coho salmon catch in Russia (blue circles). Data source: *23, 24*.

Masu salmon parr in the Charo River of eastern Hokkaido in Aug. 2010. During the last few years the number of masu salmon in this river has increased dramatically without the benefit of artificial enhancement. *Photo credit: K. Morita.*

Although masu salmon catches decreased gradually over the period 1970-2005 (*3*), they recovered rapidly after 2007 (Fig. 2). This increase, however, is region specific. Where there has been a large effort to increase masu salmon hatchery production along the Japan Sea coast, commercial catches continue to decline ($r = -0.804$, $p < 0.001$). In other regions (Pacific Ocean and Okhotsk Sea coast) where there has been a small effort to increase hatchery production, masu salmon catches have increased ($r = 0.428$, $p = 0.018$).

From personal observations, I think recent increases in abundance of masu salmon in the rivers of eastern Hokkaido are remarkable. This may be, in part, due to climatic change. This hypothesis is supported by evidence that Russian catches of coho salmon, a species with a similar life-history, appear to be synchronized with masu salmon abundance (Fig. 2, $r = 0.630$, $p < 0.001$).

Imai *et al.* (*25*) observed that all adult masu salmon upstream of the Chitose River hatchery weir were unmarked wild fish, whereas adult masu salmon captured at the weir included hatchery-origin fish (hatchery/wild = 127/19 in 2007, 13/183 in 2008). Because the hatchery weir operated between late August and mid-December, wild masu salmon migrated upstream of the weir before August and the hatchery masu salmon migrated afterwards.

Masu salmon adults in the Chitose River in October 2011. Most masu salmon spawning in the area upstream of hatchery weir were un-marked, wild fish (*25*). *Photo credit: K. Morita.*

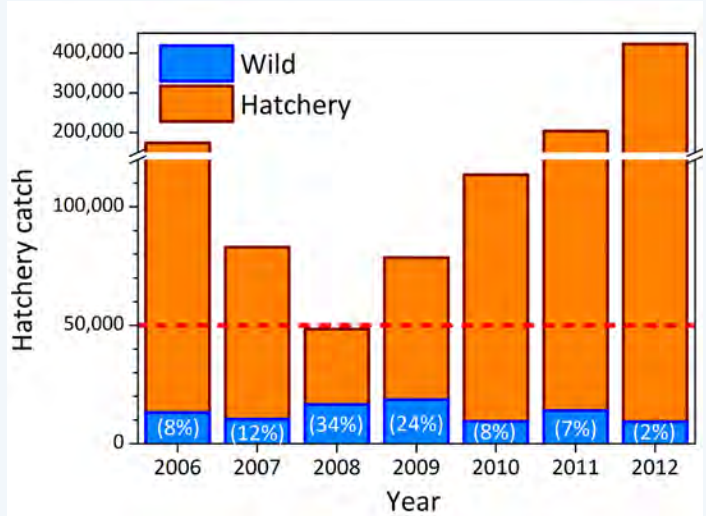


Fig. 3. Total number of chum salmon caught and the estimated contribution of naturally-spawned (wild) chum salmon at the Chitose River hatchery weir. The proportion of wild fish is given in parentheses. The dashed line indicates the minimum number of adults required for egg collection and production of 30 million hatchery fry. Data source: *6*.

A case study of wild chum salmon in the Chitose River

The Chitose River (42°50´N, 141°40´E) is one of the biggest enhanced rivers (category IV) in Hokkaido. Every year, 30 million hatchery-reared fish are stocked and returning adults are captured for broodstock. Almost all hatchery fry have been otolith thermal marked since 2002. Because water discharge is relatively stable in the Chitose River, few salmon can pass over the hatchery weir, but when flooding occurs the number of fish by-passing the weir may be substantial. Every day the number of fish captured by the hatchery weir is counted, and every 10 days (3 times per month) biological data are collected for 100 individuals, which includes fork length, body weight, age, sex, and the presence of otolith thermal marks. The contribution of wild fish to the total catch has been estimated to range 2-34% (Fig. 3).

Two stocks of chum salmon: autumn-run and winter-run

The Chitose River produces both autumn- and winter-run chum salmon. Early studies identified significant differences in meristic traits between the two groups, such as the number of gill rakers (*28, 29*). Recently, microsatellite DNA analysis showed significant genetic divergence between the two groups of fish (*30*).

The hatchery weir located in the Chitose River. Most ascending salmon are caught here from late August to mid-December, but high-water flow events allow salmon to by-pass the weir (see inset). As a result, high water levels increase the number of autumn-run salmon carcasses found in an upstream tributary (*26, 27*), which in turn increases the number of wild salmon in the next generation (see Fig. 5 in reference *6*). *Photo credit: M. Kikuchi.*

Winter-run chum salmon in the Chitose River observed in January 2013. The river produces distinct stocks of autumn-run and winter-run chum salmon. The winter-run population is sustained by natural spawning. *Photo credit: K. Morita.*

From 1888 to 1927 hatchery broodstock was collected from winter-run chum salmon, and from 1927 to 1929 broodstock was collected from both autumn and winter-run fish (*31*). After 1929, broodstock was collected only from autumn-run fish (*31*). The autumn-run chum salmon caught in 1927-1928 were wild fish (Fig. 4a) as the minimum adult age at return is two years and because the migration timing of offspring is strongly dependent on the migration timing of parental stocks (*32*, *33*).

Current hatchery weir operations end by mid-December, so there is no catch data for winter-run chum salmon (Fig. 4b). However, a significant number of winter-run chum salmon migrate to the Chitose River every year (Fig. 4c, *26*, *27*, *34*) that results in a high proportion of wild fish in the hatchery catch late in the season (Fig. 4b, *6*).

The Chitose Salmon Aquarium has counted the number of fish seen from their in-river observation window for each species once a day since 1995 (*35*). These data show a clear bimodal distribution of migration timing each year (Fig. 4c). It is rarely done, but on occasion chum salmon have been counted as late as March and April.

My colleagues and I are currently analyzing the population dynamics of both the autumn-run and the winter-run chum salmon using the fish-count data. We are aware of the need for caution when interpreting these window observations because in winter many chum salmon stay and spawn in front of the observation window, rather than simply passing by. This behavior makes it somewhat difficult to interpret the count of fish passing the observation window.

Observations show that the hatchery catch did not represent the actual patterns of migration timing. The period of hatchery weir operation varies between rivers and years. In the case of the Chitose River, the period of hatchery weir operation shifted to an earlier time during the last century, but was re-extended to a little later in the last five years. Natural reproduction of chum salmon is often observed in January in places other than the Chitose River (e.g., the Shari River), but currently there are no rivers with a hatchery weir operated after late December in Hokkaido. Clearly, the migration timing of chum salmon requires further study.

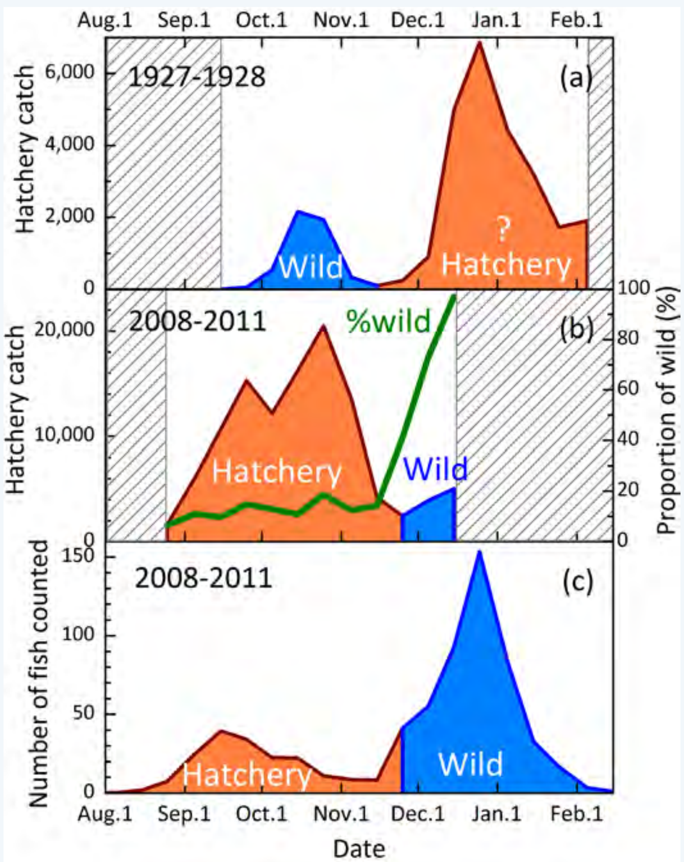
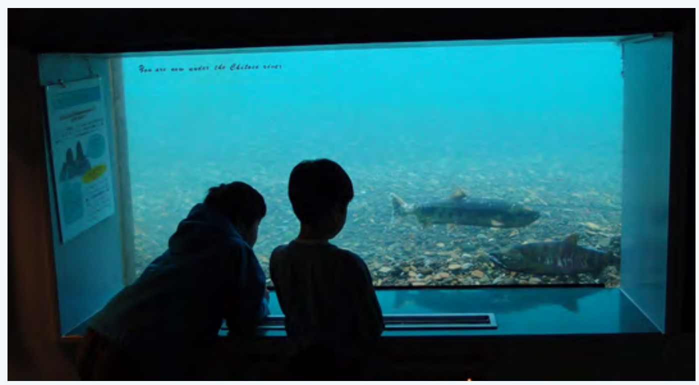


Fig. 4. Chum salmon migration timing in the Chitose River in fiscal years 1927-1928 and 2008-2011. Average number of fish caught by the hatchery weir by 10-day period (a-b). Average number of fish counted by 10-day period by the Chitose Salmon Aquarium (c). Hatched areas indicate time periods outside of hatchery weir operation. Hatchery and wild fish were classified by migration timing for the sake of convenience. Data source: *6, 31, 36, 37*.



Chum salmon observed to linger in front of the Chitose Salmon Aquarium observation window in late December 2013. The window is located downstream of the hatchery weir. *Photo credit: K. Morita.*

Efficiency of chum salmon natural reproduction

The estimated survival rate of naturally-spawned eggs to the fry stage for the 2011 year class of chum salmon in the Chitose River ranged 19-23% (*34*). For the 1957-1959 year classes of chum salmon in a tributary of the Tokachi River, the naturally-spawned egg to fry survival rate ranged 16-34% (*38*). Because the egg to fry survival rate in hatchery programs is 81-84%, the efficiency of natural reproduction is about a quarter of the efficiency in hatcheries.

In recent decades, the annual number of adult chum salmon caught by the Chitose River hatchery weir varies 50-550 thousand, and the return of adults to all Hokkaido hatcheries ranges 1.5-5 million. However, the annual number of fry released has stabilized at 30 million in the Chitose River and at 1 billion in Hokkaido because of limitations in hatchery capacity. Consequently, in most years many adult chum salmon were sold by hatcheries because the adults were surplus to the needs of hatchery egg collection.

If hatchery managers would allow surplus salmon to spawn naturally, the total number of out-migrating fry would increase substantially. Saving just one female to spawn naturally could result four years later in 10 more adult chum salmon returning to coastal fisheries (*34*).

A recently installed fish ladder (left) and rehabilitated pink salmon spawning ground above the dam (right) on the Chienbetsu River in October 2011. Many pink salmon now spawn in the area above the dam. *Photo credit K. Morita.*

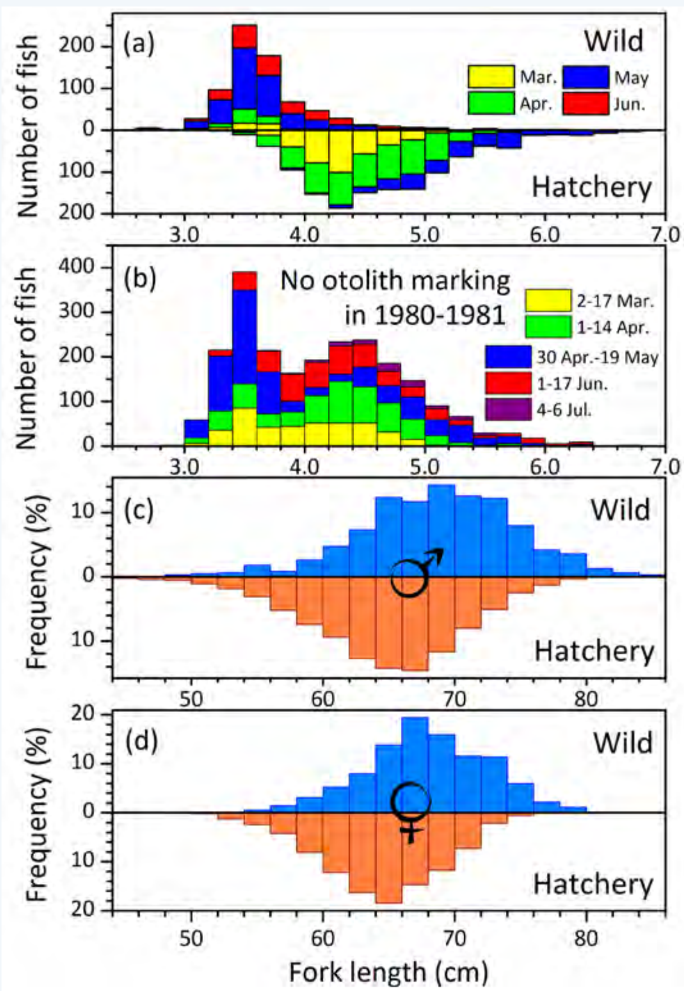


Fig. 5. Fork length distributions of otolith-marked hatchery and un-marked wild chum salmon in the Chitose River. Fry were captured at the Nishikoshi fish-catching station in (a) 2012, (b) 1980-1981, and returning adult (c) males and (d) females of 2003-2005 brood years. Data source: *34, 39, 40*.

Comparison of body size between hatchery and wild chum salmon

Body size of outmigrating wild fry is significantly smaller than that of hatchery fish (Fig. 5a). In addition, most hatchery fry outmigrate between March and April, whereas most wild fry outmigrate between May and June. Mayama *et al.* (*39*) found a significant number of naturally-spawned wild fry in their 1980-1981 samples (Fig. 5b), and they suggested most wild fry will not survive because of their smaller size and later timing of outmigration. Unfortunately, there was no mass-marking technique at the time, so consequently almost all returning chum salmon were believed to originate from hatcheries.

Although hatchery fry outmigrated from the Chitose River at a larger size than wild fish, the reverse occurred when the adults returned to the river (Fig. 5c,d). Most returning adult males larger than 80 cm (fork length) and most females larger than 76 cm were un-marked wild fish. Body size differences between wild and hatchery fish were consistent, even when compared for fish of the same age (3–6 years) and migration timing (*40*). However, the difference in body size of wild and hatchery fish was not consistent between rivers. In the Ichani River, a very small river, wild fish were larger than hatchery fish at age 3 years, but hatchery fish were larger than wild fish at age 5–6 years (*40*). Thus, in the Ichani River age-related increase in body size of wild fish was smaller than that of hatchery fish.

This pattern may be explained by a local adaptation by the chum salmon to a small river, where reproductive success of particularly large individuals may be lower due to the river's shallow depth (*40*). Natural selection would operate heterogeneously among rivers, whereas hatchery selection would operate homogenously among rivers.

Chum salmon spawning ground in the Sake River (38°47´N, 140°13´E), a tributary of the Mogami River in November 2013. “Sake” means chum salmon in Japanese. *Photo credit: K. Morita*

Current status of natural spawning habitats

A large effort to rehabilitate aquatic ecosystems has been implemented in Japanese rivers. First, the water quality of rivers has improved greatly during the last 50 years (*3*). Around 1960, most rivers in Hokkaido had polluted areas, and the impact of water pollution on Pacific salmon was a critical problem (*41*). For example, the Shari River was strongly polluted (BOD [*42*] ~10 mg/l) in early 1960, but pollution levels were reduced (BOD < 2 mg/l) after 1980. Second, many artificial structures have improved access of migratory fishes to spawning areas. For example, the upstream migration range of the Shiribetsu River (length 1,347 km) increased from 140 km (10.4%) to 790 km (58.6%) by installation of fish ladders (*43*). Re-colonization of anadromous salmonids following the installation of fish ladders is often rapid (*44, 45*).

The hatchery weir sometimes prevents salmon from migrating upstream. Urabe *et al.* (*46*) evaluated the potential spawning grounds of the Tokachi River system using GIS. They found a lot of good spawning habitats in the upper reaches, but they did not observe any adult chum salmon in these areas because of an operating hatchery weir at a downstream site. In enhanced rivers with broodstock capture (category IV rivers), the chum salmon spawning grounds are often open, available, and unused during periods of hatchery weir operation.

Many studies suggest that adequate gravel size, upwelling water, and side channels are important for spawning microhabitats of chum salmon (*8, 13, 46-50*). In particular, upwelling water is indispensable for late-run chum salmon to accelerate the developmental rate of eggs during winter. In addition to conservation of these environmental characteristics (gravel size, side channels and upwelling water), it is very important that adult salmon be allowed to move up into spawning areas in order to rehabilitate wild salmon production.

In 2013, HNFRI bought adult chum salmon (620 males and 789 females) caught by the Chitose hatchery weir on 12-14 December to allow them to spawn naturally upstream for the conservation of winter-run wild chum salmon.

Salmon in central Honshu, the southern limit of chum salmon distribution

Current status

Chum salmon populations in central Honshu are nearly at the southern limit of the species’ distribution. Although hatchery programs have reduced their production in recent years and the negative impact of climate warming is expected to be most severe at the southern limit of distribution, chum salmon production in central Honshu has not decreased. Instead, chum salmon abundance has increased exponentially in the Tone River (35°44´N, 140°51´E), which is located at the southern limit of distribution on Honshu’s Pacific Ocean coast (Fig. 6). It appears this is largely due to increases in natural reproduction because the number of hatchery fry released has decreased from 350 thousand to only 10-20 thousand (*51*). In central Honshu, many rivers are without a hatchery weir at the river mouth and these rivers might be producing significant numbers of wild chum salmon. The Naka River (36°20´N, 140°36´E), the place where hatchery practices in Japan were first implemented in 1876, now provides a nice place for salmon watching (YouTube, http://www.youtube.com/watch?v=rfzw-KGHGpE).

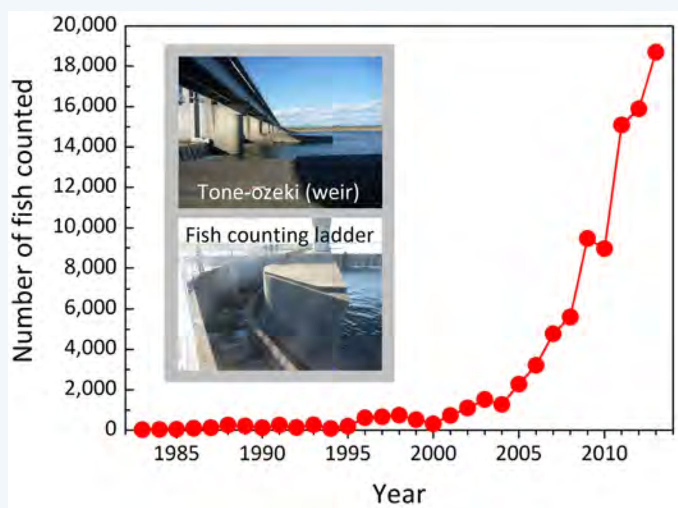


Fig. 6. Number of chum salmon ascending the Tone River (35°44´N, 140°51´E). The fish are counted at the Tone-ozeki (weir) about 50 km north of Tokyo by the Japan Water Agency. The insets show the Tone-ozeki and fish counting ladder in November 2013. Data source: *52, 53*.
Photo credit: K. Hasegawa.

There are few quantitative studies regarding the production of wild chum salmon in central Honshu. Komatsu *et al.* (*54*) estimated the total production of naturally-spawned chum salmon fry in the Ookita River (36°48´N, 140°45´E) in 1995 by identifying ALC otolith-marked fry. A total of 1.3-2.6 million fry was estimated to have been produced from natural spawning grounds measuring 2.3 km in length. Because 0.4 million fry were released from the hatchery, the estimated proportion of wild fry was 75-86%.

Evolutionary adaptation to high temperature

Researchers expect that salmon populations in Honshu are better adapted to high temperature. In fact, a new mitochondrial DNA haplotype was recognized in chum salmon from the Noto Peninsula (37°N) in central Japan (*55*). Because this haplotype has never been found in chum salmon of the northern Pacific range, this proves that chum salmon in the central Honshu still maintain unique genetic properties.

In general, migration timing of adult chum salmon is later at lower latitudes. However, the reverse occurs at 38-39°N; at these latitudes the migration timing tends to be earlier with decreasing latitude (*56*, *57*). Machidori (*56*) hypothesized that adult chum salmon in central Honshu should spawn early in autumn, so their offspring can outmigrate to sea early in spring while coastal temperatures remain low. For example, Fujiwara *et al.* (*58*) studied the adult migration timing of wild chum salmon in the Yura River, Kyoto (35°31´N, 135°17´E), and found that returns were between late October and early November, which was earlier than in northern Honshu. They suggested that early migration timing of adult chum salmon was an adaptation to the southern area of the species' range and consistent with Machidori's (*56*) hypothesis. Similarly, spawning timing of wild chum salmon in the Takatsu River (34°42´N, 131°50´E) is between late October and early November (*59*, *60*; Fig. 7).

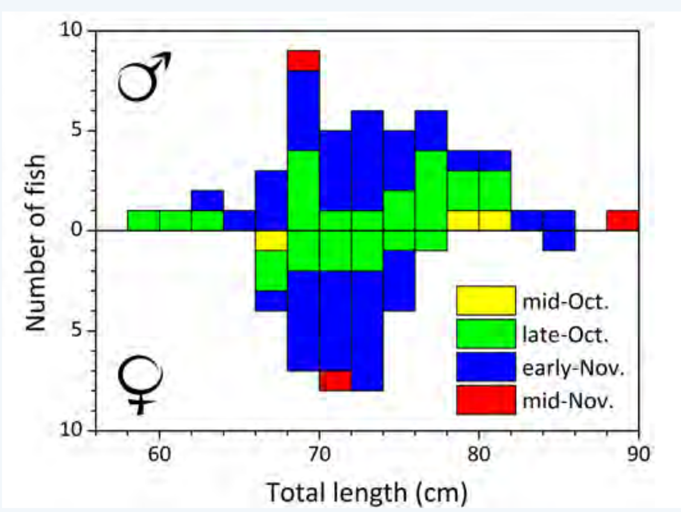


Fig. 7. Total length distribution of wild chum salmon by return period in the Takatsu River (34°42´N, 131°50´E) in earlier eras of adult hatchery fish returns (1984-1985). Mean age±S.D. = 3.86±0.67, ♂; 3.59±0.67, ♀. Data source: *59*, *60*.

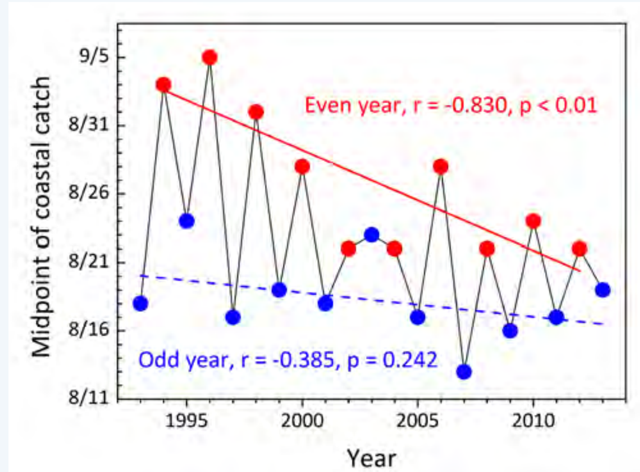


Fig. 8. Date of the annual midpoint of the catch of pink salmon along the coast of Hokkaido (1993-2013).

Recent studies have reported earlier timing of adult migrations in multiple salmonid species due to climate warming in North America (*61*, *62*) and in pink salmon in Far East Asia (*63*, *64*; Fig. 8). Thus, spatial patterns of migration timing across temperature gradients in Honshu correspond well with recent temporal changes in the migration timing due to climatic warming. Studying wild chum salmon in central Honshu at the southern range of the species may forecast future impact of climate changes on Pacific salmon populations. This approach employs the concept of substituting space for time, meaning that observed differences based on a spatial pattern could represent anticipated temporal changes due to climate.

This concept is also applicable to pink salmon. The reported distribution of pink salmon has extended to the Kido River (37°16´N, 141°01´E), Fukushima Prefecture (*65*), and annual migrations of adult pink salmon are known in several rivers of northern Honshu (*66*, *67*). The main spawning period of pink salmon in Hokkaido is between September and October, but in the Oippe River (41°10´N, 141°23´E) it is between mid-August and late-August (*68*). The migration timing of wild pink salmon in the Akka River (40°03´N, 141°51´E) is also reported to be between late August and early September (*69*).

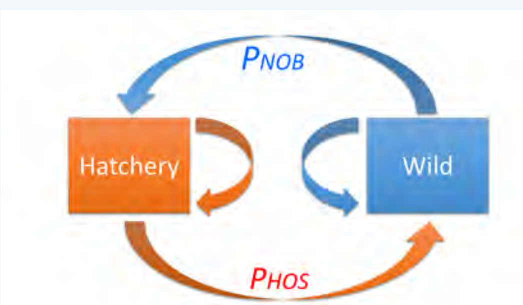
Toward a reconciliation between hatchery and wild salmon management

I assert that conservation of wild fish will guarantee the long-term sustainability of hatchery programs and the salmon fishery for both quantitative and qualitative reasons.

First, wild fish contribute significantly to hatchery broodstock from a quantitative perspective. In the Chitose River in 2008, the required number of chum salmon hatchery broodstock was collected from wild fish (see Fig. 3). Interestingly, the return rate of fish from this broodstock was very high—the hatchery catch in 2012 exceeded 400 thousand fish. There might be a link between the proportion of wild-origin broodstock and the subsequent survival of hatchery fish. At the very least, wild fish production provides insurance against failures of hatchery-released fry. In the case of pink salmon, hatchery programs cannot continue without support from wild production.

Second, from a qualitative perspective there is a positive genetic contribution to be made by wild fish to hatchery fish. There has been great concern about the fitness decline of hatchery fish. The Gifu Prefectural Research Institute developed the semi-wild amago salmon (*O. masou ishikawae*) by crossing a hatchery female with a wild male (*70*). Although the semi-wild fish were vulnerable to disease and high growth variability in the hatchery, ocean survival rates were much higher for semi-wild smolts than for hatchery smolts (a 2- to 15-fold increase). Clearly the conservation of wild fish will benefit the effectiveness of hatchery programs.

There are two alternative approaches to hatchery programs—the segregated and the integrated program (*71*). The segregated program tries to isolate wild and hatchery populations, and the integrated program attempts to manage gene flow between hatchery and wild fish to limit the hatchery selection force on the whole population. These two approaches yield quite different broodstock management strategies. In the segregated program, wild fish should not be included in hatchery broodstock and hatchery fish should not be allowed to stray to the wild population. Alternatively, in the integrated program, wild fish should be included in hatchery broodstock to maintain genetic similarity with the wild population.



$$PNI = \frac{P_{NOB}}{P_{NOB} + P_{HOS}} > 0.5$$

Fig. 9. An integrated broodstock management program using proportionate natural influence (PNI) proposed by Craig A. Busak *(71)*. P_{NOB} = proportion of natural-origin fish broodstock, P_{HOS} = proportion of hatchery-origin fish spawning naturally. If PNI > 0.5 natural selection has a greater influence than hatchery selection on the genetic constitution of the whole population.

An integrated hatchery program can be managed using an innovative and simple methodology that evaluates the proportionate natural influence (PNI) index, as proposed by Craig A. Busak (Fig. 9).

In my opinion, integrated management seems to be a realistic alternative in Japan. Most large rivers already have hatchery production. There are many wild salmon rivers where hatchery-reared fish have never been stocked, but these rivers are very small and may not be suitable for chum salmon (hence no hatchery was sited there). Unfortunately, there are very few pristine wilderness rivers in Japan that deserve *reservation* of the wild salmon population. Additionally, most Japanese rivers drain agricultural and urban watersheds and they are already managed with hatchery programs; therefore *restoration* of wild salmon habitats has severe limitations.

Rosenzweig (*72*) proposed *reconciliation* ecology as the third 'R' of conservation biology, in which species are conserved in highly altered, anthropogenic habitats on urban or industrial lands. I think that an integrated hatchery program could be the solution to reconcile hatchery and wild salmon in many well-developed hatchery-dominated Japanese watersheds.

Spawning ground of chum salmon in the Toyohira River located in the Sapporo metropolitan area in November 2012. Many (>50) chum salmon spawned in this side channel. The inset illustrates salmon carcasses in October 2013. The proportion of wild to hatchery-origin fish in this river is estimated to be about 70% *(11)*.
Photo credit: K. Morita.

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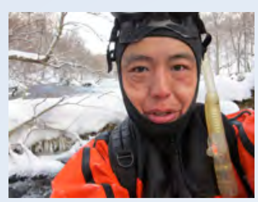

Kentaro Morita was raised in Nara prefecture at the southern limit of *Salvelinus*, where as a boy he became fascinated with salmonids in general and with charr in particular. As Hokkaido is salmonid paradise in Japan, it was natural that Kentaro was drawn northwards. He received a PhD from Hokkaido University based on his studies of conservation ecology of white-spotted charr. Since 2003, Kentaro has been working on chum, pink, and masu salmon, Dolly Varden and white-spotted charr at the Hokkaido National Fisheries Research Institute. Most of his studies are based on field work that includes both high seas salmon research in the North Pacific and snorkeling/electrofishing in Japanese rivers. Among his favorite pastimes are conducting underwater observations (as seen in this photo of him on the spawning ground of winter-run chum salmon in the Chitose River in January) and catching fish by hand or with a net while snorkeling. See his underwater salmonid photos at http://www.geocities.jp/iwanahenaito/