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# Natural spawning of chum salmon *Oncorhynchus keta* within a hatchery stock enhancement program—a case in the Otsuchi River at the Sanriku coast—

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**Abstract**—Natural spawning of chum salmon, *Oncorhynchus keta*, in the Otsuchi River within a hatchery-based stock enhancement program was assessed for the first time in the 2014–2015 spawning season. Adult chum salmon, their spawning redds and carcasses were visually counted biweekly by walking along the river 1.0 to 4.0 km from the river mouth, during 15 September 2014 to 27 January 2015. A total of 160 spawning redds and 808 carcasses were found and at least 904 adults were counted upstream of the hatchery weir, suggesting that chum salmon spawn naturally in the Otsuchi River within a hatchery stock enhancement program. The majority of spawning redds (91.3%) were found in the area of 2.0–2.5 km from the river mouth and the main spawning area appears to have shifted more than 500 m upstream compared to the previous description in 1962. Retention of carcasses in the Otsuchi River (less than 14 days) was significantly shorter than Hokkaido (30–40 days during autumn and 70–80 days during winter). Warm water temperatures and relatively rapid flow by the steep gradient of the river in Sanriku Ria likely made carcasses quickly decomposed or washed away. This study suggested a possible contribution of naturally spawning chum salmon for returning adults in the Otsuchi River and a particular ecological role of salmon carcasses in the riverine ecosystem in Sanriku Ria.

**Key words:** Chum salmon, Natural spawning, Carcasses, Otsuchi, Sanriku Ria

## Introduction

To increase the commercial harvest of chum salmon, *Oncorhynchus keta*, the hatchery-based stock enhancement program has been implemented over 120 years in Japan (Kitada 2014). Chum salmon returning to Japanese waters significantly increased up to the late 1970s presumably due improvement of the stock enhancement program, favorable growth habitat condition in the ocean and the closure of fisheries in the high seas (Morita et al. 2006). However, despite the annual number of chum salmon juveniles released being mostly constant at around 1.8 billion since 1980, except in 2011 when the East Japan Earthquake and the following Tsunami disaster occurred, the number of returning adults has shown drastic annual fluctuations and has decreased to 40–50 million in recent years after a peak of more than 80 million in 1996 (NPAFC 2014, see also Morita et al. 2006). Many factors have been suggested to be affecting the dynamics of the chum salmon stock in Japan such as global warming (Kaeriyama et al. 2014), offshore and coastal oceanographic environments (Kaeriyama 2003, Nagata et al. 2007, Saito and Nagasawa 2009, Kaeriyama et al. 2012) and long-term ocean/atmospheric events (Kaeriyama et al. 2004, 2014, Seo et al. 2011).

The other hand, the large scale hatchery-based stock enhancement program for Pacific salmon has been controversial because it might cause ecological and genetic risks to wild populations (Brannon et al. 2004, Araki et al. 2007, Araki and Schmid 2010, Kaeriyama et al. 2012, Kostow 2012). Most of the chum salmon returning to Japanese waters have been considered to be the hatchery-originated population (Kaeriyama and Edpalina 2004). However, Morita et al. (2013a) revealed that the amount of wild chum salmon (fish derived from natural spawning regardless of the origin of the parents, native or hatchery bloodstock) may constitute a substantial part of the fishery production, estimating that 28.3±1.2% of total catches of chum salmon in several rivers with stock enhancement programs in Hokkaido (see also Morita et al. 2013b). Miyakoshi et al. (2012) who assessed 238 rivers in Hokkaido found natural spawning of chum salmon in 59 and 50 rivers in 2008 and 2009, respectively. These facts suggest that a better understanding of the wild chum salmon populations in Japan and their protection are urgently required not only for conservation of a key species in the North Pacific ecosystem (Kaeriyama et al. 2012) but also an alternative to increase coastal fishery production (Nagata et al. 2012, Morita et al. 2013b).

Hokkaido has long led the stock enhancement program as well as research on the ecology and fisheries of salmon in Japan (see Nagata et al. 2012, Miyakoshi et al. 2013). In terms of stock enhancement effort, Iwate is the second most active region. Hokkaido and Iwate have constantly provided nearly 60% and 25% of chum salmon juveniles for release and have shared about 80% and 10–15% of the coastal and river catches, respectively, among 11 administrative divisions that take a part in the stock enhancement program in Japan (data from the quick report, Hokkaido National Fisheries Research Institute: http://salmon.fra.affrc.go.jp).

Clearly contrasting to Hokkaido, the coastal region of Iwate, a part of the Sanriku coast, is topographically characterized as a Ria in which many small rivers form along an irregularly rugged cliff coast adjacent to mountain chains and have enclosed estuaries in the deeply embayed coast with steadily increasing depth seaward. The Sanriku area would also have particular environment for salmon reproduction with relatively warmer water temperature in rivers during the winter because of its geographic and oceanographic conditions as well as an effect of spring waters in some areas.

These facts imply that the reproductive ecology of salmon in the Sanriku area differs from that in Hokkaido, the main habitat of salmonids in Japan, because of adaptation to its peculiar environments. However, research activity on salmon in Iwate or Sanriku is considerably less than Hokkaido and local-specific ecological characters have rarely been addressed. Further, the natural spawning of chum salmon in the Sanriku area that is a possible alternative for the stock enhancement program has never been discribed. This study aimed to access for the first time natural spawning of chum salmon in a typical river within a hatchery stock enhancement program along the Sanriku coast.

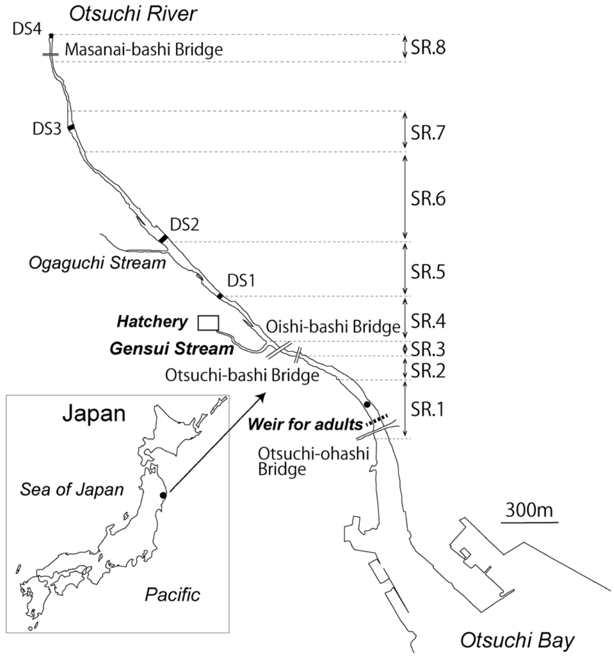


**Fig. 1.** Map showing the study area along the Otsuchi River. Observations were made1.0 to 4.0 km from the river mouth that was divided into 8 survey reaches designated as SR1–SR8. DS1-DS4 show locations of damming structures. Solid circles in the river indicate the previous location of the Ando-Bashi Bridge that was destroyed by the disaster in 2011.

## Materials and methods

### Study site

The study was carried out in the Otsuchi River, Iwate, Japan, a typical river in the Sanriku Ria coast, with 26.7 km long and 120 km$^2$ of the catchment area (Fig. 1). The study area of about 3.0 km along the Otsuchi River, 1.0 to 4.0 km from the river mouth, was divided into 8 survey reaches (SR 1–SR 8) by clear landmarks (Fig. 1). The most part of the survey reach was 10–20 m in width and less than 1 m in depth, which allowed relatively easy and accurate observation in the river.

The hatchery is located in a tributary, Gensui stream, at about 500 m upstream from the junction with the Otsuchi River (in SR3) and annually releases around 20 million chum salmon juveniles for stock enhancement. The juveniles are released through the Gensui Stream, so theoretically they migrate back to the Gensui Stream. However, the stream has less than 1 m width in most part with river wall structure and natural spawning of chum salmon has been rarely observed. Adult chum salmon are caught at a weir (in SR1) temporally constructed for the spawning season with a related facility for artificial fertilization. Artificially fertilized eggs are transported to the hatchery for incubation and rearing until release.

### Field survey

The field survey was conducted during 15 September 2014 to 27 January 2015 biweekly or more frequently (7–15 day intervals except for the 14 January 2015 survey that was carried out 19 days after the previous one). Water temperature was measured during each survey at a fixed point in SR 6 to know its seasonal variation. Water levels in SR 5 were measured telemetrically by Iwate Prefectural authorities, Tohoku Regional Development Bureau of the Ministry of Land, Infrastructure and Transport, and Japan Meteorological Agency during the survey period and were obtained through the Iwate River Information System (http://kasen.pref.iwate.jp).

### Counts of adults, spawning redds and carcasses

To estimate the relative abundance of salmon reproduction in the river, adult chum salmon, their spawning redds and carcasses were visually counted while walking gently slowly along or in the reaches according to Gallagher et al. (2007). Surveys were carried out in the morning (07:00–12:00) on clear days to make as accurate observations as possible. Aggregations of adult fish that were difficult to count accurately were photographed to confirm the approximate number of individuals. Fish that moved quickly into or out the survey reach would be double-counted or missed in this study.

### Observation of marked carcasses

In order to estimate retention of carcasses in the river, some of the carcasses found during the survey were marked using sequentially numbered plastic tape tying through the mouth to opercle and then returned to their original positions. The marked carcasses were checked during the subsequent surveys.

## Results

### Adult and redd counts

The hatchery weir that was set at the beginning of November in 2014 showed no clear effect for the number of spawning adult migrating upstream and a total of 904 adults, 160 redds and 808 carcasses were counted in the survey area (Table 1). Adult chum salmon were already present in the river at the beginning of the survey on 15 Sep (78 individuals) and their relative abundance suddenly decreased on 18 Oct (5 individuals) after the 2 surveys that found 66 and 84 individuals in 27 Sep. and 11 Oct., respectively. The relative abundance increased in the next survey at 2 Nov. (65 individuals) and peaked from late November to early December (132, 149, 139 individuals in 3 surveys, respectively). During January 2015, the number of adults seemed to be decreasing drastically (16 and 9 individuals in 2 surveys).

The redd counts showed a similar seasonal pattern with the adults showing the first small peak in 11 Oct. (10 redds) and the second during December (39, 26, 19 redds, respectively, Table 1). The greatest number of spawning redds were found in SR4 (120 redds) followed by SR5 (26 redds) with only 0–8 redds being counted in the other reaches (Fig. 2). The uppermost spawning redds found in this study were in SR6 and the lowermost in SR1 (Fig. 2). Water temperature decreased from 16.0 to 5.5 °C and water level shifted from 0.23 to 1.03 m during the study period, with both environmental factors showing no clear relation to the relative abundance of the adults in the river (Fig. 3).

**Table 1.** Numbers of adults, redds and carcassesses observed during the study.

| Date | Adults | Redds | Carcassesses | | |
|---|---|---|---|---|---|
| | | | Total | Marked | Recovered (Julian days) |
| 15 Sep.2014 | 78* | 0 | 0 | 0 | 0 |
| 27 Sep. | 66* | 8 | 8 | 8 | 2 (14) |
| 11 Oct. | 84* | 10 | 17 | 16 | 1 (7) |
| 18 Oct. | 5 | 5 | 10 | 8 | 1 (15) |
| 2 Nov. | 65 | 9 | 75 | 72 | 1 (18) |
| 11 Nov. | 59 | 27 | 55 | 55 | 0 |
| 20 Nov. | 132 | 13 | 37 | 36 | 0 |
| 4 Dec. | 149 | 39 | 60 | 60 | 0 |
| 17 Dec. | 139 | 26 | 160 | - | - |
| 26 Dec. | 102 | 19 | 167 | - | - |
| 14 Jan. 2015 | 16 | 4 | 171 | - | - |
| 27 Jan. | 9 | 0 | 48 | - | - |
| Total | 676 | 160 | 808 | 255 | 5 |

* includes minimum estimates obtained from photographs of fish aggregations.

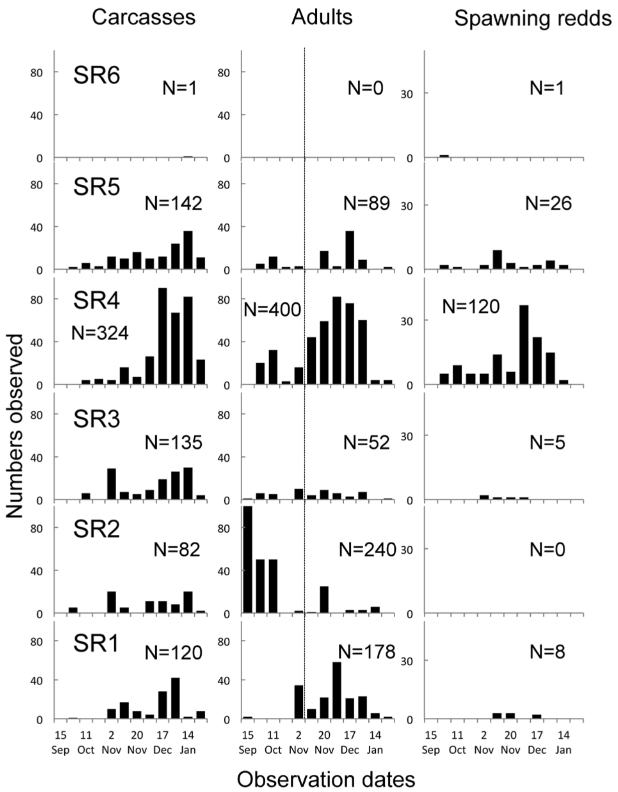


**Fig. 2.** Number of carcasses, adults and spawning redds (from the left to right) at each survey reach (from the bottom to top). Dotted line indicates beginning of operation of the hatchery weir.

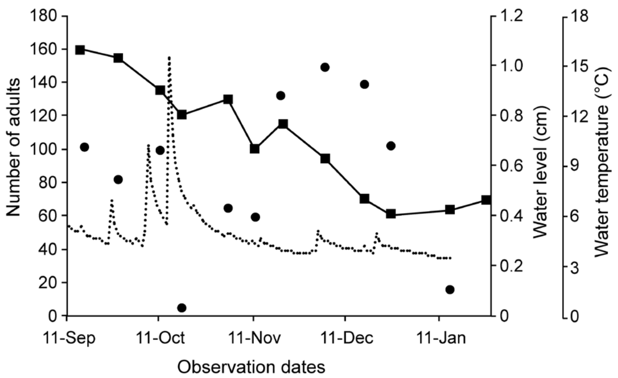


**Fig. 3.** Changes in water temperature (solid line), water level (dashed line) and number of adults observed in the survey reaches during the study.

**Carcasses**

A total of 255 carcasses found in the river were marked during the early part of the study period from 15 September to 4 December (Table 1). Most of the marked carcasses (98.1%) could not be found in the subsequent surveys, suggesting low retention of carcasses in the study area. The only 5 marked carcasses (1.9%) were found again after 7–18 days (Table 1).

## Discussion

**Natural spawning of chum salmon**

This study has reported for the first time the natural spawning of chum salmon in a river within a stock enhancement program in the Sanriku area. Natural spawning of chum salmon has been found in many rivers in Hokkaido regardless of the implementation of stock enhancement programs (Miyakoshi et al. 2012, Morita et al. 2013a). Quantitative surveys of the spawning redds of chum salmon conducted in Hokkaido reported 302–815 redds during 2006–2012 in the Toyohira River (Aruga et al. 2014), 139–444 in the Uebetsu River during 2004–2006 (Kasugai 2007) and approximately 1459–2731 in the Uyoro River during 2009 to 2011 (NPO Uyoro Environmental Trust 2012). The proportional contribution of wild fish to the returning adults in several rivers under the stock enhancement program was estimated to be 28.3±1.2% during 2001–2006, which varied greatly in time and space (0–50%) (Morita et al. 2013a). In the rivers where hatchery-reared juveniles were released but spawning adults were not captured, the wild fish occupied a significant part of the adult population (e.g., tentatively estimated as 69.8% in the Toyohira River (Aruga 2010) and 81.3% in the Uebetsu River (calculated from the data in Kasugai 2011). These facts suggested that the conservation of naturally spawning chum salmon could be an alternative approach to increase local fishery production as well as to genetically and ecologically improve the quality of hatchery brood stock. It is not quantitatively comparative but the data obtained from the Otsuchi River suggest that the natural spawning of chum salmon could be considerable not only in Hokkaido but also in Sanriku. Further information on the naturally spawning chum salmon along the Sanriku Ria coast and contributions of wild fish to total fishery production are needed.

Spawning areas of chum salmon in the Otsuchi River have never been described clearly as far as I know. Okutsu (1962) made a brief description about the natural spawning of chum salmon in the Otsuchi River that principally occurred in an area between Otsuchi-bashi and Ando-bashi Bridges corresponding to SR2 in this study (Fig. 1). However, the main spawning area of chum salmon in the 2014–2015 season was in SR4, more than 500 m upstream from the description of Okutsu (1962). Changes in gravel size of the riverbeds or loss of spring waters during the last decades could be reasons for the shift of spawning areas. But it was also possible that the East Japan Earthquake and the following Tsunami disaster made the spawning areas shifted upstream, with the subsidence of the ground or changes in spring water and gravel size in the river. Further study on the shifting process of the spawning areas will give an insight into the reproductive ecology of chum salmon in Sanriku.

**Upstream migration of the spawning adults through the hatchery weir**

The hatchery weir to catch adults for the stock enhancement program in the Otsuchi River was set at the beginning of November 2014 until March 2015, but it was interestingly showed no clear effect for the number of spawning adult migrating upstream. Ito et al. (2005) suggested that the spawning adults in the river with a stock enhancement program in Hokkaido migrate over the weir during the high water level. However, this study found a considerable amount of adult chum salmon (nearly 1000) in the upstream of the weir throughout the survey period with no clear relationship to the water level in the river (Fig. 3). The hatchery weir is generally thought to prevent further migration of spawning adults because it entirely blocks the river channels in most cases. The hatchery weir in the Otsuchi River consists of some wooden piles and polyethene netting whereas a robust screen made of plastic, wood or metal is set across the river flow in Hokkaido (Nogawa 2010). The migration behavior of salmon up to the weir in the Otsuchi River is uncertain, but it appears that the structure or operation of the hatchery weir unexpectedly allowed some fish to pass upstream to spawn.

The number of adult fish counted during the study showed a sudden decline on 18 Oct. 2014 despite the operation of the hatchery weir beginning later in early November in that year (Table 1). Salmon in Iwate have originally migrated back to the coastal region mainly from November to December and to increase the coastal catch before November, the early-run brood stock was transplanted from Hokkaido during 1970–1980's (Ogawa 2010, Saito et al. 2015). Subsequently, the peak of the coastal catch has been moved forward recently by more than one month (Ogawa 2010). The salmon stock in Iwate would then consist of two different run-timing groups (the early in October and the late in November to December), but there have been no actual observations of the seasonal differences of their upstream migration in the river. It is possible that chum salmon found in the Otsuchi River in the 2014–2015 season were divided into the early- and the late-run groups at around 18 October.

**Retention of the carcasses**

Salmonid carcasses are an important resource to provide marine-derived nutrients into rivers, which play various roles in freshwater and terrestrial ecosystems (see reviews Cederholm et al. 1999, Kaeriyama 2005, Naiman et al. 2012). Distribution and retention patterns of salmon carcasses in rivers are quite different by species, areas and seasons (Ito and Nakajima 2003). Ito et al. (2004) estimated the retention period of chum salmon carcasses in a river in Hokkaido to be 30–40 days during autumn and 70–80 days during winter. The present study, however, showed that the most of carcasses (98.1%) rapidly disappeared from the Otsuchi River approximately within 2 weeks. Residential areas are highly concentrated around the lower reaches in the Otsuchi River due the limited extent of suitable land for buildings, which directly overlap with the natural spawning areas of chum salmon. This situation likely makes wildlife animals difficult to access salmon carcasses in the river. It is reasonably supposed that warm water temperatures and relatively rapid flow by the steep gradient of the river in the Sanriku Ria topography made the carcasses quickly decomposed or washed away. These facts suggest that marine-derived nutrients provided by the salmon migration are not spread for the large watershed ecosystems in this region. It is quite possible that the ecological role of salmon carcasses in the Otsuchi River or the Sanriku area is quite different from that in Hokkaido.

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