# Salmon Distribution in Northern Japan during the Jomon Period, 2,000–8,000 Years Ago, and Its Implications for Future Global Warming

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Abstract: In Japan, the present southern limit for main chum salmon spawning is the Tone River in Chiba Prefecture on the Pacific side and the Tedori River in Ishikawa Prefecture on the Japan Sea side (about 36° North) of the Island of Honshu in Japan. Historic chum salmon distributions along the coast of the Tohoku Region, from Aomori to Fukushima Prefecture on the Pacific side, were examined based on archeological evidence dating to the Jomon Period, 8,000–2,000 years ago. The oldest salmon remains were found in the northern part of the Tohoku Region, such as in Hachinohe, from the Initial Jomon Period (8,000–6,000 years ago). Salmon remains were found in Miyako from the Early Jomon Period (6,000–5,000 years ago), in Oofunato from the Middle Jomon Period (5,000–4,000 years ago), in Rikuzentakada from the Late Jomon (4,000–3,000 years ago), and Naruse in Sendai Bay from the Final Jomon (3,000–2,000 years ago). These shifts of salmon remains from north to south appear to reflect a change in salmon distribution coincident with decreasing temperatures after the Jomon Marine Transgression peaked 6,000 years ago. Based on these observations of the past, we expect that global warming will reduce salmon production in Japan, if sea surface temperatures rise again. If so, then managers and scientists should start searching for adaptive measures now to mitigate future global warming. Such mitigation might include focusing on stock enhancement with late-run stocks, allowing more natural spawning, a greater emphasis on hatchery feeding programs, and adaptively changing the number of juvenile salmon released from hatcheries.

Keywords: chum salmon, distribution, salmon remains, Jomon Period, global warming

## INTRODUCTION

Chum salmon (*Oncorhynchus keta*) have the widest natural geographic distribution of all Pacific salmon species. Chum salmon in Asia are found from Korea to the Arctic coast of Russia and west to the Lena River. Chum salmon in North America are found from Monterey, California to the Arctic coast and east to the Mackenzie River (Salo 1991). The spawning distributions of all species of Pacific salmon are limited by environmental conditions, and these conditions are usually assumed to be the most challenging at the limits of each species' range. Because Japan includes the southern limit of chum salmon distribution, Japanese chum salmon will almost surely be affected by global warming. Because Pacific salmon have been such an important part of the Japanese diet, even a small change in the Japanese chum salmon harvest will have harsh consequences for the people that depend on these fish.

There are two conventional approaches to forecasting the effect(s) that global warming may have on salmon distribution. The first approach is to observe present salmon distribution in the North Pacific and note the accompanying sea surface temperatures that salmon prefer. Then these preferred temperatures can be combined with predicted future sea surface temperatures from global simulation models. Welch et al. (1998) and Kaeriyama (2008) used this approach to predict that the distributions of sockeye and chum salmon will be reduced to the northern part of the North Pacific Ocean in coming years. Notably, Kaeriyama (2008) predicted that chum salmon will disappear from Japan by 2100.

The second approach to predicting the effects of climate change is to examine the archeological record, looking for changes in salmon distribution, and then to compare variation in the archeological record to what is known about variation in the climate record. For example, stream conditions in the Columbia River basin in western North America were

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reconstructed using paleoecological data from 7,000–6,000 years ago when regional temperatures were up to 2ºC warmer than at present. Using this approach, Chatters et al. (1995) concluded that salmon were 30–60% less abundant during this time, relative to the present. In Japan, approximately 6,000 years ago the southern limit of chum salmon distribution was located in the northern part of Honshu, far north of the current limit. Also, 6,000 years ago the seawater temperature was approximately 5ºC warmer than the conditions today (Ishida et al. 2001).

Our first purpose with this paper is to examine the chum salmon distribution in Tohoku Region during the Jomon period, based on archeological evidence, and then to relate variation in ancient remains of salmon parts to what is known about variation in ocean temperature. In Japan, the ancient people that lived in Hokkaido utilized chum salmon. Therefore, large-scale changes in the abundance of chum salmon parts in the archeological record can be assumed to mirror changes in chum salmon abundance at the time the archeological remains were deposited. Our broader goal is to begin thinking about appropriate adaptive measures to protect salmon in the Tohoku Region from the effects of future global warming.

## MATERIALS AND METHODS

Yamada (2005) reviewed literature on archeological sites in Tohoku Region of Japan (the northeastern portion of Honshu Island) and described archeological sites containing salmon remains. These salmon remains were mapped according to the following periods: Initial Jomon (8,000–6,000 years ago), Early Jomon (6,000–5,000 years ago), Middle Jomon (5,000–4,000 years ago), Late Jomon (4,000–3,000 years ago), and Final Jomon (3,000–2,000 years ago). Fish remains in the Satohama Shell Midden in Miyagi Prefecture were examined intensively from the Early to the Final Jomon periods (Tohoku History Museum 1987). Although there were many fish remains dating from the Early Jomon Period onward, salmon remains were only found at this location during the Final Jomon Period (Table 1). Finally, summaries of the environmental conditions in the Jomon Period (Table 2) were taken from several sources (Sawa 1987; Matsushima 1988; Yamashiro 1999; Ishida et al. 2001).

## RESULTS

### Salmon Remains in theTohoku Region

The oldest salmon remains were found in the northern part of the Tohoku Region, such as in Hachinohe, and these remains date to the Initial Jomon Period, 8,000–6,000 years ago, when sea surface temperatures were warmer than the present (Table 2). Thereafter, salmon remains were found in Miyako, and these remains date to the Early Jomon Period,

**Table 1.** Fish remains in Satohama shell midden in Miyagi Prefecture in the southern part of the Tohoku Region. Numbers indicate the frequency of appearance of fish remains; '+' indicates that fish remains were found, but in small numbers.

| Fish species | Common name | Chronology (Year B.P.) | | | | |
|---|---|---|---|---|---|---|
| | | Intial Jomon (8,000–6,000) | Early Jomon (6,000–5,000) | Middle Jomon (5,000–4,000) | Late Jomon (4,000–3,000) | Final Jomon (3,000–2,000) |
| *Chondrichthyes* | Sharks | | + | + | | + |
| *Clupea pallasii* | Pacific herring | | 12 | 5 | | 24 |
| *Engraulis japonicus* | Japanese anchovy | | | | | 1 |
| *Anguilla japonica* | Japanese eel | | 1 | + | | 1 |
| *Conger myriaster* | Conger eel | | 2 | 2 | | 4 |
| *Oncorhynchus* sp. | Pacific salmon | | | | | + |
| *Hemiramphus sajori* | Japanese halfbeak | | 11 | 2 | | |
| *Mugil cephalus* | Flathead mullet | | + | | | |
| *Lateolabrax japonicus* | Japanese seabass | | 10 | 3 | | 8 |
| *Seriola quinqueradiata* | Japanese yellowtail | | 3 | 4 | | |
| *Trachurus japonicus* | Jack mackerel | | 9 | 2 | | 1 |
| *Pagrus major* | Red seabream | | 8 | 3 | | |
| *Acanthopagrus schlegelii* | Black seabream | | | | | 2 |
| *Halichoeres poecilopterus* | Multicolorfin rainbowfish | | | 1 | | |
| *Scomber* | Mackerel | | 1 | 10 | | + |
| *Thunnus* sp. | Tuna | | + | | | |
| *Scorpaena onaria* | Rock fish | | 12 | 6 | | 2 |
| *Hexagrammos otakii* | Fat greenling | | 12 | 4 | | 8 |
| *Platycephalus indicus* | Flat head | | 2 | | | |
| *Pleuronectidae* | Righteye flounder | | 2 | | | 2 |
| *Stephanolepis cirrhifer* | Thread-sail filefish | | 12 | | | |
| *Tetraodontidae* | Puffers | | 2 | + | | 4 |

**Table 2.** A summary of environmental conditions and effects on salmon production in the Kushiro River on the Island of Hokkaido in Japan and in the Columbia River in the Pacific Northwest of North America.

| Chronology | Year B.P. | The Kushiro River in Hokkaido | The Columbia River in North America |
|---|---|---|---|
| | 8,000 | | |
| Initial Jomon | | Jomon marine transgression | |
| | 6,000 | Sea surface was 3-5m higher than at present in Japan | |
| Early Jomon | | Paleolithic Kushiro Bay | Poor for salmon |
| | 5,000 | +5° C | 200 days above 10° C |
| | | Start of cooling | |
| Middle Jomon | | | |
| | 4,000 | Seawater retreated | |
| Late Jomon | | Present coastline | |
| | 3,000 | | Optimum for salmon |
| | | | 130 days above 10° C |
| Final Jomon | | Kushiro wetlands | |
| | 2,000 | | |
| Post Jomon | | | |
| | 1,200 | | Good for salmon |
| | | | 100 days above 10° C |
| Satsumon | | Present Kushiro River | |
| | 700 | | |
| Ainu | | | |
| | Present | | |
| | | Sawa (1987) | Chatters et al. (1995) |
| References | | Matsushima (1988) | |
| | | Yamashiro (1999) | |
| | | Ishida et al. (2001) | |

6,000–5,000 years ago; in Oofunato, dating to the Middle Jomon Period, 5,000–4,000 years ago; in Rikuzentakada from the Late Jomon, 4,000–3,000 years ago; and Naruse in Sendai Bay, dating to the Final Jomon, 3,000–2,000 years ago (Figs. 1, 2). These shifts in salmon remains from north to south appear to reflect changes in salmon distribution caused by decreasing temperatures after the Jomon Marine Transgression.

## Salmon Remains in the Satohama Shell Midden

Various kinds of fishes, such as seabass and yellowtail from the Early to Final Jomon periods, were found in the Satohama Shell Midden, in Miyagi Prefecture in the southern part of the Tohoku Region (Fig. 1). However, salmon remains were found only from the Final Jomon Period, when average sea surface temperatures were similar to those at present (Table 1). Salmon remains were not found in the Early to Middle Jomon periods (Table 1), when temperatures were generally higher than at present (Table 2).

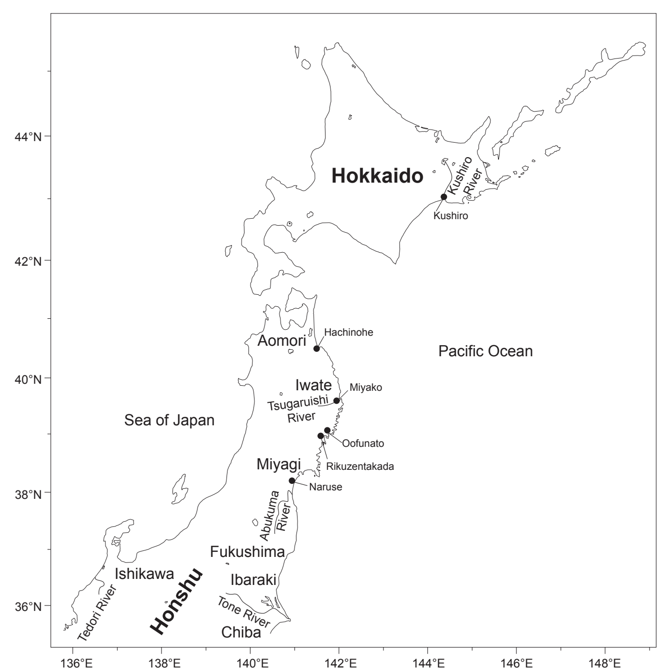


**Fig. 1.** Map indicating many of the place names that are included in the text.

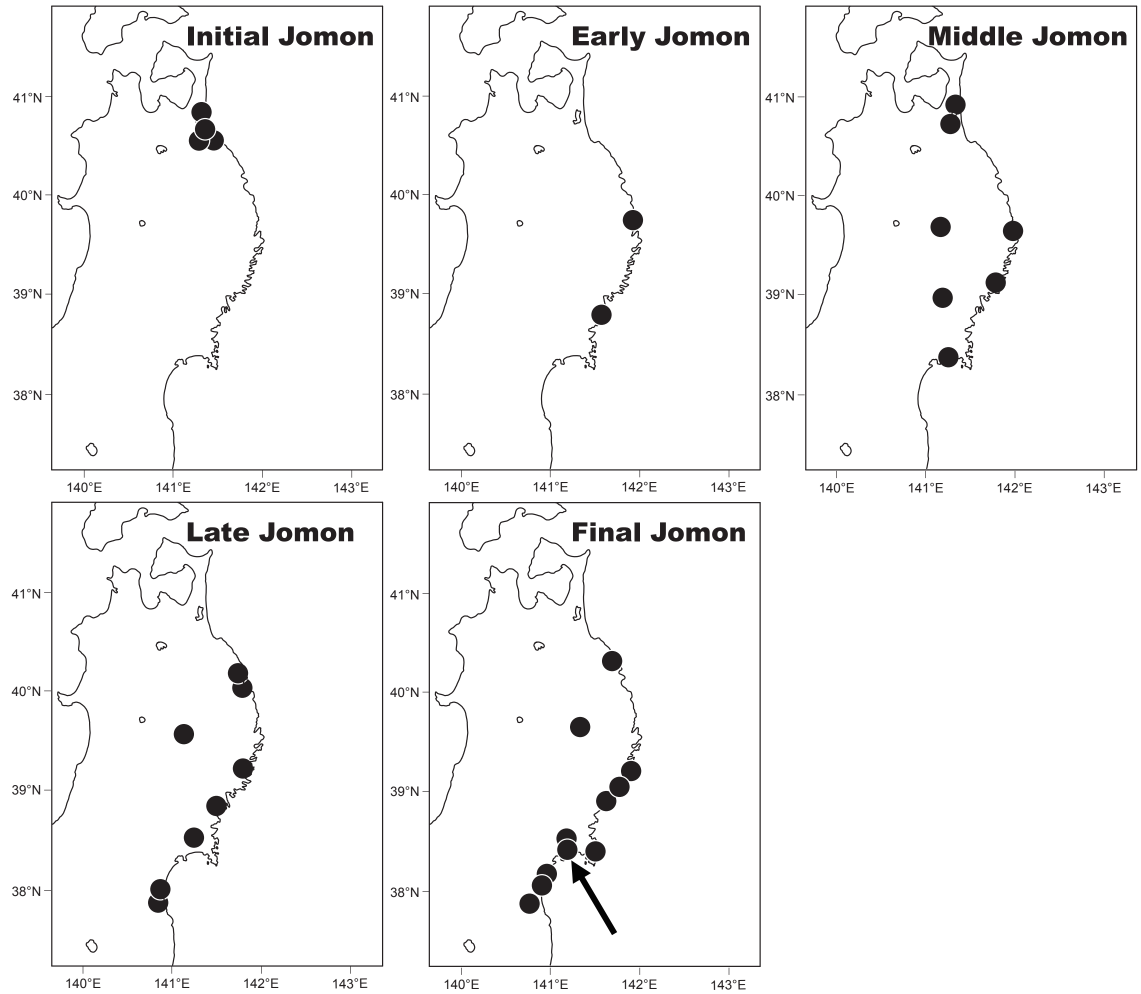


**Fig. 2.** Distribution of salmon remains in the Tohoku Region from the Initial to the Final Jomon periods. The arrow indicates the location of the Satohama shell midden.

## DISCUSSION

We propose that the shifts of salmon remains from north to south reflect a change in salmon distribution that was due to decreasing temperatures after the Jomon Marine Transgression peaked 6,000 years ago (Table 2). If so, then a northward shift in salmon distribution might occur in the ocean, under conditions caused by future global warming. Because of the importance of chum salmon in the Japanese diet, it is essential that managers begin planning as soon as possible, looking for adaptive measures to counteract the effects of global warming. We know quite a bit about the timing of chum salmon returning to natal rivers, the timing of chum salmon juveniles entering sea water, and the timing of the chum salmon migration into offshore waters.

Currently, the southern limit for chum salmon returns in Japan is the Tone River in Chiba Prefecture on the Pacific side and the Tedori River in Ishikawa Prefecture on the Japan Sea side of the Island of Honshu. Returning chum salmon may move to bottom depths ranging from 150 to 460 m to avoid the high temperatures (12–20°C) of surface waters found in the waters off Iwate Prefecture, and follow temperatures close to their thermal preference (3–11°C), which are found near the bottom waters off Iwate Prefecture in the Tohoku Region during autumn. This movement pattern appears to be an adaptation of chum salmon near the southern limit of their range (Ueno 1992). Chum salmon return to the Tohoku Region from September to February, depending on river of origin (Okazaki 1982). Recently, surface seawater temperatures have ranged from 17–22ºC in September to 5–10ºC in February along the Tohoku Region (Tomosada 1982).

Although these observations about chum salmon timing and distribution reflect general trends, there are two stocks of chum salmon returning to this area, each with different timing characteristics. The early-run stock in the Abukuma River returns in October, and the late-run stock in the Tsugaruishi River returns in December (Okazaki 1982). Because the late-run stock returns when the coastal waters are currently about 8ºC cooler than when the early-run stock returns, an emphasis on the use of the late-run stock in hatcheries might be appropriate under global warming conditions.

In the Tohoku Region, the time of entry of chum salmon juveniles into sea water is from March to June, depending on the river (Mayama and Ishida 2003). Recent seawater temperatures along the Tohoku Region have ranged from 5–8ºC in March to 12–15ºC in June (Tomosada 1982). Recently, juvenile chum salmon have remained in coastal water masses with plentiful food resources and physiologically optimal surface temperatures and salinities until they reached about 70–80 mm fork length, at which time they were able to migrate offshore, avoiding high (over 12–13ºC) sea surface temperatures and high (over 34 psu) salinities (Mayama and Ishida 2003). Under warmer conditions, juveniles will need to enter sea water earlier, before coastal water temperatures rise. Therefore, managers should consider using an enhanced hatchery feeding program so that juveniles can grow rapidly prior to release.

The measures we have considered so far are steps humans can take artificially, mainly at hatcheries, but other adaptive measures might be taken naturally by chum salmon themselves in natal rivers. At present, hatchery practices are to capture returning chum salmon with fishing weirs set near the mouths of rivers, so that there is virtually no natural spawning. In order to increase natural adaptations, it might be necessary to move the fishing weirs to the upper parts of rivers or at least allow a portion of the chum salmon returns to escape into spawning areas there. By increasing the number of chum salmon allowed to spawn naturally, thereby allowing chum salmon to enter naturally into coastal waters to migrate to limited offshore waters, we may produce chum salmon that return to Japan with the timing best adapted to warmer conditions.

Global warming could affect the ocean carrying capacity of chum salmon in ways that may be difficult to predict. During the ocean life stage, chum salmon are currently distributed in waters with the sea surface temperature ranging from 2–11ºC (Brodeur 1988). Welch et al. (1998) and Kaeriyama (2008) have predicted that the carrying capacity of salmon in the North Pacific will be reduced under global warming conditions. With changing abundances of different species and stocks originating from many jurisdictions, it will be very difficult to regulate the size of each stock. However, competition may be stronger within stocks than among stocks of the same species, and among different species. Therefore, it might be possible to reduce the competition among Japanese chum salmon by adaptively changing the number of juveniles released from the hatcheries, based on monitoring the abundance and body size of returning chum salmon.

In summary, there may be additional adaptive measures to increase chum salmon survival that have not yet been proposed. However, we recommend that planners begin looking for mitigation measures in four areas. First, late–run chum salmon stocks deserve special attention, as these may be the best adapted chum salmon to return to Japanese hatcheries under warmer conditions. Second, we recommend that managers begin research into the effects of feeding programs to support early release, so Japanese chum salmon will move out of coastal waters earlier. Third, we recommend increasing the number of naturally spawning chum salmon, and monitoring their survival and fitness to see if natural selection will lead to fish better adapted to warmer conditions. Finally, we recommend that Japanese hatchery planners consider adjusting the number of chum salmon released, as global warming may reduce the ocean carrying capacity. However, even with the measures we recommend, and even with measures not yet identified, the spawning distribution of Japanese chum salmon may still shift northward as the climate continues to change.

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