Future Climate-Related Changes in Fish Species Composition Including Chum Salmon (*Oncorhynchus keta*) in Northern Japanese Waters, Inferred from Archaeological Evidence

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Abstract: Fish remains found at archaeological sites in Kushiro (Hokkaido) and Satohama (Miyagi) in northern Japan are reviewed to infer future climate-related changes in fish species composition including chum salmon (*Oncorhynchus keta*) in northern Japanese waters. Published seawater temperature ranges of contemporary fish distribution are also examined. Marine fish assemblages, including chum salmon found in Kushiro and Satohama, contained 12–16 and 13–17 species, respectively. Sharks, Japanese sardine, Pacific herring, fat greenling, and Japanese sea bass were common at both sites. Pacific cod and rainbow smelt were detected only in Kushiro, and bartail flathead and threadsail filefish, only in Satohama. Based on contemporary temperature ranges of fishes from Kushiro, mean seawater temperature (MST) is estimated to have declined from 16.3ºC in the early Jomon period (7,000–4,500 yr BP) through 15.8ºC in the final Jomon period (3,000–2,400 yr BP) to 15.1ºC in the Satsumon and Ainu periods (700–200 yr BP). Similarly, the data from Satohama suggest that MST decreased from 16.9ºC in the early Jomon period (7,000–4,500 yr BP) through 16.6ºC in the middle Jomon period (4,500–3,500 yr BP) to 16.1ºC in the final Jomon period (3,000–2,400 yr BP). Chum salmon were found in a period when MST was lower than 16.3ºC in Kushiro and 16.1ºC in Satohama. According to the most current IPCC (Intergovernmental Panel for Climate Change) report, the mean and maximum global SSTs are projected to increase by 1.25–2.10ºC, respectively, by 2060. Based on such information, the mean and maximum MSTs in 2060 are projected to be 15.5–15.7ºC in Kushiro, and 15.8–16.0ºC in Satohama, suggesting that the present-day fish species composition in northern Japanese waters is likely to be similar to that of the final Jomon period. Therefore, our results suggest that chum salmon will remain in both Kushiro and Satohama under mean and maximum projected global SST increase scenarios.

Keywords: chum salmon, archaeological remains, Jomon period, climate change

INTRODUCTION

Chum salmon (*Oncorhynchus keta*) have the widest natural geographic distribution among all Pacific salmon species (Salo 1991). Their Asian spawning populations are found from Japan and Korea to the Arctic coast of Russia and west to the Lena River. The North American populations occur from Monterey, California to the Arctic coast and east to the Mackenzie River, Canada. Because Japan is located at the southern limit of chum salmon distribution, the species has been and will be affected by global climate change (Yotsuyanagi 1983; Ishida et al. 2001; Yamada 2005; Azumaya et al. 2007; Kaeriyama 2008; Ishida et al. 2009; Abdul-Aziz et al. 2011).

Chum salmon returns have decreased in northern Japan since the early 2000s. In particular, their returns declined from > 70 million fish in 2004 to < 50 million fish in 2010 and were recorded as 43 million fish in 2012 (Saito et al. 2015). The cause of this decline is not clear but may include changes in ocean conditions such as sea surface temperature (SST) affecting the survival of juveniles during their first marine period after release (Saito et al. 2010). On the other hand, warm- and temperate-water species, such as common dolphinfish (*Coryphaena hippurus*), ocean sunfish (*Mola mola*),

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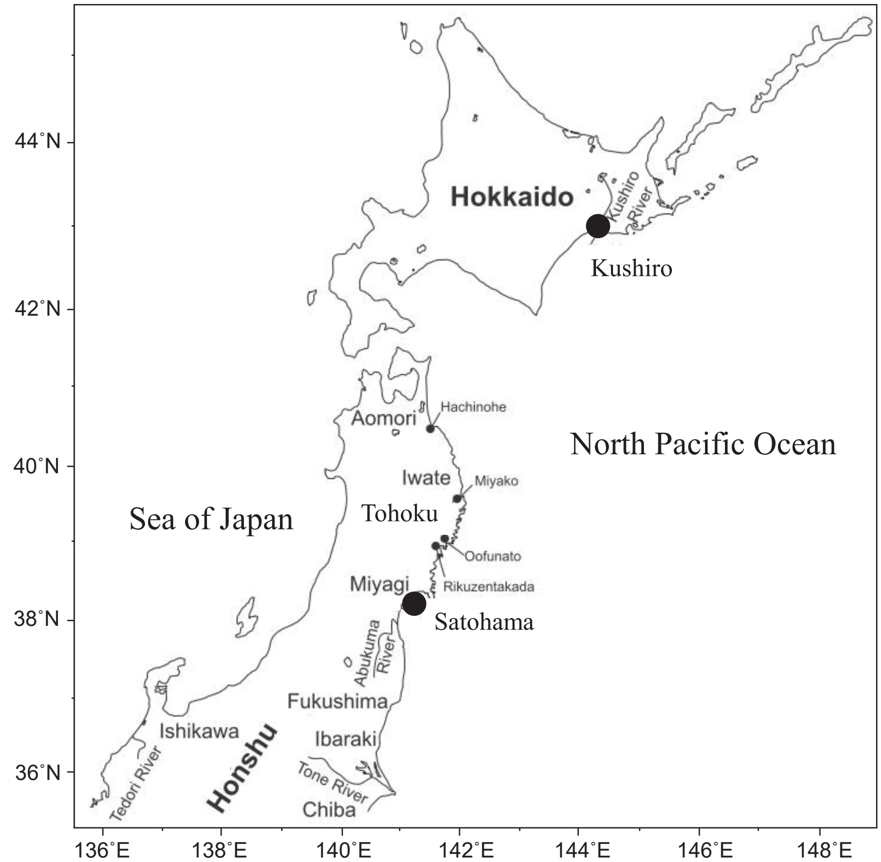

Fig. 1. Map of Japan indicating archaeological sites (large closed circles) in Kushiro (Hokkaido) and Satohama (Tohoku).

and Japanese amberjack (*Seriola quinqueradiata*), have been reported frequently in subarctic waters of Hokkaido. Notably, the catch of Japanese amberjack has increased since the late 1990s to > 12,000 mt in 2013 (Hoshino 2009; Marinenet Hokkaido). Based on these facts, it is important to determine how chum salmon and other fish species will respond to projected climate changes in order to design future hatchery programs for chum salmon and fisheries management procedures for many other species in northern Japan.

There are two conventional approaches to forecast the effects of global warming on the geographical distribution of Pacific salmon (Ishida et al. 2009). The first approach is associated with their present distribution and preferred SSTs in the North Pacific Ocean. These preferred SSTs can then be combined with predicted future SSTs from global simulation models (Welch et al. 1998a, b; Kaeriyama 2008; Abdul-Aziz et al. 2011). The second approach is to look back in time to salmonid remains found at archaeological sites and determine how they are related to historical climate changes (Chatters et al. 1995; Ishida et al. 2001, 2009).

Ishida et al. (2001, 2009) suggested that, if global warming estimates are similar to the warmer conditions that may have occurred 5,000–6,000 years ago, the southern limit of Japanese chum salmon distribution will move northward and their production will decrease, although they will not disappear from Hokkaido. In contrast, Kaeriyama (2008) predicted that chum salmon will disappear from Japan by 2100 using the SRES-A1B (Special Report on Emission Scenarios - a balance across all sources) scenario of the IPCC (Intergovernmental Panel for Climate Change; Parry et al. 2007).

The first purpose of this paper is to examine the data on archaeological remains of marine fishes, including chum salmon, from Hokkaido south to Tohoku, and relate any observed variation in this archaeological evidence to what is known about long-term fluctuations in SST when the remains were created. The second purpose is to predict climate-related changes in fish species composition in northern Japanese waters, using the recent IPCC projections (Kirtman et al. 2013). Our study concludes with a discussion of possible adaptive measures for hatchery programs for chum salmon and for fisheries management for other fishes in this region.

MATERIALS AND METHODS

Fish remains, principally bones, were found at three archaeological sites in Kushiro (Hokkaido) and at one site in Satohama (Miyagi, Honshu) in northern Japan (Fig. 1). The species and the historical periods of deposition are summarized in Tables 1 and 2 (Ishida et al. 2001, 2009). These re-

Table 1. Fish remains found at archeological sites in Kushiro, and contemporary seawater temperature (ST, ºC) related to fish distribution. '+++' , '++' , and '+' indicate the high, moderate, and low frequencies of occurrence of fish remains, respectively. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Source of information is provided in the references.

Site		East Kushiro shell midden	Nusamai No. 3 shell midden	Nusamai No. 2 shell midden	
Chronology		Early Jomon	Final Jomon	Satsumon and Ainu	
Year BP		7,000–4,500	3,000–2,400	700–200	
Species	**English common name**	**East Kushiro shell midden (Kaneko 1968)**	**Nusamai No. 3 shell midden (Kaneko 1999)**	**Nusamai No. 2 shell midden (Kaneko 1999)**	**ST related to fish distribution (Reference)**
Lamna ditropis	Salmon shark	+	+		9–16 (Nakano and Nagasawa 1996)
Squalidae[1]	Piked dogfish	+	+	+	6–12 (Nakano and Nagasawa 1996)
Clupeidae[2]	Pacific herring & sardine	+++	++	++	0–30 (Shimo et al. 2000)
Osmerus mordax	Rainbow smelt		+++	++	7–11[9]
Oncorhynchus sp.[3]	Chum salmon	+	++	++	1–13 (Shimo et al. 2000)
Gadus macrocephalus	Pacific cod		+++	+++	0–12 (Shimo et al. 2000)
Scorpaenidae[4]	Japanese rockfish	+	+++	+++	8–28 (Shimo et al. 2000)
Hexagrammos otakii	Fat greenling		++	+++	12–19 (Shimo et al. 2000)
Lateolabrax japonicus	Japanese seabass	++	++	++	7–30 (Shimo et al. 2000)
Seriola quinqueradiata	Japanese amberjack	++	+	+	12–29 (Shimo et al. 2000)
Thunnus sp.[5]	Pacific bluefin tuna	+	+		13–20 (Itoh et al 2003)
Xiphias gladius	Swordfish	+	++	+	7–28[10]
Mugil cephalus	Flathead grey mullet	+	+		10–30 (Shimo et al. 2000)
Paralichtyidae[6]	Bastard halibut	+++	+++	+++	8–23 (Shimo et al. 2000)
Pleuronectidae[7]	Barfin flounder	+++	+++	+++	10–20 (Shimo et al. 2000)
Tetraodontidae[8]	Japanese pufferfish		+		11–27 (Shimo et al. 2000)

[1]Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Japanese rockfish (*Sebastes inermis*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Bastard halibut (*Paralichthys olivaceus*)
[7]Barfin flounder (*Verasper moseri*)
[8]Japanese pufferfish (*Takifugu rubripes*)
[9]www.fishexp.hro.or.jp/cont/marine/o7u1kr00000007kt-att/o7u1kr00000007px.pdf (accessed 2015/01/23)
[10]http://kokushi.job.affrc.go.jp/H25/H25_23.html (accessed 2015/01/23)

Table 2. Fish remains found at archeological sites in Satohama, and contemporary seawater temperature (ST, ºC) related to fish distribution. Numbers indicate the frequency of occurrence of fish remains; '+' indicates that fish remains were found in small numbers and the source of these data is THM: Tohoku History Museum (1987). When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used.

Site		Satohama	Satohama	Satohama	
Chronology		Early Jomon	Middle Jomon	Final Jomon	
Year BP		7,000–4,500	4,500–3,500	3,000–2,400	
Species	**English common name**	**Early Jomon (THM 1987)**	**Middle Jomon (THM 1987)**	**Final Jomon (THM 1987)**	**ST related to fish distribution (Reference)**
Chondrichthyes[1]	Sharks	+	+	+	9–16 (Nakano and Nagasawa 1996)
Clupeidae[2]	Pacific herring & sardine	12	5	24	0–30 (Shimo et al. 2000)
Engraulis japonicus	Japanese anchovy			1	8–31 (Shimo et al. 2000)
Conger myriaster	Whitespotted conger	2	2	4	7–29 (Shimo et al. 2000)
Oncorhynchus sp.[3]	Chum salmon			+	1–13 (Shimo et al. 2000)
Hemiramphus sajori	Japanese halfbeak	11	2		5–26 (Shimo et al. 2000)
Mugil cephalus	Flathead grey mullet	+			10–30 (Shimo et al. 2000)
Lateolabrax japonicus	Japanese seabass	10	3	8	7–30 (Shimo et al. 2000)
Seriola quinqueradiata	Japanese amberjack	3	4		12–29 (Shimo et al. 2000)
Trachurus japonicus	Japanese jack mackerel	9	2	1	13–27 (Shimo et al. 2000)
Pagrus major	Red seabream	8	3		8–28 (Shimo et al. 2000)
Acanthopagrus schlegelii	Blackhead seabream			2	10–30 (Shimo et al. 2000)
Halichoeres poecilopterus	Multicolorfin rainbowfish		1		13–25[8]
Scomber sp.[4]	Chub mackerel	1	10	+	4–25 (Shimo et al. 2000)
Thunnus sp.[5]	Pacific bluefin tuna	+			13–20 (Itoh et al 2003)
Scorpaena onaria	Western scorpionfish	12	6	2	25[9]
Hexagrammos otakii	Fat greenling	12	4	8	12–19 (Shimo et al. 2000)
Platycephalus indicus	Bartail flathead	2			16–26 (Shimo et al. 2000)
Pleuronectidae[6]	Barfin flounder	2		2	1–21 (Shimo et al. 2000)
Stephanolepis cirrhifer	Threadsail filefish	12			10–22 (Shimo et al. 2000)
Tetraodontidae[7]	Japanese pufferfish	2	+	4	11–27 (Shimo et al. 2000)

[1]Salmon shark (*Lamna ditropis*) and Piked dogfish (*Squalus acanthias*)

[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)

[3]Chum salmon (*Oncorhynchus keta*)

[4]Chub mackerel (*Scomber japonicus*)

[5]Pacific bluefin tuna (*Thunnus orientalis*)

[6]Barfin flounder (*Verasper moseri*)

[7]Japanese pufferfish (*Takifugu rubripes*)

[8]www.ifarc.metro.tokyo.jp/27,1047,55,227.html (accessed 2015/01/23)

[9]http://eol.org/pages/225499/details#habitat (accessed 2015/01/23)

mains are grouped according to the following archaeological periods: the early Jomon period (7,000–4,500 yr BP), the final Jomon period (3,000–2,400 yr BP), and the Satsumon and Ainu periods (700–200 yr BP) in Kushiro; and the early Jomon period (7,000–4,500 yr BP), the middle Jomon period (4,500–3,500 yr BP), and the final Jomon period (3,000–2,400 yr BP) in Satohama. The chronology of these Jomon periods is based on Matsui (1996). Salmonid remains have been recorded in both archaeological locations (Tables 1, 2), although it is very difficult to identify salmonid remains at the species level. In Japan, three species of anadromous salmonids, chum salmon, pink salmon (*O. gorbuscha*) and masu salmon (*O. masou*), are known to occur. Based on the contemporary abundance and distribution of these species, it is reasonable to assume that the salmonid remains recorded from northern Japan are exclusively chum salmon because this species was the most abundant among the three species (e.g., 92% and 8% in catch weight for chum and the other two salmon, respectively, in 1891; Matsui 1985, 2010).

All of the marine fish taxa found at the sites are still present so it was possible to determine contemporary seawater temperature ranges from the literature (e.g., Nakano and Nagasawa 1996; Shimo et al. 2000; Itoh et al. 2003) and web sites (Tables 1, 2). When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Based on these temperature ranges, mean seawater temperature (MST) was estimated by site and period (Fig. 2). MST was calculated based on the weighted score, zero or one, allocated to all fish species, regardless of the abundance of remains using a method similar to that used by Yamashiro (1999) for shellfish fossils in Kushiro. The species were weighted, one if present, zero if absent, within a temperature range. Detailed calculations are shown in Appendix Tables 1-a, 1-b, 1-c, 2-a, 2-b, and 2-c. To evaluate the sensitivity of MST values, the effects on MST of removing each taxon from the analysis were examined and the standard deviations of MST values are indicated in Fig. 3.

Data on SSTs in the western North Pacific Ocean off Kushiro and off Tohoku near Satohama were provided by the Japan Meteorological Agency (2015). Sea surface temperatures have changed at a rate of 0.99ºC per 100 yr off

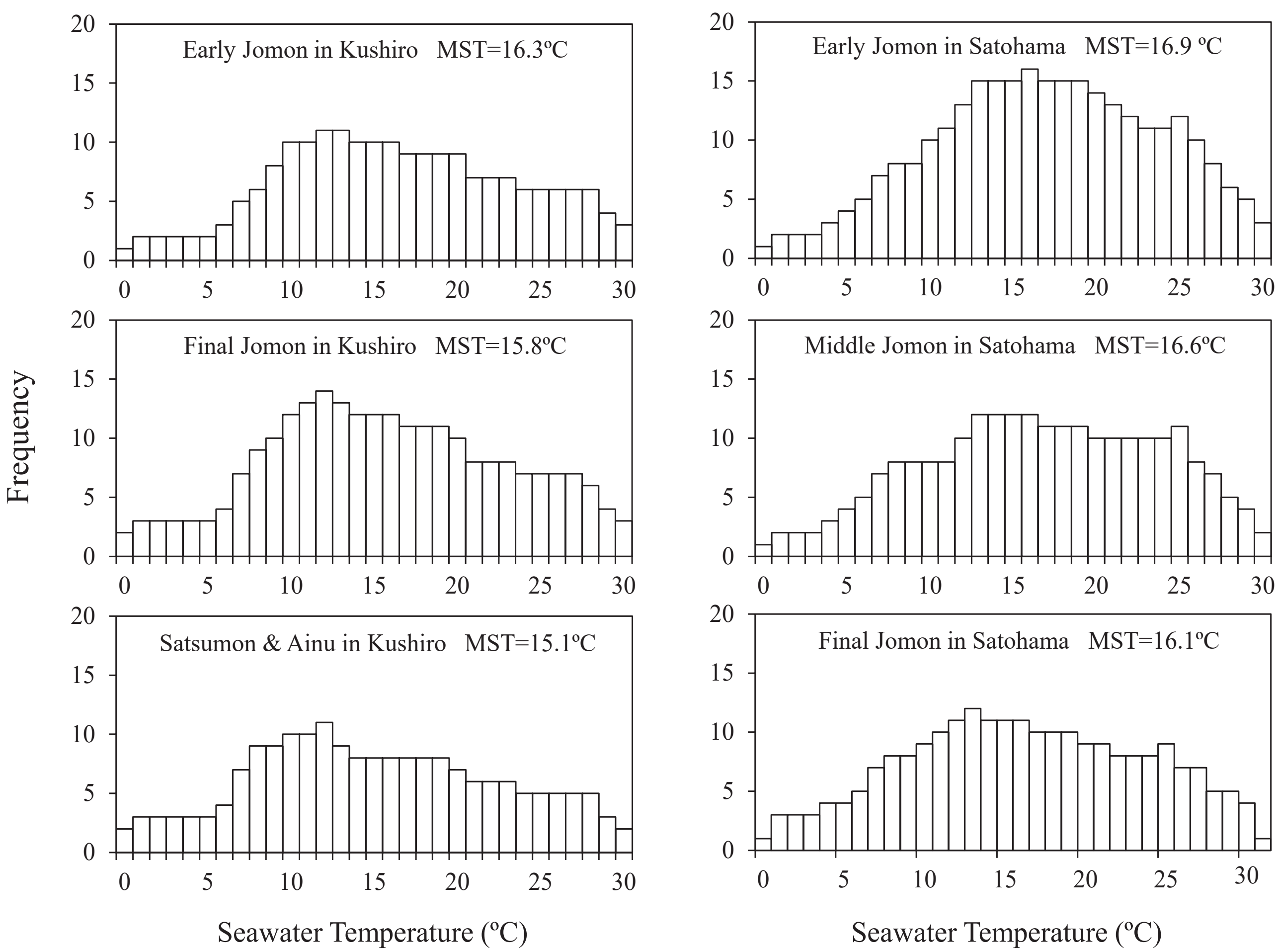

Fig. 2. Mean seawater temperature (MST) estimated from contemporary seawater temperature ranges of fish taxa found at archaeological sites in Kushiro and Satohama during different periods (MST is shown at the top of each graph). Vertical columns indicate standard deviations of MST values.

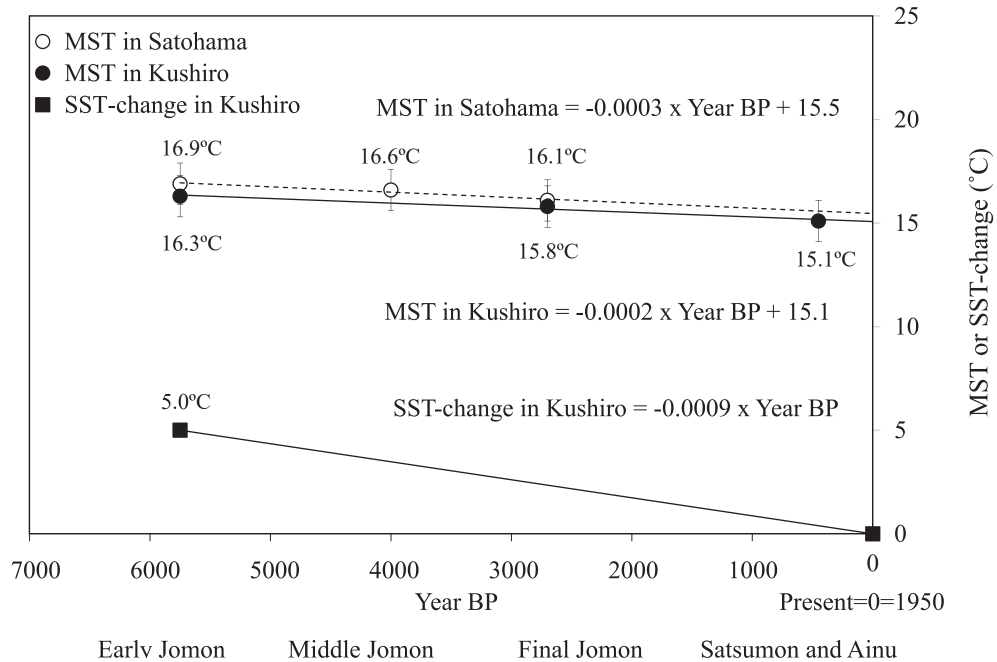

Fig. 3. Changes in mean seawater temperature (MST) based on marine fish remains found at archeological sites in Kushiro and Satohama (this paper), and sea surface temperature (SST) based on shellfish fossils found in Kushiro wetland (Yamashiro 1999).

Kushiro (data from 1908–2014) and 0.62ºC per 100 yr off Tohoku (data from 1911–2014), respectively. Therefore, a 0.54ºC (= 0.99ºC x 55 years/100 yr) change in SST off Kushiro and a 0.34ºC (= 0.62ºC x 55years/100 yr) change in SST off Tohoku from 1950 to 2005 were used in this study, in which the year 1950 is a baseline based on radiocarbon dating. Forecasts in this study were based on a mean global change in SST from 2005 to 2060 (1.25ºC) and a maximum global change (2.10ºC), depending upon the scenario (Kirtman et al. 2013). Considering the regional differences in SST changes off Kushiro and off Tohoku, the mean and maximum global changes in SST off Tohoku were calculated as 0.78ºC (= 1.25ºC x 0.62ºC/0.99ºC) and 1.32ºC (= 2.10ºC x 0.62ºC/0.99ºC). These SST changes were converted to MST using the following relations: MST = SST x (16.3ºC - 15.1ºC)/5.0ºC +15.1ºC off Kushiro, and MST = SST x (16.9ºC - 15.5ºC)/5.0ºC +15.5ºC off Tohoku, respectively, based on the relationship between SST and MST from the early Jomon period to the present.

RESULTS

Marine Fish Remains and Their Relation to Seawater Temperature Ranges

The numbers of species of marine fish, including chum salmon, recorded at the archaeological sites in Kushiro and Satohama are 12–16 and 13–17, respectively (Tables 1, 2). Sharks (*Lamna ditropis* and *Squalus acanthias*), clupeids (Japanese sardine (*Sardinops melanostictus*) and Pacific herring (*Clupea pallasii*)), fat greenling (*Hexagrammos otakii*), and Japanese sea bass (*Lateolabrax japonicus*) were commonly found in both Kushiro and Satohama. Pacific cod (*Gadus macrocephalus*) and rainbow smelt (*Osmerus mordax*) were detected only in Kushiro, and bartail flathead (*Platycephalus indicus)* and threadsail filefish (*Stephanolepis cirrhifer*) only in Satohama. Chum salmon were found in all the three periods in Kushiro, but only found in the final Jomon period in Satohama.

Mean Seawater Temperature (MST) Estimated by Archaeological Sites and Historical Periods

Based on the fish species composition data from Kushiro, MST is estimated to have declined from 16.3ºC in the early Jomon period through 15.8ºC in the final Jomon period to 15.1ºC in the Satsumon and Ainu periods (Fig. 2). Similarly, temperatures derived from the fish remains data from Satohama suggest that MST decreased from 16.9ºC in the early Jomon period through 16.6ºC in the middle Jomon period to 16.1ºC in the final Jomon period (Fig. 2). The fish remains data suggest that both sites have cooled during recent millennia. Chum salmon were found in a period when MST was 16.3ºC or less in Kushiro and 16.1ºC or less in Satohama.

Mean Seawater Temperature (MST) and Fish Composition off Northern Japan Following a Projected Global Climate Change

Past changes in MST based on marine fish remains in this study and SST changes based on shellfish fossil remains

(Yamashiro 1999) are shown in Fig. 3. Since MSTs are estimated as 16.3ºC and 15.1ºC in Kushiro and 16.9ºC and 15.5ºC in Satohama in the early Jomon period and in 1950, respectively (Fig. 3), a 1.2ºC (= 16.3ºC - 15.1ºC) and a 1.4ºC (= 16.9ºC - 15.5ºC) change in MST in each location correspond to a 5.0ºC change in SST in Kushiro in the same period. In addition, SST increased 0.54ºC = 0.99ºC x 55yr/100 yr off Kushiro and 0.34ºC = 0.62ºC x 55yr/100 yr off Tohoku from 1950 to 2005, respectively, based on the Japan Meteorological Agency (2015) data. The mean global SST increase has been projected to be about 1.25ºC from 2005 to 2060 (Kirtman et al. 2013). Therefore, MST in Kushiro is estimated as 15.5ºC = 15.1ºC + (0.54ºC +1.25ºC) x 1.2ºC/5.0ºC in 2060. Similarly, MST in Satohama is estimated as 15.8ºC = 15.5ºC + (0.34ºC +1.25ºC x 0.62ºC/0.99ºC) x 1.4ºC/5.0ºC in 2060, assuming a weak mean global SST increase in Satohama as 0.78ºC = 1.25ºC x 0.62ºC/0.99ºC compared with 1.25ºC in Kushiro (Fig. 4). Alternatively, if we use the maximum global SST increase (2.10ºC, Kirtman et al. 2013), the corresponding MSTs are 15.7ºC in Kushiro and 16.0ºC in Satohama.

Based on such information, chum salmon will remain both in Kushiro and Satohama in 2060 under the mean and maximum global SST increase scenarios. The present-day fish species composition in northern Japan is likely to look more like the fish community of the final Jomon period. Therefore, chum salmon production may decline in this region, whereas production of other fish species, especially temperate-water fish, will remain in good condition in northern Japan.

DISCUSSION

Archaeological Sites and Salmon Remains

Two archaeological sites used in this study are thought to have maintained fish remains in good condition for a long period because both sites have the following unique geographical characteristics: the three sites in Kushiro are located on high ground (i.e., about 20 m above sea level) and thus were protected from tsunami and other natural disasters in the past. The site in Satohama is only four m above sea level but was also protected from the recent 2011 Tohoku Great Earthquake and Tsunami because it was located on an inland sea (A. Yamada, unpublished data). Also, Crockford (1997) pointed out that fish bones in middens containing shells are better preserved because the calcium carbonate keeps destructive acidity low. This suggests that the present study is based on reliable archaeological evidence.

Salmonid remains were not as abundant compared with the remains of most other fish species (Tables 1, 2). Previously, among archaeologists, there were divided opinions concerning the importance of salmonid remains (Matsui 1996). Since the mid-1970s, however, small salmonid remains have been collected using fine mesh sieves, which has resulted in an increased number of articles reporting the presence of salmonid remains at archaeological sites (Matsui 1996). Therefore, even if the salmonid remains are not as abundant, their occurrence is regarded as important in characterizing the past marine environment. In other words, the present results are thought to be reasonable, even if the salmonid remains are less abundant than those of other fish species.

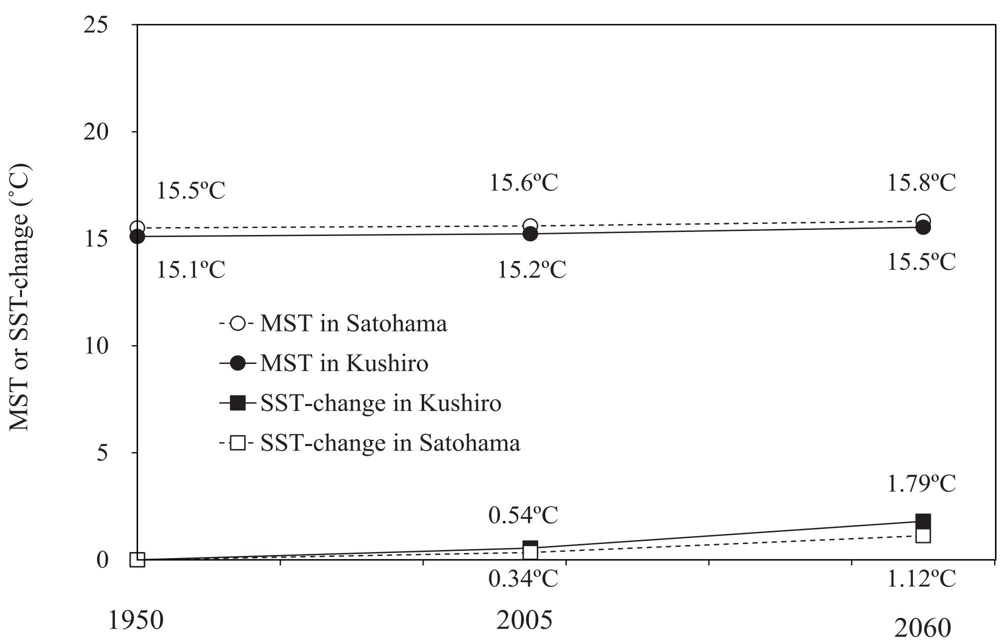

Fig. 4. Observed sea surface temperature (SST) change and equivalent changes applied to mean seawater temperature (MST) in Kushiro and Satohama. Changes from 2005 to 2060 are based on the mean global SST increase scenario (Kirtman et al. 2013).

Changes in Fish Species Composition

This study has revealed that marine fish remains at archaeological sites in Kushiro and Satohama consisted of 12–16 and 13–17 species including chum salmon, respectively (Tables 1, 2). Considering the long historical time from the early Jomon period to the present, the fish species found in both locations are quite stable. Both Japanese sea bass and blackhead sea bream utilize habits in inner parts of bays, red sea bream occur outside of bays, while tuna and Japanese amberjack are distributed in the open sea (Watanabe 1973). Because the people of the early Jomon period are thought to have caught both small (e.g., Japanese sardine, Pacific herring, and fat greenling) and large fish (e.g., Japanese amberjack and Pacific bluefin tuna), it is certain that fishing techniques including angling, netting, and spearfishing using harpoons were established during these periods (Toizumi 2014). People of the early Jomon period are also known to have utilized different marine resources seasonally near their residential sites (Aida 2007). Thus the recorded changes in the taxonomic composition of fish remains are likely due to changes in fish species living in or migrating to these sites. Trade during the Jomon periods involved raw materials such as mineral bitumen and hard shale that were transported from the Japan Sea side to Satohama (Aida 2007). Salmonid products were perhaps traded only locally in the river basins because salmonid remains are not found south of Tohoku (e.g., west of Tokyo Bay in central Honshu). Many marine fish products were found in Kushiro and Satohama, implying that there was no need to bring salmonid products from other locations. Therefore, salmonid remains found in Kushiro and Satohama are very likely to have been caught near these locations.

Interpretation of Mean Seawater Temperature (MST)

Estimated MSTs based on fish remains in this study are different from SSTs based on shellfish fossils in other studies (Matsushima 1988; Yamashiro 1999). The former can be considered as an index of fishing ground conditions because the fishes found are mobile or migrating species, while the latter may be regarded as an index of the local environmental conditions because the shellfish found are almost exclusively sedentary. Therefore, MST was changing more slowly than SST because MST reflected SST at fishing grounds. The weighted scores, one if present or zero if absent, were allocated to all fish species, regardless of the abundance of remains, because it is difficult to infer fish abundance based on the abundance of fish remains. Also, species such as stenothermal or eurythermal fish were treated equally because both fish species reflect the marine environment. It is very difficult to indicate whether this method is sufficiently sensitive for the intended purpose because predicted changes in mean MST are relatively small and there is huge variability around the MST values in Fig. 2. However the decreasing trends in MST were observed in two different locations indicated in Fig. 3, therefore the results may be reasonable based on the available data. Based on the long-term SST data, mean SSTs over the whole year, winter, spring, summer and autumn are 9.2ºC, 3.1ºC, 6.3ºC, 16.7ºC, and 10.7ºC off Kushiro and 13.5ºC, 7.4ºC, 11.0ºC, 20.8ºC, and 14.9ºC off Tohoku, respectively (based on Japan Meteorological Agency (2015) data). MSTs in our study locations are higher than the annual mean SSTs but lower than summer mean SSTs suggesting that the taxonomic composition was dominated by fish at the northern extent of their range. Fish species recorded in these locations are currently caught mainly from spring to autumn (Hokkaido Government 2015; Miyako City 2015). According to Aida (2007), fishing was conducted in Satohama all year 'round but peaked from spring to autumn during the Jomon periods. As reported earlier (Watanabe 1973; Toizumi 2014), fish species found in both locations contained not only Japanese seabass caught in inner bays, but also Pacific bluefin tuna and Japanese amberjack caught in the open sea or accidentally caught in inner bays, which implies that fishing was likely conducted over a wide area. However, the major fishing grounds were perhaps located near the archaeological sites because there is no evidence for the use of highly mobile fishing vessels during the Jomon periods, although there is a report on the use of dugout canoes and paddles (Watanabe 1973). Therefore, MSTs estimated in this study are thought to correlate with the mean SSTs during the fishing season and on the fishing grounds near the archaeological sites.

Comparison with Other Studies and Uncertainty in the Projections

Using an assumption that SSTs around Japan will increase by 1.0, 1.4, and 2.9°C, respectively, in 30, 50, and 100 years, Kuwahara et al. (2006) predicted a possible impact of the future climate change on the following four groups of marine organisms: (1) mass-caught species including chum salmon, (2) coastal and stationary species such as bastard halibut and red seabream, (3) cultured species, and (4) seaweeds. One of their implications is that mass-caught species may not be substantially affected, although the fishing grounds, fishing seasons, and catches are predicted to change slightly, because such species have generally strong swimming ability and are capable of responding quickly to changes in seawater temperature. But, the authors did not speculate about a change in distribution of chum salmon in northern Japan. Using the SRES-A1B scenario of the IPCC, Kaeriyama (2008) predicted a reduction in chum salmon distribution in the North Pacific and noted the possibility that the species will disappear from Hokkaido by 2100. However, the present study indicates that chum salmon will remain both in Kushiro and Satohama in 2060 under the mean and maximum global SST increase scenarios.

The present study is based on the near-term climate change projections of the IPCC (Kirtman et al. 2013). The projected global SST changes vary under different scenarios and may be different from the regional SST changes. Because polar and tropical regions are expected to warm the most and least, respectively, we assumed that the SST changes in the present study area were likely similar to the projected global SST changes. Therefore, we used the mean and maximum projected global SSTs to cover the variation. We also considered the regional differences between Kushiro and Tohoku to reduce the uncertainty in the future projection. Furthermore, there is an uncertainty in SST change caused by possible large volcanic eruptions which could erase the projected SST increase for many years to a decade (Kirtman et al. 2013). Therefore, our prediction may be highly possible compared with previous studies (Kuwahara et al. 2006; Kaeriyama 2008), although some uncertainties still exist in the predictions of future fluctuation in SST.

Adaptive Measures for Salmon Production and Fishery Managements

The following four measures have been recommended for the chum salmon hatchery program in Japan as a reaction to projected future climate changes (Ishida et al. 2009): (1) enhancement of late-run chum salmon stocks to match a late-winter season with warmer conditions; (2) promotion of feeding programs to support early releases of hatchery juveniles; (3) encouragement of naturally spawning chum salmon with the expectation that natural selection will lead to fish better adapted to warmer conditions; and (4) controlling the number of chum salmon juvenile releases because global warming may reduce the ocean carrying capacity (Welch et al. 1998a, b; Kaeriyama 2008; Abdul-Aziz et al. 2011). The present study suggests that chum salmon will remain in both Hokkaido and Tohoku even in 2060; thus these four measures should be taken in both regions, especially in Tohoku. Also as a result of possible future climate change, chum salmon production might decrease, but the production and catch of other fish species such as Pacific bluefin tuna and Japanese amberjack will likely increase in Hokkaido and Tohoku. Nevertheless, the following three measures are recommended: (1) utilization of new and unfamiliar fish species in the region; (2) adaptive fisheries management for each fish stock; and (3) protection of the environments in coastal waters to attract new fish species. These measures for chum salmon and other fish species are needed to maintain fisheries in both regions of northern Japan under future warmer conditions.

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Appendix Table 1-a. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at East Kushiro shell midden in Kushiro during the early Jomon period (7,000–4,500 yr BP). Frequency of occurence (FO) of fish remains where '+++' , '++' , and '+' indicates high, moderate, and low frequencies, respectively. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 1.

Species	English common name	FO	Seawater Temperature (ºC)																															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Lamna ditropis	Salmon shark	+										1	1	1	1	1	1	1	1															
Squalidae[1]	Piked dogfish	+							1	1	1	1	1	1	1																			
Clupeidae[2]	Pacific herring & sardine	+++	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Osmerus mordax	Rainbow smelt																																	
Oncorhynchus sp.[3]	Chum salmon	+		1	1	1	1	1	1	1	1	1	1	1	1	1																		
Gadus macrocephalus	Pacific cod																																	
Scorpaenidae[4]	Japanese rockfish	+									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Hexagrammos otakii	Fat greenling																																	
Lateolabrax japonicus	Japanese seabass	++								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Seriola quinqueradiata	Japanese amberjack	++													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Thunnus sp.[5]	Pacific bluefin tuna	+														1	1	1	1	1	1	1	1											
Xiphias gladius	Swordfish	+								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Mugil cephalus	Flathead grey mullet	+											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Paralichtyidae[6]	Bastard halibut	+++										1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
Pleuronectidae[7]	Barfin flounder	+++											1	1	1	1	1	1	1	1	1	1	1											
Tetraodontidae[8]	Japanese pufferfish																																	
Frequency at ST and total			1	2	2	2	2	2	3	5	6	8	10	10	11	11	10	10	10	9	9	9	9	7	7	7	6	6	6	6	6	4	3	199
Frequency x ST and total			0	2	4	6	8	10	18	35	48	72	100	110	132	143	140	150	160	153	162	171	180	147	154	161	144	150	156	162	168	116	90	3252
MST																																		16.3

[1]Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Japanese rockfish (*Sebastes inermis*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Bastard halibut (*Paralichthys olivaceus*)
[7]Barfin flounder (*Verasper moseri*)
[8]Japanese pufferfish (*Takifugu rubripes*)

Appendix Table 1-b. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at Nusamai No. 3 shell midden in Kushiro during the final Jomon period (3,000–2,400 yr BP). Frequency of occurence (FO) of fish remains where '+++' , '++' , and '+' indicates high, moderate, and low frequencies, respectively. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 1.

Species	English common name	FO	Seawater Temperature (ºC)																															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Lamna ditropis	Salmon shark	+										1	1	1	1	1	1	1	1															
Squalidae[1]	Piked dogfish	+							1	1	1	1	1	1	1																			
Clupeidae[2]	Pacific herring & sardine	++	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Osmerus mordax	Rainbow smelt	+++								1	1	1	1	1																				
Oncorhynchus sp.[3]	Chum salmon	++		1	1	1	1	1	1	1	1	1	1	1	1	1																		
Gadus macrocephalus	Pacific cod	+++	1	1	1	1	1	1	1	1	1	1	1	1	1																			
Scorpaenidae[4]	Japanese rockfish	+++									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Hexagrammos otakii	Fat greenling	++													1	1	1	1	1	1	1	1												
Lateolabrax japonicus	Japanese seabass	++								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Seriola quinqueradiata	Japanese amberjack	+													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Thunnus sp.[5]	Pacific bluefin tuna	+														1	1	1	1	1	1	1	1											
Xiphias gladius	Swordfish	++								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Mugil cephalus	Flathead grey mullet	+											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Paralichtyidae[6]	Bastard halibut	+++									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
Pleuronectidae[7]	Barfin flounder	+++											1	1	1	1	1	1	1	1	1	1	1											
Tetraodontidae[8]	Japanese pufferfish	+												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
Frequency at ST and total			2	3	3	3	3	3	4	7	9	10	12	13	14	13	12	12	12	11	11	11	10	8	8	8	7	7	7	7	6	4	3	243
Frequency x ST and total			0	3	6	9	12	15	24	49	72	90	120	143	168	169	168	180	192	187	198	209	200	168	176	184	168	175	182	189	168	116	90	3830
MST																																		15.8

[1]Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Japanese rockfish (*Sebastes inermis*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Bastard halibut (*Paralichthys olivaceus*)
[7]Barfin flounder (*Verasper moseri*)
[8]Japanese pufferfish (*Takifugu rubripes*)

Appendix Table 1-c. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at Nusamai No. 2 shell midden in Kushiro during the Satsumon and Ainu periods (700–200 yr BP). Frequency of occurence (FO) of fish remains where '+++' , '++' , and '+' indicates high, moderate, and low frequencies, respectively. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 1.

Species	English common name	FO	Seawater Temperature (ºC)																														
			0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
Lamna ditropis	Salmon shark																																	
Squalidae[1]	Piked dogfish	+							1	1	1	1	1	1	1																			
Clupeidae[2]	Pacific herring & sardine	++	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Osmerus mordax	Rainbow smelt	++								1	1	1	1	1																				
Oncorhynchus sp.[3]	Chum salmon	++		1	1	1	1	1	1	1	1	1	1	1	1	1																		
Gadus macrocephalus	Pacific cod	+++	1	1	1	1	1	1	1	1	1	1	1	1	1																			
Scorpaenidae[4]	Japanese rockfish	+++									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Hexagrammos otakii	Fat greenling	+++													1	1	1	1	1	1	1	1												
Lateolabrax japonicus	Japanese seabass	++								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Seriola quinqueradiata	Japanese amberjack	+													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Thunnus sp.[5]	Pacific bluefin tuna																																	
Xiphias gladius	Swordfish	+								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Mugil cephalus	Flathead grey mullet																																	
Paralichtyidae[6]	Bastard halibut	+++									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1								
Pleuronectidae[7]	Barfin flounder	+++											1	1	1	1	1	1	1	1	1	1	1											
Tetraodontidae[8]	Japanese pufferfish																																	
Frequency at ST and total			2	3	3	3	3	3	4	7	9	9	10	10	11	9	8	8	8	8	8	8	7	6	6	6	5	5	5	5	5	3	2	189
Frequency x ST and total			0	3	6	9	12	15	24	49	72	81	100	110	132	117	112	120	128	136	144	152	140	126	132	138	120	125	130	135	140	87	60	2855
MST																																		15.1

[1]Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Japanese rockfish (*Sebastes inermis*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Bastard halibut (*Paralichthys olivaceus*)
[7]Barfin flounder (*Verasper moseri*)
[8]Japanese pufferfish (*Takifugu rubripes*)

Appendix Table 2-a. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at archeological sites in Satohama during the early Jomon period (7,000–4,500 yr BP). Frequency of occurrence (FO) of fish remains where '+' indicates that remains were found in small numbers. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 2.

Species	English common name	FO	Seawater Temperature (ºC)																															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Chondrichthyes[1]	Sharks	+							1	1	1	1	1	1	1	1	1	1	1															
Clupeidae[2]	Pacific herring & sardine	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Engraulis japonicus	Japanese anchovy																																	
Conger myriaster	Whitespotted conger	2								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Oncorhynchus sp.[3]	Chum salmon																																	
Hemiramphus sajori	Japanese halfbeak	11						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
Mugil cephalus	Flathead grey mullet	+											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Lateolabrax japonicus	Japanese seabass	10								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Seriola quinqueradiata	Japanese amberjack	3													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Trachurus japonicus	Japanese jack mackerel	9														1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
Pagrus major	Red seabream	8									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Acanthopagrus schlegelii	Blackhead seabream																																	
Halichoeres poecilopterus	Multicolorfin rainbowfish																																	
Scomber sp.[4]	Chub mackerel	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Thunnus sp.[5]	Pacific bluefin tuna	+														1	1	1	1	1	1	1	1											
Scorpaena onaria	Western scorpionfish	12																										1						
Hexagrammos otakii	Fat greenling	12													1	1	1	1	1	1	1	1												
Platycephalus indicus	Bartail flathead	2																	1	1	1	1	1	1	1	1	1	1	1					
Pleuronectidae[6]	Barfin flounder	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1										
Stephanolepis cirrhifer	Threadsail filefish	12											1	1	1	1	1	1	1	1	1	1	1	1	1									
Tetraodontidae[7]	Japanese pufferfish	2												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
Frequency at ST and total			1	2	2	2	3	4	5	7	8	8	10	11	13	15	15	15	16	15	15	15	14	13	12	11	11	12	10	8	6	5	3	287
Frequency x ST and total			0	2	4	6	12	20	30	49	64	72	100	121	156	195	210	225	256	255	270	285	280	273	264	253	264	300	260	216	168	145	90	4845
MST																																		16.9

[1]Salmon shark (*Lamna ditropis*) and Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Chub mackerel (*Scomber japonicus*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Barfin flounder (*Verasper moseri*)
[7]Japanese pufferfish (*Takifugu rubripes*)

Appendix Table 2-b. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at archeological sites in Satohama during the middle Jomon period (4,500–3,500 yr BP). Frequency of occurrence (FO) of fish remains where '+' indicates that remains were found in small numbers. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 2.

Species	English common name	FO	Seawater Temperature (ºC)																															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Chondrichthyes[1]	Sharks	+							1	1	1	1	1	1	1	1	1	1	1															
Clupeidae[2]	Pacific herring & sardine	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Engraulis japonicus	Japanese anchovy																																	
Conger myriaster	Whitespotted conger	2								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Oncorhynchus sp.[3]	Chum salmon																																	
Hemiramphus sajori	Japanese halfbeak	2						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
Mugil cephalus	Flathead grey mullet																																	
Lateolabrax japonicus	Japanese seabass	3								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Seriola quinqueradiata	Japanese amberjack	4													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Trachurus japonicus	Japanese jack mackerel	2														1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
Pagrus major	Red seabream	3									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Acanthopagrus schlegelii	Blackhead seabream																																	
Halichoeres poecilopterus	Multicolorfin rainbowfish	1														1	1	1	1	1	1	1	1	1	1	1	1	1						
Scomber sp.[4]	Chub mackerel	10					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
Thunnus sp.[5]	Pacific bluefin tuna																																	
Scorpaena onaria	Western scorpionfish	6																										1						
Hexagrammos otakii	Fat greenling	4													1	1	1	1	1	1	1	1												
Platycephalus indicus	Bartail flathead																																	
Pleuronectidae[6]	Barfin flounder																																	
Stephanolepis cirrhifer	Threadsail filefish																																	
Tetraodontidae[7]	Japanese pufferfish	+		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
Frequency at ST and total			1	2	2	2	3	4	5	7	8	8	8	8	10	12	12	12	12	11	11	11	10	10	10	10	10	11	8	7	5	4	2	236
Frequency x ST and total			0	2	4	6	12	20	30	49	64	72	80	88	120	156	168	180	192	187	198	209	200	210	220	230	240	275	208	189	140	116	60	3925
MST																																		16.6

[1]Salmon shark (*Lamna ditropis*) and Piked dogfish (*Squalus acanthias*)
[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)
[3]Chum salmon (*Oncorhynchus keta*)
[4]Chub mackerel (*Scomber japonicus*)
[5]Pacific bluefin tuna (*Thunnus orientalis*)
[6]Barfin flounder (*Verasper moseri*)
[7]Japanese pufferfish (*Takifugu rubripes*)

Appendix Table 2-c. Seawater temperature (ST, ºC) related to fish remains, and mean seawater temperature (MST, ºC) at archeological sites in Satohama during the final Jomon period (3,000–2,400 yr BP). Frequency of occurrence (FO) of fish remains where '+' indicates that remains were found in small numbers. When fish remains could not be identified to species, seawater temperature ranges of closely related species, which occur in the same location, were used. Data sources cited in Table 2.

Species	English common name	FO	Seawater Temperature (ºC)																															
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30		
Chondrichthyes[1]	Sharks	+							1	1	1	1	1	1	1	1	1	1	1																
Clupeidae[2]	Pacific herring & sardine	24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Engraulis japonicus	Japanese anchovy	1									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Conger myriaster	Whitespotted conger	4								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
Oncorhynchus sp.[3]	Chum salmon	+		1	1	1	1	1	1	1	1	1	1	1	1	1																			
Hemiramphus sajori	Japanese halfbeak																																		
Mugil cephalus	Flathead grey mullet																																		
Lateolabrax japonicus	Japanese seabass	8								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Seriola quinqueradiata	Japanese amberjack																																		
Trachurus japonicus	Japanese jack mackerel	1														1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
Pagrus major	Red seabream																																		
Acanthopagrus schlegelii	Blackhead seabream	2											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Halichoeres poecilopterus	Multicolorfin rainbowfish																																		
Scomber sp.[4]	Chub mackerel	+					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1							
Thunnus sp.[5]	Pacific bluefin tuna																																		
Scorpaena onaria	Western scorpionfish	2																										1							
Hexagrammos otakii	Fat greenling	8													1	1	1	1	1	1	1	1													
Platycephalus indicus	Bartail flathead																																		
Pleuronectidae[6]	Barfin flounder	2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
Stephanolepis cirrhifer	Threadsail filefish																																		
Tetraodontidae[7]	Japanese pufferfish	4												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
Frequency at ST and total			1	3	3	3	4	4	5	7	8	8	9	10	11	12	11	11	11	10	10	10	9	9	8	8	8	9	7	7	5	5	4	1	231
Frequency x ST and total			0	3	6	9	16	20	30	49	64	72	90	110	132	156	154	165	176	170	180	190	180	189	176	184	192	225	182	189	140	145	120	0	3714
MST																																			16.1

[1]Salmon shark (*Lamna ditropis*) and Piked dogfish (*Squalus acanthias*)

[2]Pacific herring (*Clupea pallasii*) and Japanese sardine (*Sardinops melanostictus*)

[3]Chum salmon (*Oncorhynchus keta*)

[4]Chub mackerel (*Scomber japonicus*)

[5]Pacific bluefin tuna (*Thunnus orientalis*)

[6]Barfin flounder (*Verasper moseri*)

[7]Japanese pufferfish (*Takifugu rubripes*)