Japanese Studies on the Early Ocean Life of Juvenile Salmon

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Abstract: Almost all the salmon resources in Japan have been supported by artificial enhancement, and because of the success of this program the population size of chum salmon (*Oncorhynchus keta*) has increased dramatically since the early 1970s. About 90% of Japan's salmon catch is chum; 5–10% is pink salmon (*O. gorbuscha*) and 0.5% masu (*O. masou*). Therefore, biological research has focused on the early ocean life of juvenile chum salmon to establish the proper timing and size for release of juveniles from hatcheries, and, since the late 1960s, to study the distribution and movement of juvenile salmon in nearshore waters. Survey results indicated that juvenile chum salmon remained in coastal water masses with good food conditions and physiologically optimum surface temperature and salinity until they reached about 70–80 mm FL, when they were able to migrate offshore, avoiding high SST (over 12–13ºC) and high salinity (over 34 pus). Japan-Russia cooperative juvenile salmon surveys were conducted in the Okhotsk Sea and the western North Pacific Ocean, from early summer to winter in 1988–1996. Results suggest that the Okhotsk Sea is an important nursery area for juvenile salmon originating from Russia and Japan.

INTRODUCTION

A Historical Overview of Importance of Salmon in Japan

Pacific salmon (genus *Oncorhynchus*) have been important to the Japanese life style since ancient times (the initial Jomon Period: 6,000 B.C.) (Ishida et al. 2001). Because of religious commandments relating to diet, the Japanese people depended on animal proteins from the sea, so the fishing industries had to make many technical innovations and contrivances to meet the demand for fish (Kobayashi 1980).

Originally, a native people, the Ainu, caught adult salmon for subsistence use as the salmon ascended their home rivers and streams for spawning. Commercial coastal fishing for salmon began in the 16th century in Hokkaido. It was operated by seasonal emigrants from Honshu Island. After 1800, coastal set nets were introduced, which helped to expand salmon fishing grounds in the coastal areas (Kobayashi 1980).

A Historical Overview of Abundance

Three of the seven species of anadromous Pacific salmon inhabit Japanese coastal and oceanic waters: chum salmon or "sake" (*Oncorhynchus keta*), pink salmon or "karafuto-masu" (*O. gorbuscha*), and masu salmon or "sakura-masu" (*O. masou*). The distribution of the three species forms the southernmost limit of the genus *Oncorhynchus*. Their abundance increases from south to north, and the principal salmon production area in Japan is Hokkaido.

Chum salmon are produced in rivers on the coasts of Hokkaido and the northern part of Honshu in Japan. Pink salmon ascend rivers draining into the Okhotsk Sea and part of the Pacific Ocean. Masu salmon are distributed throughout Japan, but the anadromous type is found in rivers on the coast of the Okhotsk Sea, the Japan Sea and the northern part of the Pacific Ocean.

Total coastal catches of salmon fluctuated between 10–100 thousand tons from 1965 to 1982, and increased to over 100 thousand tons since 1983, reaching about 300 thousand tons in 1996 (Hiroi 1998). About 90% of Japan's salmon catch is chum; 5–10% is pink salmon and 0.5% masu. Therefore, biological research has been focused on chum salmon. Almost all the salmon resources in Japan have been supported by artificial enhancement. The present review of juvenile production is restricted to hatchery-produced chum salmon.

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A Historical Overview of Size Changes over Time

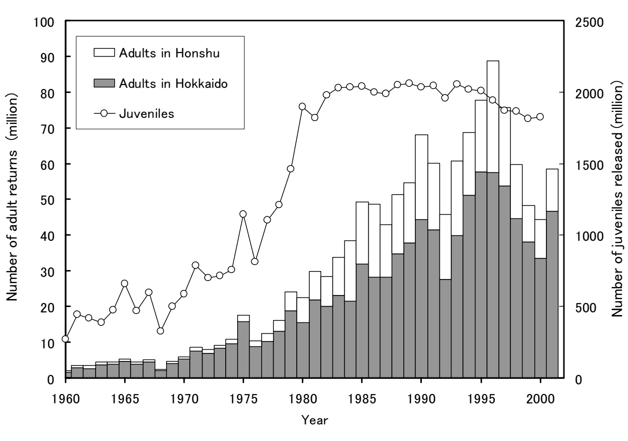
Size of chum salmon adults returning to rivers of Hokkaido has decreased since the late 1970s (Kaeriyama 1989, 1992, 1996, 1998; Ishida et al. 1993). Annual decline in average fork length was 4.9 mm/year in female and 3.7 mm/year in males between 1979 and 1989 in Hokkaido (Kaeriyama and Urawa 1992). The body weight of returning adults has also declined with increasing number of returns. Additionally, the average age of returning adults has increased in conjunction with an increase in the stock size since the 1973 brood year (Kaeriyama 1989, 1992, 1996, 1998; Ishida et al. 1993). These phenomena are considered to reflect density-dependent effects, although density-dependent mortality is not yet found (Kaeriyama 1992, 1999).

Hatchery Production

According to historical documents, efforts to enhance spawning salmon by improving their natural spawning environment through primitive artificial spawning channels were practiced in the 18th century. Artificial salmon hatching techniques were introduced from the U.S.A. to Japan in 1876, but did not reach a large scale until 1888 when the first public salmon hatchery was established on a tributary of the Ishikari River in Hokkaido (Kobayashi 1980). At present, there are 21 national, 13 prefectural and 269 private hatcheries in Japan.

The number of adult chum salmon returning to Japan remained at an average of about 3 million fish between 1900 and 1970. However, adult returns have increased exponentially since the early 1970s, and reached about 89 million fish (58 million individuals in Hokkaido and 31 million individuals in Honshu) in 1996 (Fig. 1). During this period, the number of juveniles released from hatcheries increased from 800 million in the early 1970s to 2 billion in 1982, and has remained at about 2 billion juveniles since then. Return rate (percentage of adult returns to released juveniles) has increased to 2% since the 1966 brood year and reached more than 3% after 1984 brood year. The rise in return rate was the result of successful artificial enhancement techniques, such as releasing after feeding (Kobayashi 1980; Mayama 1985; Kaeriyama 1989), as well as the influence of favorable ocean conditions in the North Pacific Ocean (Kaeriyama 1998).

Fig. 1. Annual changes in numbers of adult returns and juvenile releases of chum salmon in Japan.



Pink salmon are also produced in hatcheries. The number of juvenile pink salmon released increased from 40 million fish annually in the late 1970s to 130 million fish annually in 1987, and has remained at 140 million fish since the late 1980s. The number of adult salmon returning to Japan has increased since the 1985 brood year, reaching about 20 million fish in the 1994 brood year (Hiroi 1998; Kaeriyama 1999).

In the propagation of masu salmon in Japan, fry have been released in spring. This technique is similar to that used in the propagation of chum and pink salmon fry that migrate to the sea in early spring soon after their release. However, the release at the fry-stage has not been an effective method in areas where the river environment has deteriorated. Techniques for releasing yearling smolts of masu salmon have been studied since the early 1980s (Mayama 1990, 1991).

HISTORICAL OVERVIEW

A Brief History on Early Ocean Life Studies

Because of the success of hatchery programs, populations of chum salmon increased dramatically in Japan over the last few decades. Nevertheless, we had no detailed information about the mortality of juvenile salmon during their ocean life.

In 1952, the National Hokkaido Salmon Hatchery (HSH) was established under the Fish Resource Conservation Law and began scientific research and enhancement activities to rebuild salmon populations. Until the early 1960s, research at HSH focused on freshwater life history and technical aspects of efficient hatchery production. During this time, Japanese high seas salmon surveys by the National Research Institute of Far Seas Fisheries (NRIFSF) (formerly the Far Seas Fisheries Research Laboratory) were conducted in conjunction with the high seas fisheries in spring and summer, the offshore fishing seasons for salmon since 1956 (Ishida and Ogura 1992). Thus, there were few studies on the early ocean life history of juvenile salmon after they had migrated down Japanese rivers.

Pioneering studies on migration ecology of juvenile chum salmon during their coastal life were carried out in the 1950s. However, migration timing and growth of juveniles were estimated from incidental catches in coastal commercial set-nets in Hokkaido (Sano and Kobayashi 1952, 1953; Mihara 1958).

Until the early 1960s, chum salmon were released as unfed fry into streams as soon as the yolk sac was absorbed. Experiments on the release of chum salmon fry after a brief period feeding with dry food began in Hokkaido in 1962. To optimize timing of release of juveniles, a research program on the distribution and movement of juvenile salmon in coastal waters was begun in the late 1960s (Mayama 1985).

Seasonal changes in juvenile salmon distribution and growth in coastal areas were surveyed along the coasts of Hokkaido by the research division of HSH since 1969, using a purse seine and surface trawl. In 1971, a similar survey program was begun in northern Honshu under the auspices of the Fisheries Agency (Kaeriyama et al. 1993, 1994).

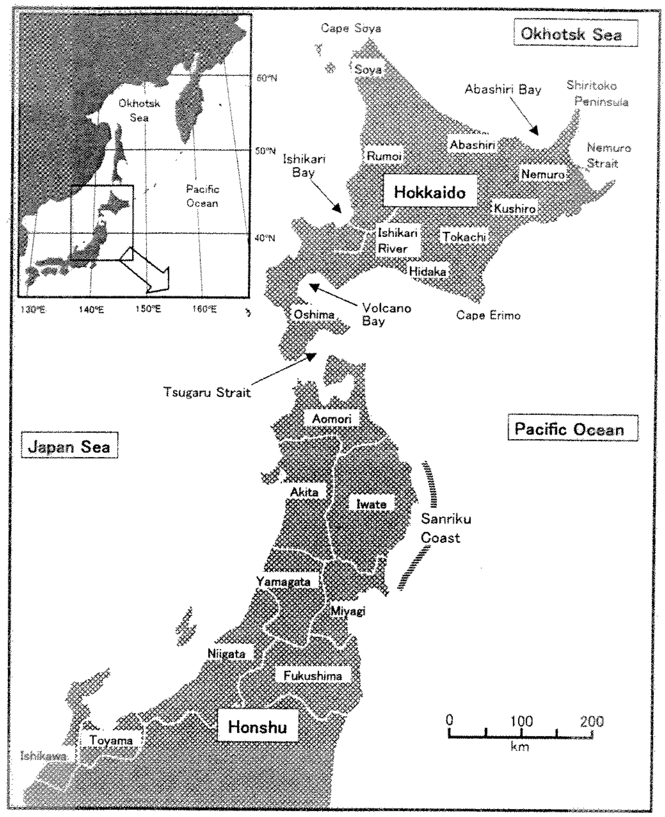
Results from these surveys indicated that the offshore movement of juvenile chum salmon is closely related to the environment of prey or physical oceanographic conditions. Physiological, ecological and morphological changes in the development of juvenile chum salmon during their early ocean life were also investigated. As a result, the early life history of juvenile chum salmon before their offshore migration had gradually become clear (Kaeriyama 1986; Irie 1990).

In the 1970s, surveys in about 20 areas along the coasts of Hokkaido and Honshu, including about 10 in the coastal waters of Hokkaido, described the local life patterns of juvenile chum salmon. Annual reports on the salmon enhancement programs including the coastal surveys have been published by HSH and various prefectures in Honshu. However, the survey areas were limited to the nearshore, i.e., from estuaries to about 5 km offshore, where small vessels could operate or coastal set nets were used.

A national research project entitled "Technical development of large-scale farming of anadromous salmon" was conducted with financial support from the Agriculture, Forestry, and Fisheries Research Council for five years (1977–1981) by seven national fisheries research institutes, sixteen prefectural fisheries experimental stations, and three universities. The research project included cooperative studies between nearshore and offshore research groups to elucidate migration routes of marked juvenile chum salmon originating from the Ishikari River (Fig. 2) entering the Japan Sea (Ito et al. 1980; Kato and Mayama 1980; Mishima and Shimazaki 1980; Mayama et al. 1982; Kato 1985). Migration and growth patterns of juvenile chum salmon during their offshore migration were clarified through this joint group research.

Since the 1980s, the biomass of Pacific salmon has increased throughout the North Pacific Ocean. Adult chum salmon returns increased to more than 50

Fig. 2. Map of the Japanese coastal waters with main study areas for juvenile salmon.



million fish until the late 1980s in Japan. The rapid increase in chum salmon abundance was regarded as a good example of the benefits of sea ranching. However, the Japanese salmon enhancement program was confronted with new problems such as a decrease in body size and an increase in age at maturity of chum salmon (e.g. Kaeriyama and Urawa 1992). At the same time, the Japanese high seas salmon fishery was prohibited in the U.S.S.R. 200-mile zone in 1977, and in the U.S.A. 200-mile zone in 1989, restricting availability of high seas data to Japanese scientists. More extensive cooperation with scientists in other nations as well as those of domestic organizations was deemed necessary to conserve salmon populations in the North Pacific Ocean (Nagasawa 1992).

General migration patterns and distribution of Japanese chum salmon juveniles were described by Irie (1990). However, their offshore migration routes to the North Pacific Ocean have not been identified. To investigate these offshore migration routes, Japan-Russia cooperative juvenile salmon surveys were conducted in the Okhotsk Sea and the western North Pacific Ocean in 1988–1996 (Ueno and Ishida 1996; Ueno et al. 1998). Results suggested that the Okhotsk Sea was an important nursery area for juvenile salmon originating from Japan and Russia (Ueno and Ishida 1996; Ueno et al. 1998).

Decreases in the high seas fishery catch following establishment of foreign 200-mile zones enhanced the significance of Japanese coastal fisheries. A new nine-year innovative "Marine Ranching Program (MRP)" was initiated by the Ministry of Agriculture, Forestry and Fisheries from 1980 till 1989, linking the governmental, academic and private sectors. Masu salmon was one of the target anadromous species, because it remains in coastal areas. In this research program, ecological surveys of juvenile masu salmon on migration clarified their feeding habits and growth during their coastal life (Kato 1983; Kiso 1995).

In the late 1990s, natural mortality from predators (Nagasawa 1998) and from environmental stress (Fukuwaka and Suzuki 1998, 2002) were studied during the early ocean life of juvenile chum salmon.

To advance research on juveniles, the National Salmon Resources Center (NASREC; formerly HSH) began a new monitoring program for otolith thermal marks in 1998 to obtain stock-specific biological information, including the early ocean life history in a wide coastal area around Hokkaido.

In October 1998, the National Fisheries Research Institutes were reorganized and the high-seas salmon research transferred from NRIFSF to the Hokkaido National Fisheries Research Institute (HNFRI). The HNFRI conducts fishery surveys under national or international research plans on migratory fish such as salmon as well as on ground fish, mainly walleye pollock (*Theragra chalcogramma*), to measure the distribution and abundance of these species in the Subarctic region of the North Pacific Ocean. The HNFRI also collects information on biological characteristics of species, such as age, growth, maturation, migration, feeding habits, and population structure to establish appropriate fisheries management systems and to ensure the well-being of marine resources and ecosystems.

REVIEW OF RESULTS

Distribution and Abundance in Estuaries

The importance of estuaries as nursery areas has not been evaluated, because chum salmon have strong preferences for seawater and migrate to the sea soon after yolk absorption. Furthermore, few rivers have well defined estuaries; they empty directly into the sea, except along the Sanriku coast which is a Rias-type coastline with a lot of bays, peninsulas and capes. Many Japanese scientists have not distinguished between "estuary" and "coastal waters" in the strict sense of the words.

The coast of northern Japan, except for the Sanriku coast (Fig. 2) of the Pacific Honshu, has a simple shoreline and very few estuaries. Almost all rivers producing chum salmon are small and enter the open sea. Therefore, there are few studies on juveniles in estuaries.

The distribution of juvenile chum salmon in estuaries was first reported by Sano and Kobayashi (1952). They observed that juvenile chum salmon released from a hatchery on the Japan Sea side of Hokkaido began to move down the river at the end of February. Juveniles congregated in the estuary, peaking in abundance in early and middle May, and moving offshore by late June (Sano and Kobayashi 1952, 1953). In these early studies on estuarine life, the relationship between fish distribution and environmental factors was not discussed because environmental data were not collected consistently.

Between 1952 and 1957, Mihara (1958) collected ecological information on the coastal life of juvenile chum salmon from 48 rivers in Hokkaido by means of questionnaires to coastal fishermen. The purpose was to plan a means of avoiding bycatch with coastal fishing nets. He reported that juvenile chum salmon released as unfed fry from February to June arrived in estuaries from late February to late July.

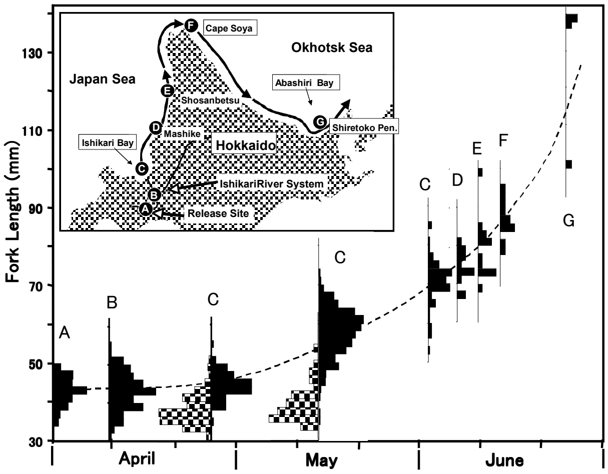
There are many small coastal rivers producing chum salmon in Japan, especially in Honshu. Juvenile chum salmon released into a small river on the Sanriku coast in northern Honshu arrived in the estuary within 24 hours (Seki 1978a; Iwata and Komatsu 1984), suggesting that growth and survival were more affected by the environment of the littoral zone around the estuaries than the freshwater habitat (Seki 1978a).

Chum salmon acquire salinity tolerance earlier than many other salmonids. Little information was available on adaptation during actual seaward migration until the observations by Iwata and Komatsu (1984).

Most chum salmon fry migrating from a small stream of the Sanriku coast were found in the surface layer (salinity 10–15 pus) of the estuary of the river. No fish were seen in the underlying seawater. Many fry remained in the brackish water for two days before migrating seaward (Iwata and Komatsu 1984). Iwata and Komatsu concluded that estuaries were an important area for the osmoregulatory adjustment of chum fry.

Juvenile chum salmon collected with a beach seine in the intertidal (littoral) zone of waters adjacent to the Ishikari River, Hokkaido (Fig. 2), from March to May were always small, ranging mainly from 30 to 45 mm, and averaging 37 mm in fork length (FL) (Fig. 3). Specific conditions for the short residence of smaller juveniles in the littoral zone were suggested (Mayama et al. 1982, 1983). A similar distribution pattern of small juveniles was observed in the coastal waters of Sanriku (Seki 1978a; Terazaki et al. 1982; Kaeriyama 1986) and the Nemuro Strait off eastern Hokkaido (Kasahara 1985).

Fig. 3. Seasonal changes in fork length distribution of juvenile chum salmon originating from the Ishikari River System, 1979. Histograms show lengths of juvenile chum salmon caught on beaches (left side) and offshore (right side) along the Ishikari coast. (Data from Ito et al. 1980; Kato and Mayama 1980, 1982; Mayama et al. 1982).



Juvenile chum salmon were often seen schooling in ports (Irie et al. 1981; Irie and Nakamura 1985; Seki and Shimizu 1997). The length of residence and growth of juvenile chum salmon in small harbors on the Pacific coast of eastern Hokkaido were surveyed during late April to early August by Irie and Nakamura (1985). The number of juvenile chum salmon found in these harbors increased from late April through early June and then decreased from mid-June through mid-July.

Estuarine environments containing important nursery areas for small and physiologically weak juveniles have been destroyed and lost because of recent construction and development in Japan. Research is needed to elucidate the habitat requirements of juvenile salmon in estuaries and adjacent waters of the littoral zone.

Diet of Juvenile Salmon in Estuaries

Information on the diet of juvenile salmon in estuaries is limited for the same reasons that data on distribution and abundance are scarce. Most chum salmon fry reach the estuaries within 24 hours after release from hatcheries on coastal rivers. They appear inactive on the first day, and begin feeding the following day (Iwata and Komatsu 1984).

Terazaki et al. (1982) and Terazaki and Iwata (1983) studied the feeding habits of juvenile chum salmon captured by beach seine in estuaries and the adjacent shore of the Ohtsuchi River of the Sanriku coast. Zooplankton was collected with vertical tows using a Norpac net at the same location. Epibenthic crustaceans such as *Jassa falcata* (Amphipoda) and harpacticoid copepods were major prey of juvenile chum salmon living in the littoral zone, including estuaries in spite of abundant pelagic zooplankton. Terazaki and his colleagues suggested that juveniles could probably catch epibenthic animals more easily than zooplankton in shallow estuarine waters.

The main diet of juvenile chum salmon captured in areas of low salinity (< 21 pus) was terrestrial insects, mainly chironomid larvae, and epibenthic crustaceans such as amphipods. Harpacticoid copepods were dominant in stomach contents of juveniles captured in areas of relatively high salinity (21–30 pus) around estuaries of rivers in the Sanriku coast (Kaeriyama 1986). The results indicated a change in prey types from terrestrial origin to oceanic origin.

Irie (1987) found that juvenile chum salmon in small harbors in eastern Hokkaido mainly fed on harpacticoid copepods and gammarid amphipods. Juvenile salmon fed first on the abundant food organisms in their surroundings and also preferably on the relatively larger ones. Irie (1990) indicated that not only did increased food intake accompany growth, but also a shortage of food in the harbors, especially prey of larger size, was a major cause of migration.

Besides copepods, other principal prey items of juvenile chum salmon during their estuary life include insects, amphipods and fish larvae (Table 1).

When stomach contents of juvenile chum salmon and plankton net samples were compared at each sampling station, remarkable differences were usually found in their composition (Seki 1978a; Terazaki et al. 1982; Terazaki and Iwata 1983). Efficient methods for sampling prey animals are necessary to get useful information on food availability for juvenile chum salmon in estuaries.

Movement Patterns into Coastal Waters

There is limited information about environmental conditions during the movement of juvenile chum salmon from estuary to coastal waters. Because lengths of juvenile chum salmon in estuaries ranged mainly from 30 to 50 mm FL, movement of the juveniles from estuaries to coastal waters is estimated to have occurred successively as juveniles exceeded about 40–50 mm FL (Sano and Kobayashi 1952; Seki 1978a; Mayama et al. 1982, 1983; Terazaki et al. 1982; Kasahara 1985; Kaeriyama 1986). In the inner part of the bay at the southern end of the Sanriku coast, juvenile chum salmon moved from estuary to coastal waters when surface water temperatures rose to 13°C (Seki 1978a).

The abundance of juvenile chum salmon in small harbors decreased from mid-June through mid-July (Irie and Nakamura 1985). Juvenile chum salmon remained in the harbors for about one month and moved away when they grew larger than 45 mm FL. It seemed unlikely that most of the juvenile salmon migrated from the harbors due to changes in water temperature or salinity. It appeared that increased

Table 1. Information on the stomach contents of juvenile chum salmon sampled from various estuary waters and the littoral zone in Japan.
continue…

Year	Month	Area [*1]	Number of fish examined	Fork length (mm)		Relative importance of						
				Mean	Range	Fishes	Eggs	Larvaceans	Polychaetes	Gastropods	Insects	Decapods
Percentage composition in volume												
1981	May–Jun	Katsurakoi (Kushiro, HK)	126	46	32–74	22	-	-	+	-	2	3
1982	Apr–Jun	”	114	49	32–71	15	-	-	+	-	2	1
1983	Apr–May	”	43	45	32–70	35	-	-	+	-	4	1
Percentage composition in number												
1984	Apr	Konbumori (Kushiro, HK)	20	-	35–43	-	3.0	-	0.1	-	-	0.4
1984	May	”	80	-	33–52	-	2.6	-	0.9	-	0.6	0.7
1984	Jun	”	164	-	31–66	0.0	7.2	-	0.0	-	2.2	0.1
1984	Jul	”	36	-	38–54	-	6.4	-	0.1	-	0.4	0.0
Average number of prey animals found per stomach												
1978	Apr	Ohtsuchi (Iwate, HS)	3	50	40–61	-	-	-	-	-	-	0.7
1979	Mar–Apr	”	117	43	30–80	-	0.1	0.2	0.2	-	0.2	0.9
1980	May	”	14	54	40–80	0.4	0.0	0.1	0.2	-	4.0	0.2
1980	May	Ohkawa River (Miyagi, HS)	-	-	40–80	-	-	-	-	-	0.5	-
1980	Apr	Omose R. (”)	-	-	45–65	-	-	-	-	-	18.4	-
1980	Apr–May	Koizumi R. (”)	-	-	35–70	0.9	-	-	-	-	4.7	-
1980	Apr–May	Mitobe R. (”)	-	-	35–70	-	-	-	-	-	2.7	0.1
1980	Mar	Ishikari Bay (HK)	10	-	32–44	-	-	3.1	-	0.3	-	-
1980	Apr	”	440	-	30–60	0.0	-	-	-	0.9	0.7	-
1980	May	”	301	-	30–50	0.0	0.4	0.0	-	0.3	0.8	-
Percentage frequency of occurrence of prey animals												
1981	May–Jun	Katsurakoi (Kushiro, HK)	126	46	32–74	16	-	-	3	-	24	28
1982	Apr–Jun	”	114	49	32–71	38	-	-	5	-	8	7
1983	Apr–May	”	43	45	32–70	10	-	-	2	-	10	5
1979	Apr	Toyama Bay (HS)	22	0.9g[*2]	-	-	6	-	-	-	36	-
1980	Mar	”	473	0.7g[*2]	-	-	-	3	2	-	52	1
1981	Mar	”	242	0.6g[*2]	-	0	1	-	-	-	59	-
1982	Mar–Apr	”	204	0.9g[*2]	-	-	-	-	-	-	64	-

*1: HK and HS in parentheses mean Hokkaido and Honshu, respectively.
*2: Mean body weight.
*3: Toyama Prefectural Fisheries Experimental Station.

food requirements accompanying their growth and a shortage of food in the harbors were major causes of migration. Irie (1990) concluded that small harbors were one of the important places for juvenile chum salmon during early physiological and ecological adaptations to ocean life.

Diet in Coastal Waters

Seasonal changes in food abundance appear to be one of the important factors affecting offshore movement of juvenile chum salmon from coastal waters.

Until the 1960s, very little was known about the feeding habits of juvenile chum salmon in coastal waters, though more was known about feeding of

…continued

prey animals in stomachs											
			Copepods								
Euphausiids	Amphipods	Mysids	Total	Calanoids	Harpacticoids	Others	Ostracods	Cumaceans	Cladocerans	Others	Source
27	13	21	(13)	4	9	-	+	1	-	-	Irie 1987
27	19	2	(31)	11	20	-	+	1	-	-	”
3	15	-	(28)	4	24	-	-	1	-	-	”
-	26.6	0.1	(69.7)	32.2	37.5	-	-	0.1	-	-	Irie 1990
0.6	32.8	0.1	(48.7)	0.6	48.1	-	-	0.4	-	1.1	”
0.0	25.1	0.5	(65.1)	2.0	63.1	-	-	0.2	-	0.1	”
-	4.1	0.3	(87.8)	0.3	87.5	-	-	0.1	-	0.1	”
-	7.0	-	(104.0)	0.3	102.7	1.0		-	-	-	Terazaki & Iwata 1983
-	0.7	-	(67.1)	46.0	11.2	9.9		-	0.2	0.0	”
-	19.6	-	(2.1)	0.2	1.1	0.8		-	-	0.6	”
-	80.6	-	-	-	-	-	-	18.3	-	-	Kaeriyama 1986
-	7.9	-	-	-	-	-	-	-	-	-	”
-	-	-	(2.6)	-	2.6	-	-	-	-	-	”
-	3.8	-	(32.9)	24.6	8.3	-	-	-	-	-	”
-	-	-	(2.7)	2.7	-	-	-	-	-	-	Seki et al. 1981
0.7	0.9	-	(16.6)	11.8	4.8	-	-	-	-	0.0	”
0.3	0.3	-	(17.4)	16.0	1.4	-	-	0.1	-	0.3	”
7	58	14	-	29	63	-	1	7	-	-	Irie 1987
18	30	3	-	10	46	-	3	10	-	-	”
5	25	-	-	15	55	-	-	5	-	-	”
14	-	-	73	-	-		-	-	-	-	TPFES*3 1984
15	4	-	59	-	-		-	-	8	-	”
16	19	-	50	-	-		-	-	3	-	”
25	23	-	39	-	-		-	-	-	-	”

juveniles in fresh water in Japan. The first paper on feeding habits of juvenile chum salmon in coastal waters, published in 1971 (Okada and Taniguchi 1971), reported on the diets of juvenile chum and pink salmon along the Pacific coast of southern Hokkaido from May to June.

On the basis of several papers (Seki et al. 1981; Terazaki and Iwata 1983; Irie 1990) dealing with feeding habit of juveniles, copepods were regarded as the most important prey of juvenile chum salmon. Hyperiid amphipods (*Parathemisto japonica*), branchiopods (cladocerans), terrestrial insects (dipterans and hymenopterans), decapod larvae, euphausiids, fish larvae (mainly sand lance), and larvaceans (appendicularians) are predominant prey in coastal waters (Table 2). Furthermore, cumaceans, polychaetes, mysids and eggs of invertebrates and fishes were frequently found in stomachs of juvenile chum salmon.

Prey of juvenile chum salmon vary with the salmon's movement from estuary to coastal waters and with their growth. Okada and Taniguchi (1971)

Table. 2. Information on the stomach contents of juvenile chum salmon sampled from various coastal waters in Japan. continue…

			Fork length (mm)		Relative importance of							
Year Month	Area [*1]	Number of fish examined	Mean	Range	Fishes	Eggs	Larvaceans	Polychaeta	Sagittas	Gastropods	Bivalvia	Insects
Occurrence of prey animals												
1970 Jun	Usujiri (Oshima, HK)	27	-	36–104	+	-	-	-	-	+	-	+
1970 May–Jun	Mori (Volcano Bay, HK)	67	-	„	+	+	-	-	-	+	-	+
Percentage composition in number												
1981 May	Kesennuma (Miyagi, HS)	-	-	-	5.6	-	11.1	-	-	-	-	-
1981 Jun	„	-	-	-	-	-	87.2	-	-	-	-	0.6
1984 May	Kushiro (HK)	7	-	40–70	0.6	-	-	-	-	-	-	2.8
1984 Jun	„	20	-	40–80	3.3	-	-	-	-	-	-	
1984 Jul	„	80	-	70–140	0.5	-	2.2	2.2	-	-	-	23.8
1984 Aug	„	10	-	70–100	-	-	-	-	-	-	-	98.5
1985 Jun	Kushiro (HK)	11	-	110–130	26.4	-	-	-	-	-	-	-
1985 Jul	„	27	-	40–120	-	-	-	0.2	-	-	-	3.0
1993 Apr	Fukura (Yamagata, HS)	61	71	35–100	2.9	-	6.4	13.1	-	1.0	-	-
1994 Mar	„	29	51	-	0.2	-	59.6	-	-	-	-	-
1994 Apr	„	65	66	-	1.1	-	22.0	-	-	-	-	-
Average number of prey animals found per stomach												
1980 May–Jun	Otsuchi (Iwate, HS)	76	81	60–130	-	-	-	-	0.2	-	-	0.2
1980 May	Ishikari Bay (HK)	585	-	34–78	0.2	0.1	5.4	-	-	5.4	-	0.5
1987 May–Jun	Hidaka (HK)	283	-	-	4.9	-	165.7	5.1	1.7	-	46.6	6.1
1988 Jun–Jul	„	256	-	-	-	-	172.0	-	-	-	6.1	2.4
1995 Apr	Mashike (Rumoi, HK)	56	51	-	7.3	-	-	0.0	-	0.4	-	-
Percentage frequency of occurrence of prey animals												
1978 May	Kesennuma (Miyagi, HS)	327	-	40–125	29.1	-	-	-	-	-	-	4.6
1978 May–Jun	„	121	-	60–125	28.1	-	-	-	-	-	-	0.8
1977 Jul	Abashiri Bay (HK)	7	-	46–76	-	29	-	-	-	14	-	86
1978 May–Jul	„	63	-	38–63	46	3	-	-	-	24	-	25
1979 „	„	261	-	32–110	5	2	16	-	-	-	-	24
1980 „	„	140	-	29–110	14	3	14	-	-	-	-	21
1978 Apr–Jun	Rumoi (HK)	111	-	41–98[*2]	27.9	0.9	4.5	3.6	-	12.6	-	5.4
1979 May	„	8	87.4[*2]	74–96[*2]	12.5	-	-	-	-	25.0	-	-
1978 May–Jun	Cape Soya (HK)	49	-	56–99[*2]	22.4	-	2.0	-	-	-	-	-
1979 „	„	100	55.9[*2]	35–85[*2]	27.0	-	-	-	3.0	1.0	-	24.0
1978 May–Jun	East Soya (HK)	89	-	34–97[*2]	13.5	-	1.1	3.3	-	1.1	-	28.1
1979 „	Soya (HK)	120	80.7[*2]	58–100[*2]	72.5	0.8	-	-	-	-	-	10.8
1979 Jun	East Soya (HK)	60	61.3[*2]	37–88[*2]	43.3	-	-	-	-	-	-	30.0
1979 Apr–May	Toyama Bay (HS)	1133	2.8g[*3]	-	1.1	3.8	3.2	-	-	0.3	-	10.4
1980 „	„	752	2.6g[*3]	-	7.2	3.8	2.9	-	1.0	1.0	-	14.5
1981 Apr–Jun	„	572	2.3g[*3]	-	1.0	6.0	5.9	-		1.7	-	25.4
1982 „	„	470	2.5g[*3]	-	1.0	3.9	-	-	-	-	-	15.2
1983 Jun	Aomori (Pacific, HS)	81	-	80–110	33	-	-	-	-	-	-	5

continue…

…continued

prey animals in stomachs													
					Copepods								
Decapods	Euphausiids	Amphipods	Mysids	Cirripedes	Total	Calanoida	Harpacticoida	Others	Ostracods	Cumaceans	Cladocerans	Others	Source
+	+	+	-	-	+	+	-	-	+	-	-	+	Okada & Taniguchi 1971
+	+	+	+	-	+	+	+	-	+	+	-	-	„
-	9.8	68.5	-	-	(0.5)	-	0.5	-	-	-	-	5.6	Kaeriyama 1986
-	-	1.5	-	-	(1.1)	0.9	0.2	-	-	-	4.6	4.5	„
58.7	-	2.2	-	-	35.7	-	-		-	-	-	-	Irie 1990
8.6	-	7.7	-	-	80.2	-	-		-	-	-	0.2	„
21.2	1.1	18.7	0.3	-	24.3	-	-		2.0	0.6	3.2	-	„
-	-	1.5	-	-	-	-	-		-	-	-	-	„
46.9	0.3	2.7	-	-	22.8	-	-		0.3	-	-	0.6	Irie 1990
7.1	10.8	25.1	-	-	50.8	-	-		1.1	0.1	0.8	1.0	„
-	18.0	0.3	-	-	42.8	-	-	-	-	-	12.7	-	Suzuki et al. 1994
-	1.8	17.8	-	-	(15.7)	15.7	-	2.3	-	-	-	-	Suzuki et al. 1995
-	12.0	0.6	-	-	(19.0)	16.7	2.3	-	-	-	42.7	-	„
3.8	1.3	21.4	-	-	(125.3)	121.1	1.0	3.2	-	-	212.8	-	Terazaki & Iwata 1983
-	10.7	0.5	-	-	(92.6)	92.6	0.0	-	-	0.1	-	0.1	Seki et al. 1981
-	5.6	6.7	7.2	-	(58.0)	57.5	0.5	-	-	-	47.7	-	Seki & Shimizu 1998
11.8	5.1	15.2	17.4	16.9	(160.6)	160.6	-	-	-	4.8	5.1	0.0	„
4.0	-	1.0	-	-	(2.4)	1.7	0.7	-	-	-	-	0.2	Kawamura et al. 1998
-	-	51.7	-	-	-	21.4	6.7	-	-	-	-	9.8	Seki 1978b
-	-	50.4	-	-	-	3.3	-	-	-	-	-	4.1	„
14	14	100	-	-	-	100	-	-	-	-	-	-	Irie 1990
8	17	32	-	-	-	92	-	-	-	-	-	-	„
5	2	37	1	-	-	51	6	-	1	+	12	1	„
13	7	37	-	-	-	59	11	-	-	1	7	-	„
15.3	-	3.6	-	1.8	-	40.5	31.5	-	-	0.9	-	-	Suzuki et al. 1979
-	-	12.5	-	-	-	100.0	-	-	-	-	-	-	Suzuki at al. 1980
26.5	-	26.5	-	-	-	67.3	8.2	-	-	-	-	-	Suzuki et al. 1979
23.0	-	20.0	-	-	-	8.0	4.0	-	-	5.0	-	6.0	Suzuki et al. 1980
19.1	-	57.3	-	5.6	-	56.2	57.3	-	-	28.1	-	1.1	Suzuki et al. 1979
34.2	-	7.5	-	-	-	40.0	-	-	-	-	-	3.3	Suzuki et al. 1980
11.7	-	23.3	-	-	-	16.7	3.3	-	-	10.0	-	-	Suzuki et al. 1980
10.3	27.4	24.1	-	-	52.5	-	-		-	-	0.7	-	TPFES[*4] 1984
-	21.8	13.8	-	-	49.8	-	-		-	-	21.3	-	„
-	19.8	9.7	-	-	17.2	-	-		-	-	14.2	-	„
1.9	10.7	1.9	-	-	16.7	-	-		-	-	1.0	-	„
-	20	42	-	-	7	-	-		7	-	-	-	Irie 1990

continue…

Table. 2. continued

continue…

Year	Month	Area [*1]	Number of fish examined	Fork length (mm)		Relative importance of							
				Mean	Range	Fishes	Eggs	Larvaceans	Polychaeta	Sagittas	Gastropods	Bivalvia	Insects
1985	May	Aomori (Pacific, HS)	25	-	60–120	4	4	4	-	-	-	-	4
1981	Jun	Hidaka (HK)	60	-	50–140	32	-	-	-	-	-	-	22
1982	Jul	„	51	-	50–120	14	-	12	-	-	-	-	6
1983	„	„	21	-	90–120	14	-	-	-	-	-	-	66
1981	Jul	Tokachi (HK)	29	-	70–120	10	-	-	-	-	-	-	28
1982	„	„	32	-	90–140	13	-	-	-	-	-	-	13
1983	„	„	50	-	60–110	8	-	10	-	-	-	-	16
1983	Jul	Kushiro (HK)	25	-	90–120	-	-	20	-	-	-	-	16
1984	„	„	86	-	100–120	1	-	1	-	-	-	-	16
1983	Jul	Akkeshi (kushiro, HK)	67	-	80–120	12	-	-	-	-	-	-	9
1984	„	„	30	-	90–130	3	-	7	-	-	-	-	3
1985	Aug	„	30	-	90–120	10	-	-	-	-	-	-	70

*1: HK and HS in parentheses mean Hokkaido and Honshu, respectively.
*2: Total length (mm).
*3: Mean weight (g).
*4: Toyama Prefectural Fisheries Experimental Station.

indicated a rapid rather than gradual change in prey size from small animals, such as micro-copepods (young *Parathemisto* spp.), decapod zoea and insects, to larger ones, such as adult *Parathemisto japonica* and euphausiids, as juveniles exceeded about 55 mm FL. Similar changes were observed by Irie (1990) and Suzuki et al. (1994).

Irie (1990) reported that, in small harbors in eastern Hokkaido, the prey size of juvenile chum salmon of about 43 mm FL increased rapidly. The juveniles appeared to feed on larger food organisms (amphipods, fish larvae and euphausiids) as they grew. Suzuki et al. (1994) evaluated the relation between fish size and selectivity of juvenile chum salmon feeding on pelagic zooplankton during their coastal life in the Japan Sea off northern Honshu, and suggested that juvenile chum salmon 50–60 mm FL selected large prey such as *Calanus sinicus*, euphausiid furcilia larvae and polychaetes. Larger juvenile chum salmon, i.e. >80 mm FL, during offshore migration were found to migrate actively in schools searching for food, and selectively fed on larger zooplankton found in patches and in high density (Irie 1990).

Another study on change in feeding patterns of juvenile chum salmon conducted on the southern Sanriku coast was reported by Kaeriyama (1986). He showed that juvenile chum salmon searched for larger, actively moving prey distributed patchily in the sea, and selectively fed on them. This feeding method of juveniles in coastal waters was therefore regarded as "wide-foraging type", and differed from the "sit-and-wait type" of juveniles feeding in rivers. Suzuki and Fukuwaka (1998) reported that the change in foraging behavior of juveniles was influenced by abundance of large prey. Fingerlings intensified their foraging selectivity with an increase in the abundance of larger prey. On the contrary, the abundance of smaller prey did not influence prey size selectivity.

Food items of juvenile salmon do not usually correlate well with zooplankton fauna collected at the same sampling sites. The disagreements are caused by changes in feeding behavior associated with changes in developmental stage or body size, as mentioned above. Also, temporal movement of prey may cause differences. Seki and Shimizu (1998) collected juvenile chum salmon and zooplankton in coastal waters of southwestern Hokkaido. Zooplankton collected with simultaneous horizontal tow nets from seven different layers were most abundant at 30 m depth, and the density decreased markedly in near-surface layers. However, feeding was successful in chum salmon juveniles inhabiting shallow waters (5–15 m in depth). The authors suggested that prey organisms might become available to salmon juveniles in coastal shallow waters as a result of limited vertical migration of zooplankton and by up-welling. As described above for estuaries, efficient methods for sampling prey animals are required to obtain useful information on food avilability for juvenile chum salmon.

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prey animals in stomachs													
					Copepods								
Decapods	Euphausiids	Amphipods	Mysids	Cirripedes	Total	Calanoida	Harpacticoida	Others	Ostracods	Cumaceans	Cladocerans	Others	Source
16	8	88	-	-	-	-	-		12	-	4	-	Irie 1990
3	5	72	-	-	35	-	-		-	-	-	-	Irie 1990
8	8	24	-	-	49	-	-		14	-	-	-	„
-	19	10	-	-	33	-	-		-	-	-	-	„
10	14	17	-	-	38	-	-		-	-	-	-	Irie 1990
28	22	19	-	-	31	-	-		3	-	-	-	„
2	40	44	-	-	42	-	-		-	-	-	-	„
28	28	12	-	-	20	-	-		4	-	-	-	Irie 1990
57	7	9	-	-	22	-	-		7	1	-	-	„
25	6	36	4	-	40	-	-		15	-	3	-	Irie 1990
33	7	10	7	-	23	-	-		-	-	-	-	„
-	25	15	-	-	85	-	-		-	-	-	-	„

Timing and Speed of Movement to High Seas

Until the 1960s, migration and growth of juvenile chum salmon during their coastal life was estimated from by-catches in coastal commercial fisheries. These observations had shown that chum salmon disappeared from coastal areas at a specific time and body size every year.

Data on juvenile chum salmon in the coastal waters off Hokkaido, collected by means of questionnaires to coastal fishermen during 1952 to 1957, showed that juvenile salmon stayed in coastal waters form April to late June, and disappeared rapidly when sea surface temperature (SST) increased above 17°C (Mihara 1958). In this early study, SST conditions during offshore migration of juvenile chum salmon were similar among different areas around Hokkaido, although conditions at any one time varied widely among areas.

Japan is located at the southern limit of the geographical distribution of chum salmon. Along the coast, effects of the warm current are pronounced during spring and summer. Therefore, juvenile chum salmon must migrate offshore until the environment becomes inadequate. In order to delay the time of release and produce larger juveniles, the release of chum salmon juveniles after feeding was begun in the 1960's. It was necessary to clarify the time limit to determine the duration of feeding in the hatchery.

To establish the proper timing and size for release of juveniles from hatcheries, a research program was started in the late 1960s. Seasonal changes in juvenile distribution and growth in coastal areas were surveyed since 1969 using a purse seine and surface trawl along the coasts of Hokkaido. A similar survey program started in northern Honshu in 1971. The survey areas were limited to near-shore, from estuaries to about 5 km offshore. Local life patterns of juvenile chum salmon off the coasts of Hokkaido and Honshu were monitored in about 20 areas, including a total about 10 coastal areas off Hokkaido.

The distribution and migration of juvenile chum salmon was investigated for five years, 1977–1981, using a purse seine at depths of 5–25 m, up to 5 km offshore on the Ishikari coast of the Japan Sea side of Hokkaido (Mayama et al. 1982, 1983; Mayama 1985). Juveniles were low in abundance in April, increased rapidly from late May to early June, and disappeared by mid-June. The rapid decrease in numbers of larger juveniles was found at the same time every year. The temperature at a depth of 5 m showed a linear increase with time, and reached 11–12°C in late May to early June, when abundance of juveniles had decreased. Salinity at the same depth decreased in April and mid-May (27.2–33.6 pus) as a result of an increasing amount of water from the river, and then increased rapidly in late May (33.3–34.0 pus). At this time, the effect of the Tsushima Warm Current increased, raising the water temperature and salinity, and seemed to produce some physiological effects that induced offshore migration of chum salmon juveniles.

Investigations by Irie (1985a, 1990) were conducted over a wide area in Abashiri Bay and adjacent waters of the Okhotsk Sea, and in the Pacific Ocean off Hokkaido and northern Honshu, and in Tsugaru Strait and adjacent waters of the Japan Sea. From all results in each region, it appeared that offshore migrating juvenile chum salmon mainly concentrated in areas with SST from 9° to 13°C and surface salinity from 31.0 to 33.9 pus, and that upper limits were at about 14°C in temperature and 34 pus in salinity. These two studies suggested that juvenile chum salmon showed a certain preference for water temperature, salinity, and water masses. A similar relationship between oceanographic conditions such as SST and salinity and distribution of juvenile chum salmon has been found through surveys on the Japan Sea coasts of northern Honshu (Kaeriyama et al. 1993, 1994) and Pacific coasts (Koganezawa and Sasaki 1985; Kaeriyama 1986, 1989).

Kaeriyama (1986, 1989) observed differences in patterns of offshore migration between early and late seaward migrating juveniles off the Sanriku coast of the Pacific side of northern Honshu. The early migrating juveniles remained in the coastal waters for a long time (about 80 days) through early spring (February–March), and then migrated offshore as the Oyashio Current approached the coast (April–May), with SSTs ranging from 8–11°C. Late migrating juveniles remained in the coastal region for a shorter time (about 40 days), until late spring (April–May), and migrated offshore after retreat of the Oyashio Current from the coast (June) when SSTs ranged from 11° to 13°C.

The relation between size, or developmental stage, and offshore migration was investigated simultaneously (see section on growth patterns, below). Based on the ecological change that coincided with morphological or physiological changes, Kaeriyama (1986) and Irie (1985b, 1990) concluded that juveniles of 8–12 cm FL are in the process of offshore migration.

A decrease in abundance of food organisms appears to be the main cause of migration of juvenile chum salmon to offshore waters (Irie 1990). Kaeriyama (1986) identified two causes of offshore migration, as indicated previously, an active migration caused by the search for prey, and a passive migration arising from lack of food or escape from unsuitable environmental conditions such as high SST.

It became clear that juvenile chum salmon remained in coastal water masses with good food conditions and physiologically optimum SST and salinity, until they reached about 70–80 mm FL, when they were able to migrate offshore, avoiding high SST (over 12–13°C) and high salinity (over 34 pus). These results were used to propose an optimum size and time for release of juveniles to produce high survival during early sea life (Nogawa 1992).

While early life of juvenile chum salmon before their offshore migration had been clarified, the offshore migration routes to the North Pacific Ocean were not identified.

A national research project on anadromous salmon enhancement was conducted from 1977 to 1981. The project included a cooperative study between nearshore and offshore research groups to describe the migration patterns and growth of juvenile chum salmon originating from the Ishikari River on the Japan Sea side of Hokkaido. Four million chum salmon fry were marked by europium, one of the rare earth elements, and released in a tributary of the Ishikari River in April 1979 (Kato and Mayama 1980; Mayama et al. 1982).

The nearshore research group, including HSH, captured juvenile chum salmon with a purse seine and beach seine in the coastal area of Ishikari Bay, and also with stationary trap nets along the coasts of the northern Japan Sea, and Cape Soya (Mayama et al. 1982). Using the research vessel *Hokusei-maru* of Hokkaido University, the University and NRIFSF collected juvenile chum salmon in offshore waters of the Japan Sea and off the Okhotsk Sea coast (Mishima and Shimazaki 1980; Ito et al. 1980).

Europium was detected in scales and livers of juvenile chum salmon collected in the coastal waters along Hokkaido (Kato 1985). After leaving the natal waters around the river mouth of the Ishikari River, juveniles migrated northward along the Japan Sea coast, appeared on the east coast of Cape Soya, and were collected in offshore waters 8 to 16 km from the coast, from Abashiri Bay to the Shiretoko Peninsula, facing the Okhotsk Sea (Fig. 3) (Ito et al. 1980; Ito 1982; Kato and Mayama 1980, 1982; Kato and Kitaguchi 1981; Mayama et al. 1982; Kato 1985). The migration route of the marked juveniles was very similar to the path of the Tsushima and Soya Warm Current running along the northern part of Hokkaido. Mean fork length and body weight were 126 mm and 26.4 g, in the areas between Abashiri Bay and Shiretoko Peninsula in late June, and body weight was 10 times that of juveniles in Ishikari Bay.

General offshore migration patterns and distribution of juvenile chum salmon in coastal waters originating in Japan were reported by Irie (1985a, b, c, 1990).

Studies of Early Sea Mortality

Progressive hatchery technologies have led to a great increase in the stock size of Japanese chum salmon. Hatchery-reared chum salmon reach the sea within several days after release into rivers (Mayama et al. 1982; Kaeriyama 1986; Seki et al. 1997). During early sea life, mortality of juvenile chum salmon has been estimated to be high, but little is known about natural mortality of released juveniles in estuaries and coastal waters of Japan. This subject has received little discussion despite a marked increase in survival rate with favorable oceanic conditions, and a successful artificial enhancement program in Japan.

As shown in the following section, predation by fishes, seabirds and mammals has been considered a major factor in early sea mortality of juvenile Pacific salmon (Nagasawa 1998). Nevertheless, the physical environment, particularly salinity and water temperature in coastal waters, also affects the abundance of adult chum salmon. Mayama (1985) suggested that inadequate coastal water temperature and timing of fry release strongly influence the survival of Japanese hatchery-reared chum.

From experiments with marked juvenile chum salmon to determine the effect of release timings on return rate in the Pacific coast of Hokkaido, optimal timing for release was estimated as the later period when coastal water temperature exceeds 5°C (Seki and Shimizu 1996).

To investigate factors regulating abundance of hatchery-reared chum salmon, Fukuwaka and Suzuki (2000) examined survival, distribution, and nutritional condition of juveniles in the coastal waters of the Japan Sea off Honshu, the southern limit of chum salmon distribution in the western North Pacific. Survival during ocean life correlated negatively with the number of released juveniles and high coastal SST. When density of juveniles increased, the weight of their stomach contents decreased. These results indicated that chum salmon abundance affected prey availability, and a restricted nursery area intensified intraspecific competition of chum salmon juveniles for food resources. The coastal carrying capacity may regulate abundance of chum salmon along the Japan Sea coast of Honshu, where ocean survival is lower than on the Pacific side (Kaeriyama 1989).

Hayano et al. (1997) examined whether ocean survival was affected by abundance of potential prey organisms in shallow coastal waters of the northern Japan Sea, Hokkaido. Harpacticoid copepods, *Harpacticus* spp., an important prey of juvenile chum salmon, were predominant in 1991 and 1992, but were at a very low level in 1990 (Asami and Hirano 1993). Juvenile chum salmon released into the Shokanbetsu River during this investigation, returned after 2–5 years. Return rates of adults released as juveniles in 1990, 1991 and 1992 were 0.09%, 0.31% and 0.34% respectively (in 1992 only ages 2–4 years were used to estimate return rate, it being already high). Return rate in the 1990 class was lowest, prompting Hayano et al. (1997) to suggest that this may have been due to low density of harpacticoid copepods during the release of juvenile chum salmon.

Fukuwaka and Suzuki (2002) estimated early sea mortality rate during coastal life using large-scale mark-recapture experiments. To estimate daily mortality in early coastal life, they analyzed the data record of nine mark-recapture experiments. These marked fish were released from hatcheries in 1992–1997 into rivers flowing into the Japan Sea coast of Honshu. Estimated instantaneous mortality rates in coastal waters ranged from 0.033 to 0.268 day^{-1} in the 14–43 days after release. High mortality may therefore occur in a short period after release. Censuses of juvenile salmon abundance after their early sea life may be needed to assess the abundance of salmon entering the Pacific basin.

The objective of this study was to assess the usefulness of a mark-recapture model, assuming different sampling effort, for estimating the mortality rate of chum salmon during their early coastal life. Results indicated that large-scale mark-recapture experiments are useful for estimating mortality during early sea life, which is considered to be a critical period for Pacific salmon.

Few studies on the natural mortality of hatchery juveniles in estuaries and coastal waters have been carried out in Japan. We need to identify the survival mechanism of hatchery-reared chum salmon and factors reducing their survival in order to establish optimum management in coastal waters.

Studies of Predation

Juvenile chum salmon may be most vulnerable to predators when entering and adapting to the sea because of poor adjustment to the new habitat, osmoregulatory stress, low food availability and open shallow waters (Kawamura et al. 2000). White-spotted charr (*Salvelinus leucomaenis*) predation on juvenile chum salmon in coastal waters in southeastern Hokkaido was greatest immediately after the salmon were released from the hatchery, but low after about two weeks (Takami and Aoyama 1997). These results suggest that fish predation on juvenile chum salmon during the seaward migration from hatcheries may be significant in coastal waters near the river mouth. However, release of large hatchery-reared juveniles may reduce mortality from fish predation.

Generally speaking, predation is thought to be a major source of natural mortality of juvenile salmonids during their early sea life. Nagasawa and Kaeriyama (1995) provided the first review of predation by fishes and seabirds on Japanese chum salmon juveniles in their early ocean life. In this report, they recorded only four species of fishes as predators. Three years later, Nagasawa (1998) published a revised review on this predation by fishes and seabirds using additional new information (e.g. Nagasawa and Mayama 1997). Although over 90 fish species had been reported to occur with chum salmon juveniles, only nine were recorded as predators in river-mouths and at sea (Table 3). The author discussed the impact of predation by fishes on juvenile chum salmon, suggesting that fish predation might cause substantial loss of chum salmon juveniles in localities where

Table 3. Recorded predators of juvenile chum salmon in coastal and estuarine waters in Japan. (From Nagasawa 1998; based on various souces, and Kawamura et al. 2000).

Predators		Sources
Fishes		
Japanese dace	*Tribolodon hakonensis*	Nagasawa 1998
Far Eastern dace	*T. brandti*	„
White spotted charr	*Salvelinus leucomaenis*	„
Japanese halibut	*Paralichthys olivacaeus*	„
Japanese sea perch	*Lateolabrax japonicus*	„
Spiny dogfish	*Squalus acanthias*	„
Arabesque greenling	*Pleurogrammus azonus*	„
Pink salmon	*Oncorhynchus gorbuscha*	„
Masu salmon	*O. masou*	„
Seabirds		
Rhinoceros auklet	*Cerorhinca monocerata*	Nagasawa 1998
Black-tailed gull	*Larus crassirostris*	„
Slaty-backed gull	*L. schistisagus*	Kawamura et al. 2000
Japanese cormorant	*Phalacrocorax capillatus (P. filamentosus)*	„
Red-breasted merganser	*Mergus serrator*	„

these predatory fishes, especially Japanese dace (*Tribolodon hakonensis*) and arabesque greenling (*Pleurogrammus azonus*), were abundant. However, there has been no quantitative study on the impact of fish predation during the early ocean life of juvenile chum salmon in Japan.

There is, however, limited information about seabird predation on pelagic fish in coastal waters of Japan (Watanuki 1990). A review paper by Nagasawa (1998) indicated that rhinoceros auklets (*Cerorhinca monocerata*) and black-tailed gulls (*Larus crassirostris*) have been recorded as predators of juvenile chum salmon. These seabirds breed abundantly in northern Japan, and the impact of their predation on Japanese chum salmon populations may be significant.

Kawamura et al. (2000) also suggested that large numbers of seabirds present in inshore waters of their study area, the Japan Sea coast of Hokkaido, were a significant potential hazard to the survival of juvenile chum salmon during their seaward migration and early coastal life. They observed beak marks on the sides of juvenile chum salmon, and three species of seabirds feeding on juvenile chum salmon: slaty-backed gull (*Larus schistisagus*), black-tailed gull, and Japanese cormorant (*Phalacrocorax filamentosus*).

Furthermore, based on a census of seabirds and their feeding behavior on juvenile chum salmon around the same river mouth, Kawamura and Kudo (2001) estimated the loss of chum salmon juveniles by gulls at 11.1 % of the total fish released. Consumption may have been underestimated because of the restricted area of observations and the limited number of predator species examined. They concluded that predation by seabirds (gulls, cormorants, and red-breasted merganser, *Mergus serrator*, and possibly rhinoceros auklets) has more impact than predation by fish on survival of juvenile chum salmon during seaward migration and early coastal life. Thus five seabirds, and nine fish species, are regarded as major predators of juvenile chum salmon in estuarine and coastal waters of Japan (Table 3).

When considering the relation between the physical environment and risk of fish predation, Fukuwaka and Suzuki (1998) suggested that nearshore distribution of juvenile chum salmon minimized the overlap with oceanic predators, and the extension of the riverine plume may decrease the predation rate of juvenile chum salmon by marine predators.

There is yet little information about the impact of fish and seabird predation on chum salmon populations, and it should be emphasized that more field and experimental work is needed to assess it.

Studies of Salmonid Growth Patterns in Estuaries, Coastal Oceans and High Seas

In Japan, nearly 100% of juvenile chum salmon are reared in hatcheries and released into small rivers in spring. Until the early 1960s when feeding chum salmon fry with dry food was begun, fry migrated from hatchery ponds to streams as soon as the yolk sac was absorbed. As a result, juvenile chum salmon might arrive at the estuaries almost within 24 hours in small coastal rivers (Seki 1978a; Iwata and Komatsu 1984). Information on size of offshore migrants had not yet been obtained, except that from by-catches of juveniles (Sano and Kobayashi 1952, 1953; Mihara 1958).

The size of juvenile chum salmon stayed in estuaries and small harbors ranged from about 30 to 50 mm FL, and moved to coastal waters as they exceeded a certain size, 45–50 mm FL (Sano and Kobayashi 1952; Seki 1978a; Mayama et al. 1982, 1983; Terazaki et al. 1982; Kasahara 1985; Irie and Nakamura 1985; Kaeriyama 1986)

Growth of chum salmon juveniles originating in the Ishikari River System was traced using europium-marked fish in coastal waters from the Japan Sea side through the Okhotsk Sea side (Ito et al. 1980; Kato and Mayama 1980; Kato and Kitaguchi 1981; Ito 1982; Mayama et al. 1982, 1983; Kato 1985). In the coastal areas of Ishikari Bay, mean fork length and body weight were 43 mm and 0.6 g in early April, which was a little larger than those in the river. They grew to 64 mm and 2.1 g in early May (Kato 1985). Juvenile chum salmon were 60–80 mm FL and 2.5–4.0 g in body weight just before they disappeared from the Ishikari coast (Mayama et al. 1982, 1983). Europium-marked fish were 87 mm mean FL and 5.7 g mean weight off the coast of Cape Soya, northern Hokkaido, in mid-June. Juveniles around Cape Soya were much larger than those in the Japan Sea coastal areas during the same period. Mean fork length and mean weight were greatest, 126 mm and 26.4 g, in the areas between Abashiri Bay and the Shiretoko Peninsula of the Okhotsk Sea coast in late June. Thus, the body weight in Abashiri Bay-Shiretoko Peninsula was 10 times that of juvenile chum salmon in Ishikari Bay. These results on growth of juvenile chum salmon during offshore migration indicate that juveniles occupy different areas as they attain a larger size.

Many marked juvenile chum salmon have been released from hatcheries in Japan for various research programs. Growth patterns of juvenile salmon during early life can be estimated using data on size of juveniles recaptured in coastal waters. Specific growth rates (SGR) of juvenile chum salmon are exponential during early life, and are calculated for both body weight and fork length as follows: $SGR=(L_nSt-L_nSo)/t$ (LeBrasseur and Parker 1964), where t is days after release, St is the size at t days after release, and So is the size at release.

Almost all juvenile chum salmon released from hatcheries in Japan arrive at the estuary within a few days without growing in fresh water. The growth rates of juveniles recaptured in estuarine and coastal waters were therefore regarded as representative of growth during early sea life. Average specific growth rates of juvenile chum salmon vary from 0.0222 to 0.0631 in body weight, and 0.005 to 0.020 in fork length (Table 4). Higher values were noted in long distance migrants such as juveniles recaptured in areas between Abashiri Bay and the Shiretoko Peninsula of the Okhotsk Sea coast (Ito et al. 1980). Annual differences in SGR of juvenile chum salmon during coastal life were greater than differences at any one time in south-north geographical cline.

Swimming behavior of a school tends to become more active with size of juvenile chum salmon. Juveniles appear to feed on larger food organisms as they grow. Therefore, distribution patterns of juvenile chum salmon during early ocean life closely follow changes in body size or developmental stage.

During the 1980s, size and developmental stage at time of migration offshore were investigated simultaneously. Physiological, ecological and morphological changes in the developmental process of chum salmon during early life were studied by Kaeriyama (1986) and Irie (1990). Kaeriyama (1986) classified early life developmental stages of chum salmon into alevin (20–38 mm FL), fry (38–50 mm FL), pre-fingerling (50–80 mm FL), and post-fingerling (80–120 mm FL), the period from fry to fingerling comprising the juvenile stage. Irie (1990) also observed great changes in the inshore/offshore distribution of juvenile chum salmon among size classes of about 30–50 mm, 50–80 mm, 80–120 mm and larger than 120 mm FL. Early and later seaward migrating groups migrated offshore at the transition from juvenile to young (about 120 mm FL) and the post-fingerling stage (about 80 mm FL), respectively (Kaeriyama 1986, 1989). On the basis of ecological changes such as feeding habits, swimming behavior and distribution, which coincided with morphological or physiological changes, Irie (1990) considered that juveniles of 80–120 mm FL are in the process of migrating offshore.

Growth patterns of juvenile chum and pink salmon were examined using biological data collected by dip-net, gillnet, purse seine, and surface trawl in the Okhotsk Sea and the western North Pacific Ocean from July to February. During early summer, variation in fork length was relatively narrow, being only 80 to 130 mm. During mid-summer, fork lengths of most juvenile chum salmon caught off the Pacific coast of Hokkaido and off the Okhotsk coast of Iturup and Kunashiri islands ranged from 70 to 140 mm. In contrast, off the Pacific coasts of the Kunashiri and Iturup islands, both small sized (70–110 mm FL) and large sized juveniles (160–210 mm FL) were observed (Ueno and Ishida 1996). Large sized juvenile chum salmon were collected in coastal waters of Iturup Island in early August in 1990. The mean size was 187.3 mm FL and 62.5 g body weight. The mean number of circuli on the scales was 21.0, and the maximum radius of scales was 0.85 mm. The mean number of circuli on the scales indicated that the juveniles emerged between mid-December and mid-March, suggesting that they originated from rivers in Hokkaido or Honshu (Ueno et al. 1992). Fork lengths of juvenile chum salmon were about 200 mm

Table 4. Information on the specific growth rate (SGR) of marked juvenile chum salmon released from hatcheries during the early sea life in Japan.

Year	River system [*1]	Mean size at releasing		Recaptured juveniles			Specific growth rate (SGR) [*2]	Remarks	Source
		Fork length (mm)	Weight (g)	Number of fish	Weight (g) or Fork length (mm)	Days after release			
Growth rate in body weight									
1953	Ishikari R. (Ishikari, HK)	30.6[*3]	0.27	-	-	-	0.0421		Kobayashi 1977
1979	〃	40.0	0.58	11	1.46–3.61	65	0.0222		Kato & Mayama 1982
〃	〃	〃	〃	10	2.64–4.48	66–73	0.0260		〃
〃	〃	〃	〃	9	4.42–6.99	68–74	0.0325		〃
〃	〃	38.3	0.54	29	0.87–8.40	44–50	0.0382		Ito et al. 1980
〃	〃	〃	〃	11	0.87–4.94	63–69	0.0368		Ito 1982
〃	〃	〃	〃	3	28.69–36.93	64–66	0.0631		Ito et al. 1980
1980	Saroma Lake (Abashiri, HK)	-	1.46-4.49	31	1.43–8.12	19–33	0.0464		Ito 1982
1965	Yurappu R. (Oshima, HK)	36.2-40.1	0.44-0.65	21	1.05–5.00	26–58	0.0392		Kobayashi & Abe 1977
1982	Katagai R. (Toyama, HS)	44	0.7	24	0.9–4.2	30–60	0.0467	"Small" fish at release in late Feburary	TPFES[*4] 1984
〃	〃	52	1.2	113	1.3–4.8	15–40	0.0509	"Large" fish at release in mid-March	〃
Growth rate in fork length									
1979	Ishikari R. (Ishikari, HK)	40.0	0.58	11	57–74	65	0.0083		Mayama et al. 1982
〃	〃	〃	〃	10	66–80	66–73	0.0090		〃
〃	〃	〃	〃	9	81–94	68–74	0.0111		〃
〃	〃	38.3	0.54	29	48–99	44–50	0.0133		Ito et al. 1980
〃	〃	〃	〃	3	137–139	64–66	0.0200		〃
1981	Oh R. (Miyagi, HS)	47	-	47	65–95	23–68	0.0116	Seaward migrants in later spring (May)	Kaeriyama 1986
1982	〃	48	-	10	50–120	14–80	0.0104	Seaward migrants in early spring (Feb-Mar)	〃
1982	〃	49	-	10	85–110	49–59	0.0113	Seaward migrants in later spring (April)	〃
1983	Kitakami R. (Miyagi, HS)	53	-	20	62–99	10–39	0.0118	Offshore migrating group (pelagic item feeder)	〃
1983	〃	53	-	26	52–93	12–49	0.0107	Neritic staying group (coastal item feeder)	〃
1983	〃	53	-	3	58–66	17–45	0.0050	Inshore group (insect feeder)	〃
1994	Akaishi R. (Aomori, HS)	44.6	0.9	15	62–90	1–36	0.0086		HSH [*5] 1995
〃	〃	52.5	1.5	19	44–79	1–44	0.0080		〃
1995	〃	50.2	1.4	17	45–66	1–22	0.0086		HSH 1996
1996	〃	46.0	0.7	10	42–70	0–40	0.0090		HSH 1997
1997	〃	59.5	2.1	37	55–112	0–35	0.0136		NSRC[*6] 1998
〃	〃	48.4	1.0	52	41–96	9–40	0.0161		〃
1998	〃	66.6	3.1	36	60–88	18–27	0.0074		NSRC 1999
〃	〃	48.9	1.1	28	55–74	18–27	0.0135		〃
1999	〃	51.8	1.3	54	51–79	16–32	0.0099		NSRC 2000
2000	〃	54.6	1.5	11	56–75	27–31	0.0056		NSRC 2001
1994	Kawabukuro R. (Akita, HS)	44.6	0.9	15	62–90	1–36	0.0086		HSH 1995
1994	Fukura Bay (Yamagata, HS)	73.8	3.2	12	66.2–98.8	11–28	0.0068		HSH 1995
1984	Miomote R. (Niigata, HS)	55.0	1.5	111	42.1–76.6	6–23	0.0136		Ishikawa et al. 1993

continue…

Table 4. continued.

Year	River system [*1]	Mean size at releasing		Recaptured juveniles			Specific growth rate (SGR) [*2]	Remarks	Source
		Fork length (mm)	Weight (g)	Number of fish	Weight (g) or Fork length (mm)	Days after release			
1992	Miomote R. (Niigata, HS)	50.1	1.6	104	-	4–25	0.0165		Ishikawa et al. 1993
1994	〃	46.5	1.0	501	38.1–81.6	0–43	0.0126		HSH 1995
1996	〃	55.8	1.1	22	50–91	5–36	0.0083		〃
1997	Hime R. (Niigata, HS)	52.4	1.1	70	49–92	10–41	0.0082		NSRC 1998
1995	Shou R. (Toyama, HS)	57.4	1.7	103	47–85	1–26	0.0101		HSH 1996
1996	〃	52.5	1.4	142	46–86	1–30	0.0111		HSH 1997
1994	Tedori R. (Ishikawa, HS)	66.1	2.3	18	75.2–101.2	24–42	0.0100		HSH 1995
1995	〃	69.3	2.8	60	73–115	24–52	0.0062		HSH 1996
〃	〃	61.8	1.9	21	70–100	26–49	0.0094		〃
1996	〃	70.0	2.2	43	67–123	29–52	0.0101		HSH 1997
〃	〃	63.7	2.8	47	75–121	16–53	0.0113		〃
1997	〃	63.3	2.0	15	82–114	19–37	0.0142		NSRC 1998
1998	〃	74.1	3.5	12	76–116	30–43	0.0135		NSRC 1999
〃	〃	79.7	4.2	134	58–104	3–32	0.0068		〃
1999	〃	62.2	2.0	51	67–120	6–36	0.0157		NSRC 2000
〃	〃	73.9	3.1	65	83–128	20–43	0.0104		〃
〃	〃	64.7	2.2	25	73–126	16–50	0.0128		〃
2000	〃	71.5	3.0	27	74–101	19–42	0.0055		NSRC 2001
〃	〃	58.6	1.6	11	72–102	25–51	0.0087		〃

*1: HK and HS in parentheses mean Hokkaido and Honshu, respectively.
*2: SGR = (LnSt-LnSo)/t, ST: size at recapture, So: size at release from hatchery, t: day after release.
*3: body length.
*4: Toyama Prefectural Fisheries Experimental Station.
*5: Hokkaido Salmon Hatchery.
*6: National Salmon Resources Center.

in September in the Okhotsk Sea, and then gradually increased to about 230 mm in the western North Pacific Ocean by February. Pink salmon grew faster than chum salmon (Fig. 4).

Growth and nutritional conditions of juvenile chum and pink salmon migrating to the Okhotsk Sea and the North Pacific Ocean were examined using biochemical indices such as protein contents, the RNA-DNA ratio, and percentage of triglyceride in dorsal muscle as well as biological data such as fork length, body weight, and condition factor. Both chum and pink salmon exhibited good growth, especially chum salmon captured in late August to early September, judging from the protein content and the RNA-DNA ratio. The relationships of RNA-DNA ratios and triglyceride contents suggested different strategies for survival between the two species. Chum salmon showed higher growth rates and less energy storage in earlier stages, but decreased growth rate and increased energy storage as growth progressed. Pink salmon had both low energy and low growth rates at first, but both these gradually increased as growth progressed (Azuma 1996).

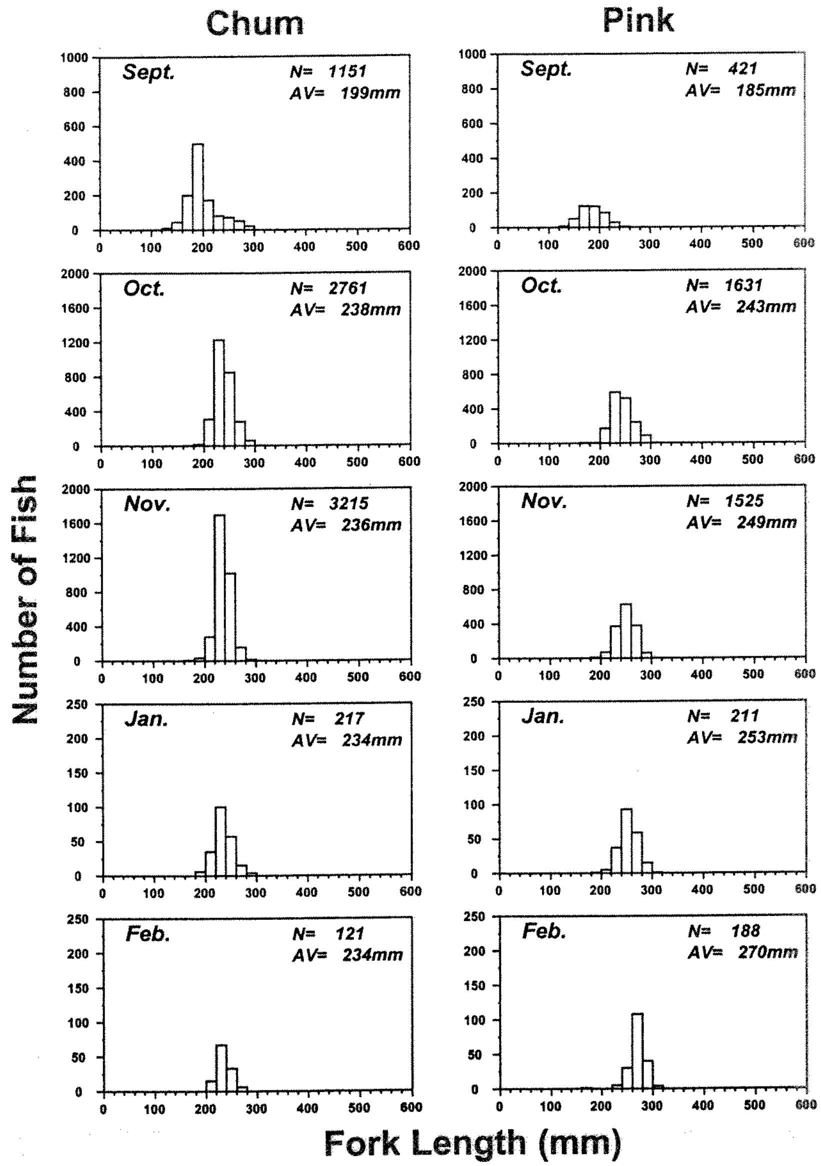
Studies of Hatchery versus Wild Fish Interactions

Until about 1900 when large scale salmon hatcheries were introduced, chum salmon stocks in Japan were maintained by wild populations. However, recent chum salmon resources have been entirely supported by artificial reproduction. Since little research on salmon was done before the advent of hatcheries, we have no studies on the interactions between hatchery and wild fish in Japan.

High Seas Work

Juvenile chum salmon originating in Japan migrate along the coast of Honshu and Hokkaido during early summer. However, their offshore migration routes to the North Pacific Ocean were not identified.

Fig. 4. Seasonal changes in fork length of juvenile chum and pink salmon caught by research vessels from 1988–1996. (Data from Ueno and Ishida 1996; Ueno 1998).



To investigate the offshore migration routes of juvenile chum salmon, Japan-Russia cooperative juvenile salmon surveys were conducted in the Okhotsk Sea and the western North Pacific Ocean, using a purse seine, dip-nets, drift gillnet and a surface trawl, from early summer to winter in 1988–1996 (Ueno and Ishida 1996; Ueno 1998). The results indicated that juvenile chum salmon mainly occurred in the southern and central waters of the Okhotsk Sea from summer to mid-autumn. Then they migrated out from the Okhotsk Sea to the waters off the Kuril Islands in the western North Pacific in late autumn. In winter they were distributed in the western North Pacific Ocean (Fig. 5). Pink salmon juveniles appear to have similar migration patterns (Fig. 6). Migrating chum and pink salmon juveniles were mainly concentrated in waters with surface temperatures higher than 10°C in August, but shifted to waters with lower temperature, from 5° to 10°C, during September to February (Fig. 7).

A trawl and acoustic survey of salmon juveniles was conducted in the Okhotsk Sea and Pacific Ocean off the Kuril Islands in October and November of 1996. The echoes from juveniles were weak, about –32dB to –43dB, but salmon juveniles were detected. Ninety percent of detected fish were in the zone shallower than 40 m, and 2.8 percent were detected in water deeper than 70 m, where the temperature was 1° to 4°C (Sakai and Ueno 1998). Juvenile chum salmon were concentrated in a limited area of the Okhotsk Sea; abundance was estimated at 60–100 million fish in 1993, and 200–334 million fish in 1996 (Ueno 1998).

Fig. 5. Seasonal changes in distribution of juvenile chum salmon caught by research vessels from 1988–1996. "X" indicates no catch; size of circle indicates abundance of juvenile salmon caught by purse seine, surface trawl, dip net, and drift net. (Data from Ueno and Ishida 1996; Ueno 1998).

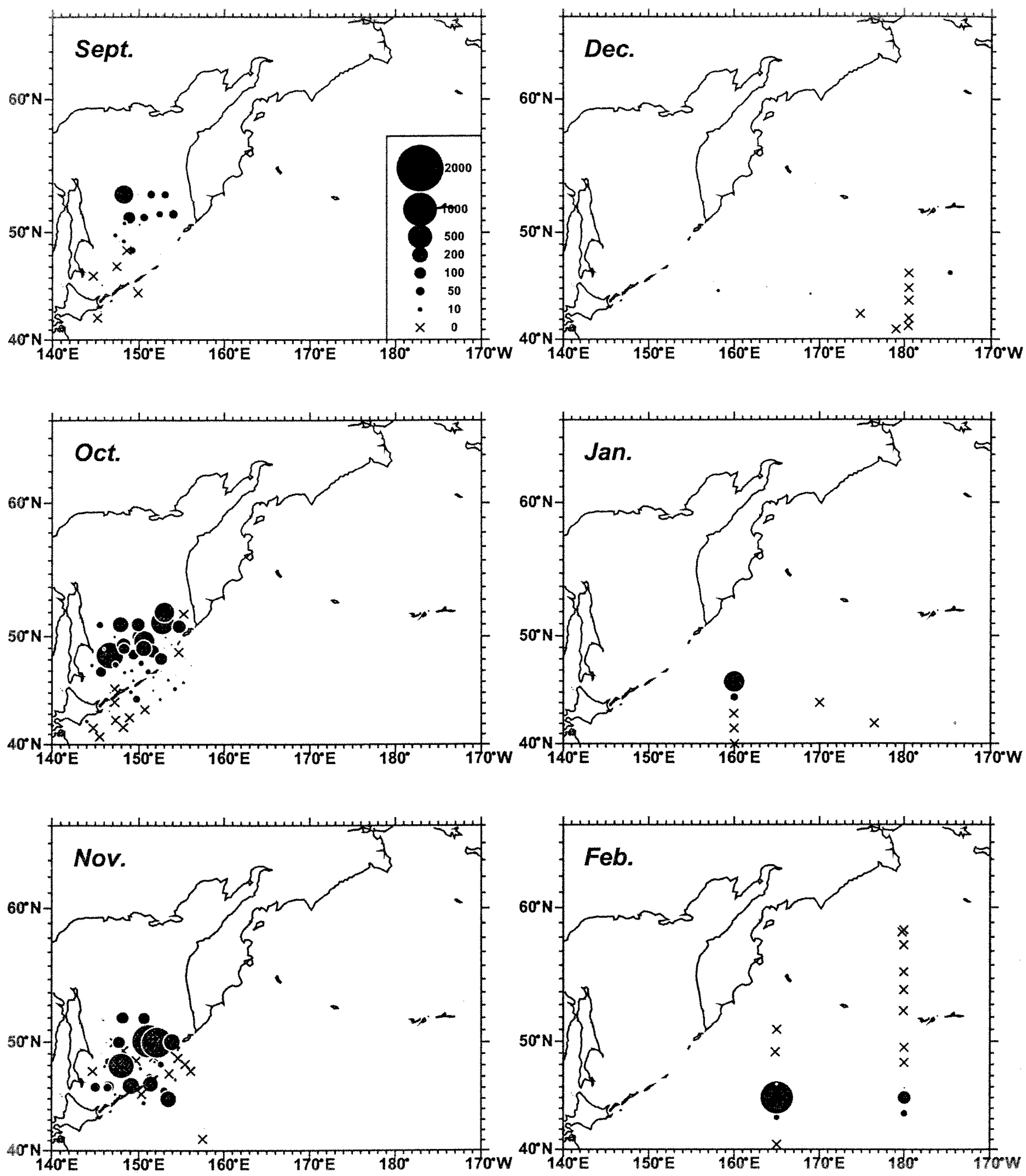


Fig. 6. Seasonal changes in distribution of juvenile pink salmon caught by research vessels from 1988–1996. "X" indicates no catch; size of circle indicates abundance of juvenile salmon caught by purse seine, surface trawl, dip net, and drift net. (Data from Ueno and Ishida 1996; Ueno 1998).

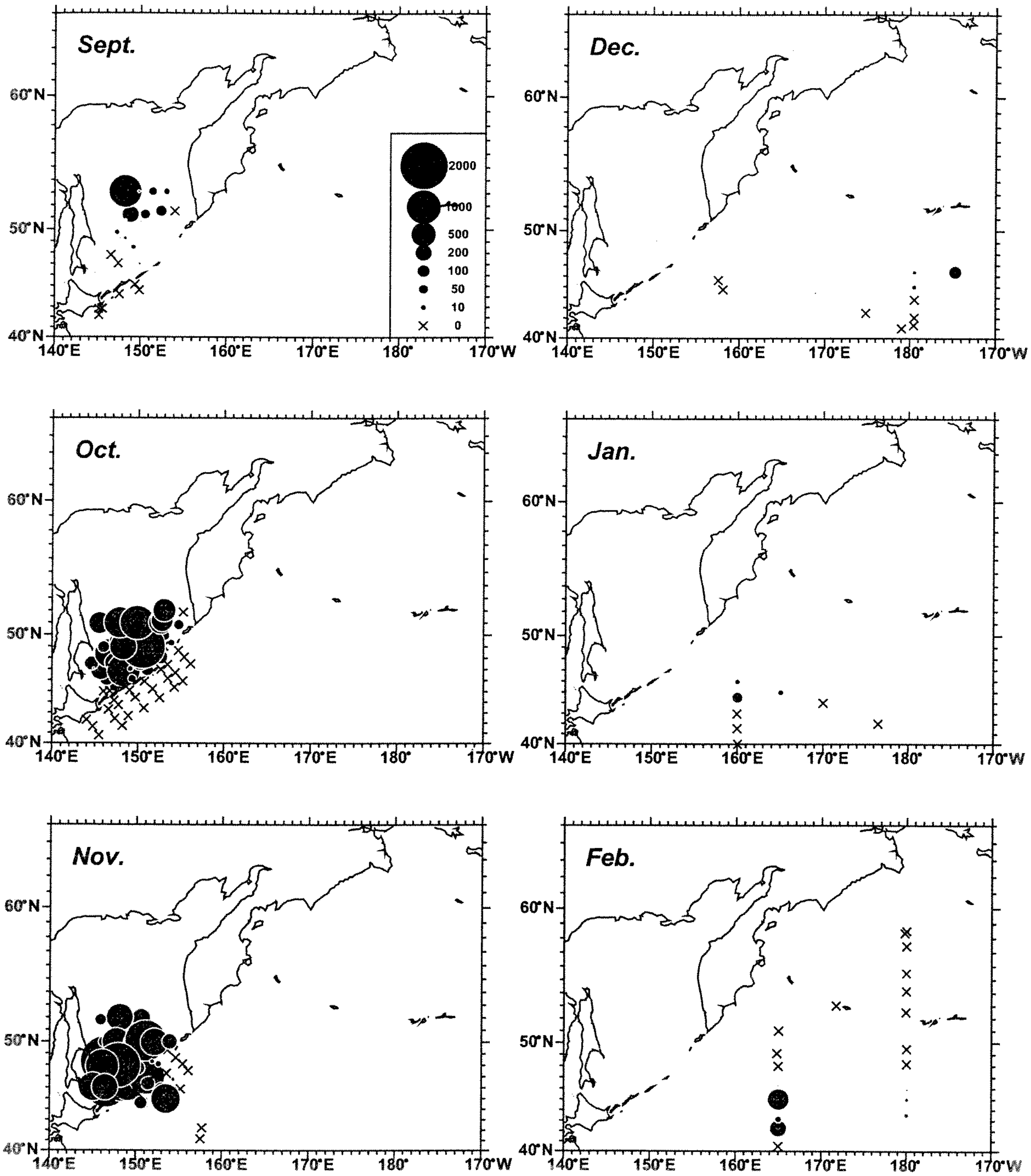
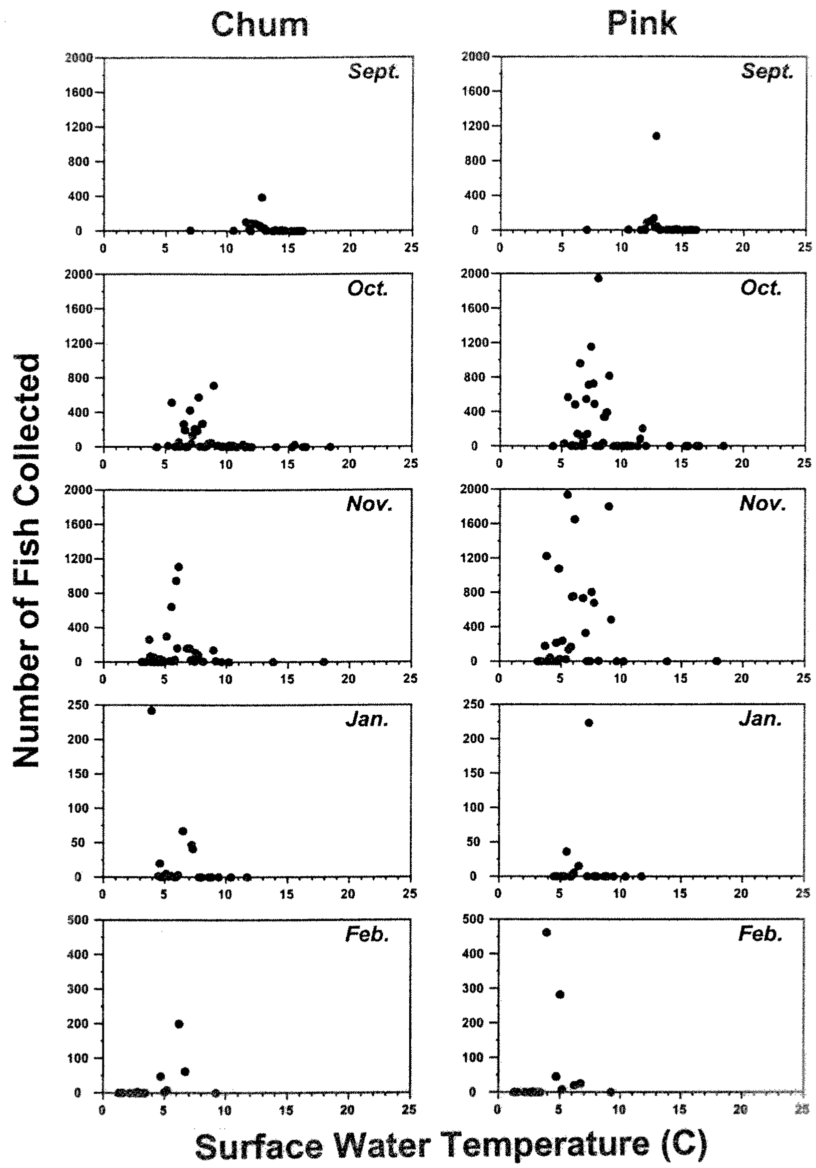


Fig. 7. Seasonal changes in surface water temperature and number of juvenile chum and pink salmon caught by research vessels from 1988–1996. (Data from Ueno and Ishida 1996; Ueno 1998).



To investigate trophic relations and feeding habits of juvenile salmon and other major pelagic fishes, the stomach contents of juvenile pink, chum, masu, sockeye (*O. nerka*), chinook (*O. tshawytscha*), and coho salmon (*O. kisutch*), Atka mackerel (*P. monopterygius*), and Arabesque greenling were examined from collections taken in the Okhotsk Sea and Pacific waters off the Kuril Islands during autumn of 1993 (Tamura et al. 1999). The major prey of pink, chum, and sockeye salmon were planktonic Amphipoda, *Themisto* sp. and *Primno* sp. Chum and pink salmon also fed on a variety of invertebrates such as Gastropoda, Copepoda, Euphausiacea, and *Saggita* spp. Masu, chinook, and coho salmon mainly fed on Cephalopoda and fishes (Table 5). Prey species (diet niche) overlap was highest between pink and chum salmon, which were the most abundant species in these waters. Prey species composition in their stomach contents is considered to reflect planktonic species composition in the environment.

Stock origins of juvenile chum salmon in the Okhotsk Sea were identified by morphological characters such as pyloric caeca counts and by genetic characters such as allele frequencies (Ueno et al. 1998). The results indicated that juvenile chum salmon from southern stocks such as Japan, Sakhalin, and Primorye migrated northwards through the southern part of the Okhotsk Sea in July and were distributed in the central part of the Okhotsk Sea in August and September. In October and November, they migrated southwards to the central and southern part of the Okhotsk Sea and moved to the North Pacific Ocean through the straits of the northern and central Kuril Islands. Northern Russian stocks such as

Table 5. Information on the stomach contents of age .0 Pacific salmon sampled in the southern Okhotsk Sea and the Pacific coast waters off Kuril Islands during October and November 1993.

Species	Number examined	Fork length (mm)	Percentage composition by weight									Source
			Fishes	Sagittas	Squids	Pteropods	Insects	Decapods	Euphausiids	Amphi-pods	Copepods	
Pink	637	180-340	1.2	11.4	0.8	6.2	+	6.1	14.5	59.5	0.5	Tamura et al. 1999
Chum	424	160-300	2.2	21.6	0.7	4.8	+	0.5	16.1	52.6	1.4	Tamura et al. 1999
Sockeye	33	220-290		36.3	3.4	0.1		0.1	7.1	52.6	0.5	Tamura et al. 1999
Masu	25	250-400	95.3						3.5	1.2		Tamura et al. 1999
Chinook	17	270-350	25.2	0.1	72.4	0.0		0.4		1.9		Tamura et al. 1999
Coho	14	220-340			99.5					0.5		Tamura et al. 1999

Magadan and western Kamchatka were distributed in the northern and eastern part of the Okhotsk Sea, and followed the southern stocks (Ueno et al. 1998). Among juvenile chum salmon (age 0.0) caught in the Okhotsk Sea, the Japanese regional stock was predominant (71%) in October, but its contribution to the sample decreased to 36% in November. Juvenile chum salmon migrating to Pacific waters east of the Kuril Islands in November were composed of 57% Japanese, 30% Russian and 13% Alaskan stocks. Young chum salmon (age 0.1) caught in winter in the western North Pacific Ocean consisted of 29% Japanese, 65% Russian and 6% Alaskan stocks in January, and 37% Japanese, 45% Russian and 18% North American stocks in February (Urawa et al. 1998).

Twenty-four species of fishes and two squid species were identified in the southern Okhotsk Sea and western North Pacific Ocean off Kurill Island in October and November 1993 during juvenile salmon surveys. Juvenile salmonids (*Oncorhynchus* spp.) were the most abundant, followed by myctophids, juvenile Arabesque greenling, and gonatids including boreopacific gonate squid (*Gonatopsis borealis*) and probably schoolmaster gonate squid (*Berryteuthis magister*). Deep-sea smelts (*Leuroglossus schmidti*) were also abundant. Juvenile Arabesque greenling were abundantly taken in the Okhotsk Sea in October but disappeared from its surface waters in November probably because they settled onto the continental shelf. There were marked differences in the oceanic distributions of Arabesque greenling and Atka mackerel, suggesting that these species segregate their habitats. Deep-sea smelts mostly occurred in the Okhotsk Sea, but myctophids were caught only in the North Pacific Ocean. Nagasawa et al. (1995) suggested that the surface layer of the southern Okhotsk Sea provides favorable habitats for the feeding and growth of juvenile fishes such as salmonids and Arabesque greenling from summer to mid-autumn, but ends its role in late autumn when sea surface temperatures decrease and those juveniles leave.

Juvenile salmon studies suggest that the Okhotsk Sea is an important nursery ground for juvenile salmon originating from Russia and Japan.

FUTURE ISSUES AND QUESTIONS

Four future issues for juvenile salmon studies are identified.

1) Assessment of juvenile salmon abundance. Are there reliable methods for assessing the change in abundance of juvenile salmon?
2) Stock identification and estimation of stock composition of juvenile salmon by genetic methods and otolith thermal marks. Where and when do juveniles of Japanese stocks mix with Russian stocks? Do these stocks affect survival and growth of each other?
3) Investigation of factors affecting survival and abundance of juvenile salmon during their early ocean life. What are the main factors affecting survival and abundance of juvenile chum salmon released into rivers in Japan?
4) The life history of other salmon species, such as pink, masu and sockeye salmon, should also be studied in order to improve salmon management in Japan.

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