

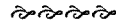
Movements, Food and Predators of Juvenile Chum Salmon (*Oncorhynchus keta*) Entering the Coastal Sea of Japan off Northern Hokkaido in Warm and Cool Years

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Abstract: The coastal ecology of juvenile chum salmon (*Oncorhynchus keta*) was studied in the Sea of Japan off Mashike in northern Hokkaido, Japan, from March to June 1995–1998. Spring surface seawater temperatures (SSTs) were consistently higher than the 10-year average in 1995 and 1998 (SST-H years), and consistently lower in 1996 and 1997 (SST-L years). Peak catch rates of juvenile chum salmon occurred within 500 m from shore in May when the juveniles were approximately 70 mm and 3 g in size. Mean fork length and body weight increased faster during SST-H years than SST-L years even though stomach fullness was lower in SST-H years. Stomach contents were primarily fish larvae, sand lance, and terrestrial insects during SST-H years, and neritic and oceanic zooplankton during SST-L years. Predation by juvenile masu salmon (*O. masou*) on juvenile chum salmon was the only observed occurrence of fish predation not thought to be associated with net feeding. Beak scars and feeding on juvenile chum salmon by seabirds were observed. We concluded that seabirds were the primary predators of juvenile chum salmon during early marine life, and their predation is likely to be higher in SST-H years than SST-L years.

INTRODUCTION

Chum salmon (*Oncorhynchus keta*) stocks in Japan have been increasing in abundance since the 1970s, but the stocks in the Sea of Japan off Hokkaido have been lower than those in the Sea of Okhotsk and the Pacific Ocean off Hokkaido (Kaeriyama 1989). Reasons for this may be the Tsushima warm current, predation, and competition for prey (Kaeriyama 1989; Kawamura et al. 1998). Juvenile fat greenling (*Hexagrammos otakii*) is a potential competitor for prey in the coastal waters of the Sea of Japan (Kawamura et al. 1998). Except for the Ishikari and Suttu Bays, the coast along the Sea of Japan has a simple shoreline and very few estuaries. We call the waters off this shoreline open coastal waters. Estuaries are thought to be important areas for juvenile chum salmon to grow while avoiding predators (Percy 1992). Early marine life of juvenile chum salmon has been studied in inshore waters of the east and west sides of the Pacific Ocean, but most surveys

have been limited to estuarine and marsh nursery grounds (Kaczynski et al. 1973; Mason 1974; Healey 1979; Congleton et al. 1981; Bax 1982; Kaeriyama 1986; Murphy et al. 1988; Percy et al. 1989; Irie 1990). Little is known about the early marine life of juvenile chum salmon inhabiting open coastal waters in the Sea of Japan (Kawamura et al. 1998). To examine the relationship between survival of juvenile chum salmon and environmental factors in open coastal waters, we studied the early marine ecology of juvenile chum salmon, annual variations in environmental factors, and predation in open coastal waters in the Sea of Japan off northern Hokkaido, Japan.

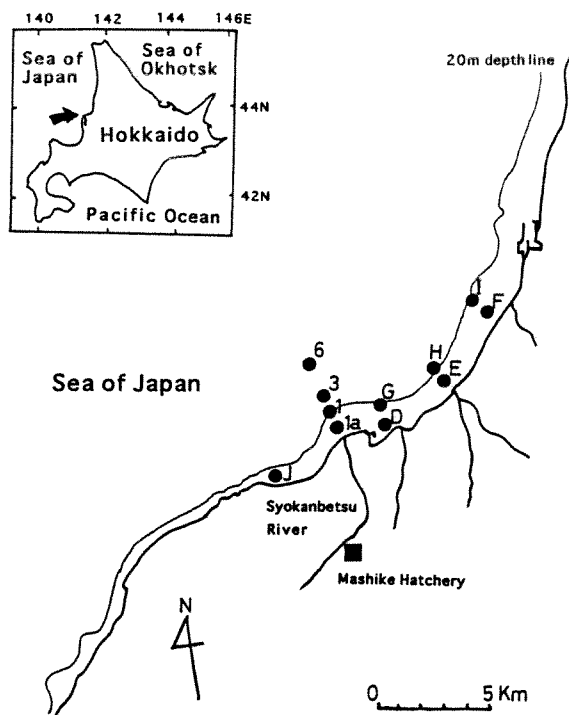
MATERIALS AND METHODS

Sampling Sites and Gear

We sampled at eleven stations in inshore waters off Mashike in the Sea of Japan off Hokkaido from 1995 to 1998 (Fig. 1). The survey was carried out

six to nine times from mid-May to mid-June, 1995 to 1998. We captured juvenile salmon inhabiting the layer between the surface and two meters depth with a Sayori net towed at a speed of approximately two knots for thirty minutes at seven to ten stations each sampling period. The Sayori townet had a mouth opening eight meters wide and five meters deep. The net was eighteen meters long with wing nets seven meters either side, and towed by two fishing boats. Thirteen million juvenile chum salmon are released in the Syokanbetsu River from the Mashike Branch of Hokkaido Fish Hatchery from early April to mid-April every year (Fig.1). The juveniles weighed about one gram and were about fifty millimeters in fork length. We defined CPUE as numbers of fish caught per 30-min. tow with the Sayori townet.

Fig. 1. Map showing the sampling sites in waters off Mashike in the Sea of Japan off northern Hokkaido, Japan. Near shore sampling stations (1a, D, E, F and J) within 500 m of the shore. Stations 1, 3, 6, G, H and I are coastal water sites.



Environmental Factors

We have obtained seawater temperature data from the water supply of the abalone culture center of Mashike fishermen's association since 1985. The water is pumped from seven meters depth near sampling station D (St. D) (Fig.1). We also measured the seawater temperature and salinity with a sensor attached to the bottom of the mouth of the Sayori townet. Salinity, seawater temperature and transparency were measured at stations 1, 3, 6, D and E.

Stomach Content and Growth Analysis

Sampled fish were fixed in five percent neutral formalin for seven hours and then transferred to seventy percent ethanol. In the laboratory, we measured fork length (FL) to 0.1 mm, body weight (BW) to 1 mg, stomach content weight (SCW) to 1 mg, and calculated stomach fullness (SF) as a percentage body weight:

$$SF = ((SCW)/(BW-SCW)) \cdot 100$$

Prey items in stomachs were counted and identified to species whenever possible. Specific growth rate (SGR) of juvenile chum salmon was calculated in body weight and fork length as follows;

$$SGR = \text{Ln}(Wt_2 - Wt_1) / (t_2 - t_1) \cdot 100$$

where Wt_1 and Wt_2 are mean body weight at day t_1 and t_2 , respectively. For SGR in fork length, we multiplied by 1000 rather than 100.

Predators

Fish

To examine stomach contents, we captured some carnivorous fish with gill nets set in inshore waters, 400 m (9.8 m depth) and 800 m (11.2 m depth) from shore near the Syokanbetsu River mouth during seaward migration and early marine life of chum salmon juveniles, early April to late April, 1997 (Fig. 1). Two hundred and seventy-eight arabesque greenling (*Pleurogrammus azonus*), six Masu salmon (*O. masou*) and 96 long shanny (*Stichaeus grigorjewi*) were captured. In 1999, we examined 72 stomachs of arabesque greenling captured by a small set net located in northern inshore waters 90 km from Mashike in early June. We also examined 20 stomachs of juvenile masu salmon caught by the Sayori townet in 1996 and 1998.

Seabirds

To examine the fluctuations in abundance of seabirds and to determine their predation on juvenile chum salmon, we established an observation station near the Syokanbetsu River mouth. We counted seabirds and observed their feeding behaviour with binoculars from 10 a.m. to 6 p.m. several times every ten days, from early February to late June in 1999. We used the highest count each ten days as a measure of abundance of seabirds. To compare the timing of seabird's migration among years, we recorded the first sightings of rhinoceros auklet (*Cerorhinca monocerata*) from a fishing boat during the Sayori townet surveys, 1995 to 1998, as an index of avian fish predators.

RESULTS

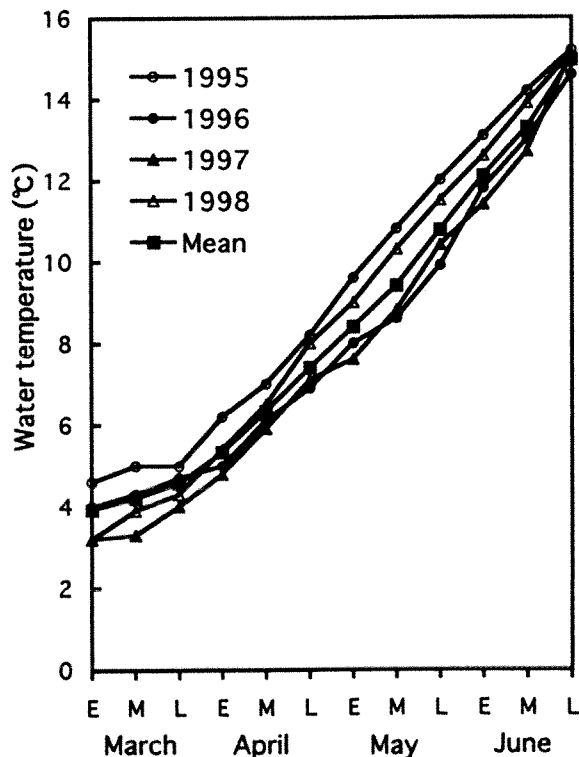
Environmental Factors

Surface seawater temperatures from early March to late June in 1995 and 1998 were higher (high temperature years) and those during the same months in 1996 and 1997 were lower (low temperature years) than the mean seawater temperature over ten years from 1985–1994 (Fig. 2). The difference in surface seawater temperatures between high temperature years and low temperature years was more than 2°C in mid-May. The fluctuations in salinity ranged from 26‰ to 34‰ with no trend. Transparency ranged from 4 meters to 22 meters one kilometer offshore, also with no trend.

Seaward Distribution and Critical Size

We captured fourteen species of fish including two unidentified fish larvae from mid-March to late June, 1995 to 1998. Chum salmon juveniles were numerically predominant, followed by juvenile fat greenling. Also, threespine stickleback (*Gasterosteus aculeatus*), Japanese needlefish (*Hemiramphus sajori*), surf smelt (*Hypomesus pretiosus*), juvenile masu salmon, and juvenile and larval pacific sand

Fig. 2. Seawater temperatures (7 m depth) off the coast of Mashike during the period from March to June, 1995 to 1998. Mean is the average over 10 years from 1985 to 1994. The high temperature years 1995 and 1998, and low temperature years 1996 and 1997 are shown separately. E, early; M, mid; L, late.



lance (*Ammodytes personatus*) were abundant in inshore waters. The other species, walleye pollock (*Theragra chalcogramma*) larvae, Japanese anchovy (*Engraulis japonica*), needlefish (*Strongylura anastomella*), Temminck's surfperch (*Ditrema temmincki*), and adult Japanese icefish (*Salangichthys microdon*) were caught in low numbers from late April to late June. Jelly fish (*Aurelia aurita* and *Beroe cucumis*) were more abundant in 1996 and 1997 than in 1995 and 1998.

Juvenile chum salmon were distributed similarly in all four years of the study (Fig. 3). Juvenile chum salmon inshore waters were distributed in two groups, near shore and in coastal waters. The near shore group, within 500 meters of the shore, had one peak CPUE in May, when a large number of juveniles was present, but exhibited low CPUEs in April during sea entry. The coastal waters group was captured more than one kilometer from shore and showed two peaks in CPUE, except in 1997, the first in April, and the second in late May to early June. The timing of the first peak coincided with the dispersal of juvenile chum salmon during sea entry, and the second was composed of juveniles migrating offshore. The coastal waters group was less abundant than the near shore group. In high temperature years, juvenile chum salmon migrated offshore earlier, from late May to early June, than in low temperature years (early June to mid-June in 1996).

Mean fork length of the near shore group decreased from late May to early June in 1995 and 1998 (Fig. 4) as larger individuals moved away. The timing of peaks in mean fork length was different among years; the peaks in high temperature years were earlier than in low temperature years. However, mean fork length at the peaks was similar among years, being 73 ± 0.9 mm (mean \pm SD), ($n = 1046$) in 1995, 78.2 ± 3.9 mm (6) in 1996, 74.9 ± 5.0 mm (232) in 1997, and 74.3 ± 7.1 mm (3270) in 1998. Except for a few juveniles in 1996, maximum fork length of the near shore group ranged from 73 mm to 74.9 mm. Similarly maximum mean body weight ranged from 3.2 g to 3.6 g. Mean fork length in the coastal waters group was larger (< 80 mm) after late May than the near shore group in 1995 and 1996.

The distribution of juvenile fat greenling < 60 mm in fork length was similar to that of juvenile chum salmon. Juvenile fat greenling from near shore stations was distributed similarly to the near shore group of juvenile chum salmon, with one peak of CPUE from mid-April to early May (Fig. 3). The juvenile fat greenling had moved from pelagic to demersal waters by mid-May.

Juvenile masu salmon showed a different distribution from chum salmon and fat greenling juveniles. Juvenile masu salmon were similarly distributed in both near shore and coastal stations (Fig. 3), but the

Fig. 3. CPUE of chum salmon, fat greenling and masu salmon juveniles caught at near shore or coastal water stations. Index of CPUE shows the average value per one net tow plus one. E, early; M, mid; L, late.

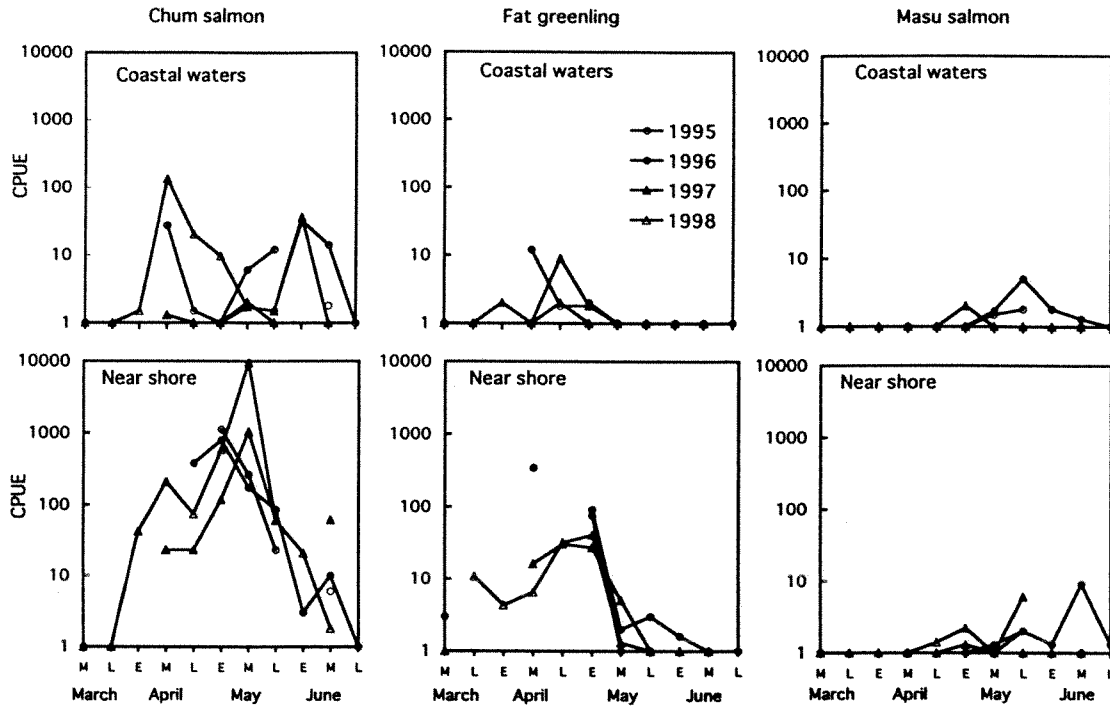
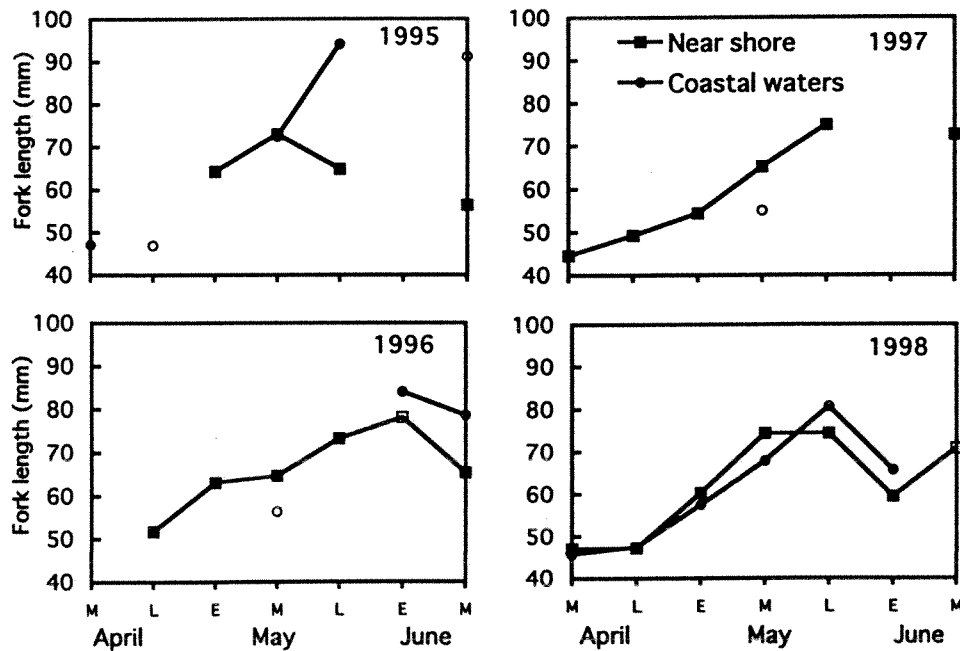


Fig. 4. Mean fork length of juvenile chum salmon caught at near shore or coastal water stations from mid-April to mid-June, 1995 to 1998. Sample sizes: near shore juveniles, 3–4116 fish; coastal waters, 1–261 fish. Open symbols indicate less than ten fish. E, early; M, mid; L, late.



juveniles entered the sea one month later than juvenile chum salmon. Masu salmon juveniles had one peak of CPUE from May to mid-June.

Prey Quantity and Growth

Stomach fullness of juvenile chum salmon was below 1% for a short time after sea entry, but it increased hereafter (Fig. 5). There was a difference in time and magnitude at the peak of stomach fullness between high temperature years and low temperature years. Though high temperature years had lower levels and unclear peak in stomach fullness in May and June, low temperature years showed a high peak in stomach fullness on late April or early May. Juvenile chum salmon of the near shore and coastal waters groups showed similar fluctuations in stomach fullness.

The stomach content composition of juvenile chum salmon captured in May showed differences between high temperature years and low temperature years. In high temperature years, stomach content composition were mainly composed of fish larvae, sand lance and terrestrial insects, but those in low temperature years consisted of neritic and oceanic zooplankton, *T. discaudatus*, *Oikopleura* spp, *Neocalanus plumchrus*, *Eucalanus bungii bungii* and *Pseudocalanus newmani*. On the other hand, epibenthic organisms, harpacticoid copepods were frequently found in the stomach of the juveniles for a short time after sea entry.

Growth of juvenile chum salmon was higher in high temperature years than in low temperature years (Fig. 6). Comparing the SGR in fork length and body

weight from late April to mid-May, SGR in high temperature years also showed higher levels (0.016 and 0.023 in fork length, 0.054 and 0.077 in body weight) than low temperature years (0.009 and 0.015, 0.030 and 0.053).

Predators

Fish

We examined the stomach contents of adults of three species, arabesque greenling, long shanny and masu salmon, and juvenile masu salmon from early April to early June, when juvenile chum salmon were abundantly distributed in inshore waters. Few juvenile chum salmon ($n = 10$) were found in the stomachs of adult Arabesque greenling ($n = 72$) caught by a small set net in early June. As the juvenile chum salmon ingested were undigested relative to other stomach prey, we concluded that arabesque greenling attacked the juvenile chum salmon while they were in the set net. The diet of arabesque greenling ($n = 278$) caught by a gill net near the Syokanbetsu river mouth, in contrast to that of arabesque greenling caught in the set net, was composed of euphausiids (*Thysanoessa inermis*) only.

Juvenile masu salmon ($n = 20$) captured with a Sayori townet ate few chum salmon juveniles from late April to early June. Smaller juvenile chum salmon, less than 50 mm in fork length, were eaten by three of 20 masu salmon juveniles. Adult masu salmon ($n = 6$) caught by gill net near the river mouth in early April fed only on euphausiids.

Fig. 5. Mean stomach fullness of juvenile chum salmon caught at near shore or coastal water stations from mid-April to mid-June, 1995 to 1998. Sample sizes: near shore, 3–849 fish; coastal waters, 1–244 fish. Open symbols indicate less than ten fish. E, early; M, mid; L, late.

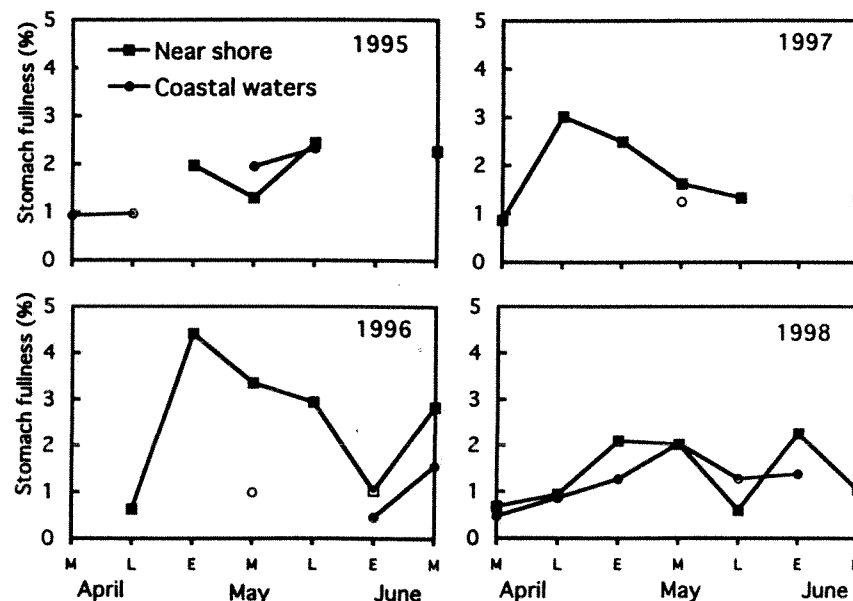
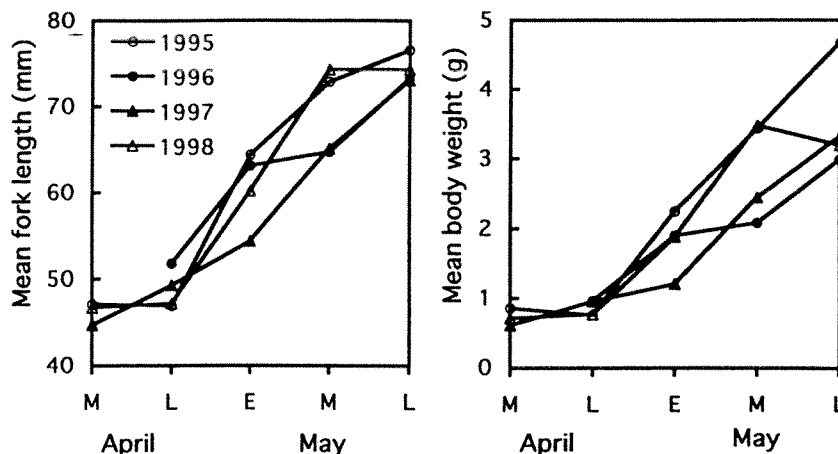


Fig. 6. Size (length and weight) of juvenile chum salmon caught in near shore waters off Mashike in high temperature and low temperature years during the period of growth until offshore migration. Sample sizes: 68–4165 fish. E, early; M, mid; L, late.



Most maturing long shanny ($n = 96$) captured by gill net from early April to mid-April had empty stomachs. Juvenile chum salmon were never found in the stomach contents of long shanny.

Seabirds

Gulls, ducks and cormorants showed three different patterns of abundance in the Syokanbetsu River mouth from February to June in 1999 (Fig. 7). Firstly, slaty-backed gull (*Larus schistisagus*), black-tailed gull (*Larus crassirostris*) and red-breasted merganser (*Mergus serrator*) showed a peak in abundance in late April when juvenile chum salmon actively migrated to the sea and entered the coastal waters. About one thousand five hundred gulls flocked around the mouth of the river in late April. Secondly, Japanese cormorant (*Phalacrocorax capillatus*) increased during the coastal life of juvenile chum salmon. Thirdly, harlequin duck (*Histrionicus histrionicus*) decreased in number from mid-April to mid-June. We observed three species, slaty-backed gull, black-tailed gull and Japanese cormorant feeding on juvenile chum salmon. We found juvenile chum salmon captured in inshore waters with beak marks (Fig. 8). The ratio of injured juveniles ($n = 3$) to total catch ($n = 1113$) was 0.27 percent at sampling site D in late April.

Rhinoceros auklet migrated to inshore waters from late April to early May in high temperature years, and from mid-May to late May in low temperature years, but we did not see them feed on juvenile chum salmon.

DISCUSSION

Our study showed the relationship between the early open coastal life of juvenile chum salmon and annual fluctuations in seawater temperature. The

early marine life has four parts: (1) Movement to the sea when juveniles are transported to the sea by the river, tide and wind. (2) Adaptation period when juveniles appear to move near the bottom for a short time to avoid predators, judging from the results of

Fig. 7. Changes in numbers of seabirds every ten days in the vicinity of the Syokanbetsu River mouth during pre-and post-seaward migration of juvenile chum salmon. E, early; M, mid; L, late.

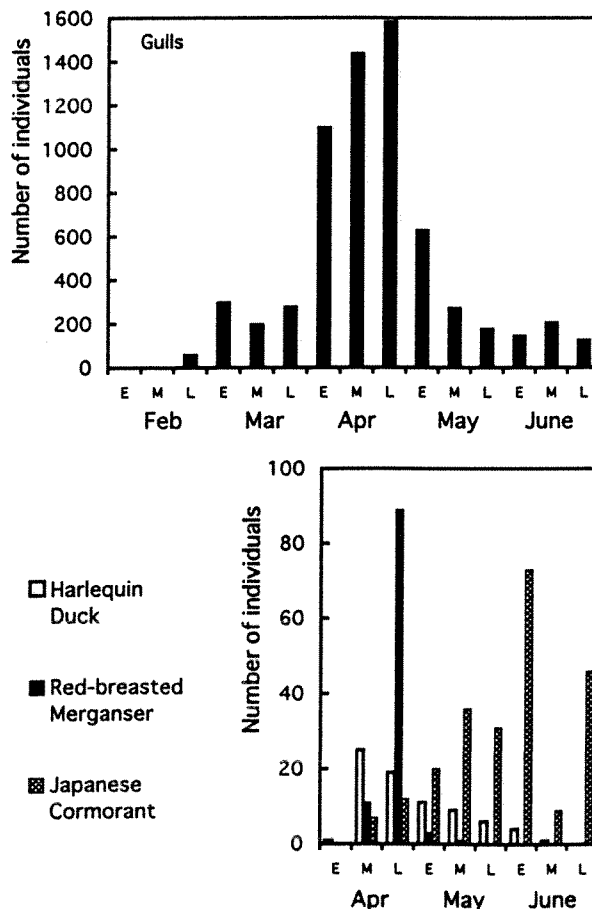
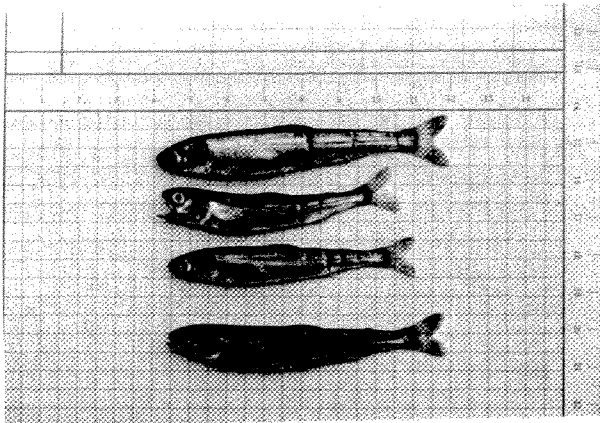


Fig. 8. Juvenile chum salmon with beak marks of seabirds. The juveniles were captured in a Sayori tounet in inshore waters (St. D). Bottom fish has no beak marks, for comparison.



stomach content composition and low CPUE near the surface. The diet of juvenile chum salmon during the adaptation period was basically epibenthic organisms, such as harpacticoid copepods, and was consistent with other studies (Kaczynski et al. 1973; Feller and Kaczynski 1975; Healey 1979; Sibert 1979; Murphy et al. 1988; Pushchina and Goryainov 1994). (3) Growth period when the juveniles actively fed on prey organisms near the surface. (4) Offshore migration period when the juveniles migrated offshore after reaching a critical size (73 to 76 mm in mean fork length, 3.2 to 3.6 g in mean body weight).

Juvenile chum salmon remained in near shore waters off Mashike until they reached a critical size. They may have remained in this restricted zone near shore because of better availability and variety of food, and establishment of orientation for navigation in the ocean. Juvenile chum salmon occupy marsh and estuary habitats with shallow and low salinity waters before migrating into the coastal ocean (Kaczynski et al. 1973; Mason 1974; Healey 1979; Congleton et al. 1981; Mayama et al. 1982, 1983; Kaeriyama 1986; Murphy, et al. 1988; Percy et al. 1989). The juveniles we studied, however, had no estuarine habitat as a nursery ground. The coastal topography off Mashike may be one of the causes of low survival of chum salmon juveniles in the Sea of Japan.

Prey availability and growth of juvenile chum salmon were affected markedly by environmental factors, especially seawater temperature. In high temperature years, chum salmon juveniles had a higher growth rate and consumed many fish larvae and terrestrial insects. However, stomach fullness in high temperature years showed lower peaks. This lower stomach fullness may reflect intra- and/or inter-species competition for food and habitat in high temperature years (Kawamura et al. 1998). Brodeur and Percy (1990) similarly found that oceanographic

conditions could affect the feeding ecology of pelagic planktivores off the Oregon and Washington coasts. Quality of food and energy efficiency for food availability may affect growth of juvenile chum salmon. Fish larvae seem to be better prey than zooplankton copepods.

It is hypothesized that high mortality of Pacific salmon (*Oncorhynchus* spp.) occurs during early marine life (Parker 1968; Bax 1982; Healy 1982; Percy 1992). Juvenile chum salmon during entering and adapting to the sea may be most vulnerable to predators because of poor adjustment to the new habitat, osmoregulation, food availability and open shallow waters.

The results from stomach contents of carnivorous fish showed that we could not regard adult arbesque greenling and juvenile masu salmon as significant predators. Predation may largely depend on the spatial and temporal difference in availability of food and habitat among juvenile chum salmon and two other carnivorous fish. Murphy et al. (1988) observed that juvenile coho salmon (*O. kisutch*) did not feed on chum and pink salmon (*O. gorbuscha*) juveniles in estuarine basins in Alaska because of differences in diet and timing of migration.

Predation on juvenile Pacific salmon by avian predators (common murre, *Uria aalge*; ring-billed gull, *Larus delawarensis*; western gull, *L. occidentalis*; Brandt's cormorant, *Phalacrocorax penicillatus*; pelagic cormorant, *P. pelagicus*; common merganser, *Mergus merganser*) has been reported in several rivers and coastal waters in north America (Bayer, 1986; Ruggerone 1986; Wood 1987a, b). There is limited information about seabird predation on pelagic fish in coastal waters in Japan (Watanuki 1987, 1988; Nagasawa 1998). Our findings first showed that slaty-backed gull, black-tailed gull and Japanese cormorant could feed on juvenile chum salmon, and that juvenile chum salmon with beak marks of seabirds were captured in inshore waters off Hokkaido. Carss and Marquiss (1991) have also illustrated bird-damaged fish in the UK. Red-breasted merganser appears to consume juvenile chum salmon in the river mouth like other seabirds. The large number of seabirds present in inshore waters off Mashike, are a significant potential hazard to the survival of juvenile chum salmon during their seaward migration and early coastal life in the Sea of Japan off Hokkaido.

It is important for the survival of juvenile chum salmon to compare the effect of environmental factors in open coastal waters between high temperature years and low temperature years. In high temperature years, environmental conditions are as follows: the sea is calm, the period of flood from rivers is short, extension seaward of brackish waters is weak,

critical seawater temperature, 13°C, occurs early (Kaeriyama 1989; Irie 1990), and duration of food availability is short. These environmental factors may depress the survival of chum salmon juveniles during early marine life. Irie (1990) has already shown that juvenile chum salmon off Hokkaido have a preference for the coastal waters with low temperature (8–13°C) and low salinity (31.0–33.9‰). As the preferred conditions are apparently restricted in time and space in high temperature years, intra- and/or inter-species competition may become stronger (Kawamura et al. 1998). In addition, predation by seabirds on juvenile chum salmon may be higher in high temperature years because of calm water and a longer feeding period because of their earlier arrival. Consequently, changes in environmental factors in low temperature years may improve the survival of juvenile chum salmon in the open coastal waters off the northern coast of the Sea of Japan.

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