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Role of a riverine plume as a nursery area for chum salmon *Oncorhynchus keta*

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ABSTRACT: We examined the spatial distribution of juveniles in coastal water to assess how riverine plumes serve as nursery areas for chum salmon in early ocean life. The distribution of juveniles was restricted within a low-salinity water mass that was formed by riverine discharges. We detected 2 juvenile sizes at which distributions changed. Distributions of small juveniles (≤50 mm in fork length) and medium-size juveniles (50 to 75 mm) were found in nearshore regions and were less affected by water temperature and salinity. Distributions of large juveniles (>75 mm) were located in waters whose salinity was 25 to 30 psu, and were less-affected by the distance from the shoreline. Results suggested that the juvenile distribution was affected by tolerance to environmental stress (high temperature or high salinity) and by refuge from fish predators. Juvenile chum salmon can use riverine plume habitats to avoid environmental stress, to search for prey patches, and to expend less energy for migration.

KEY WORDS: Riverine plume · Nursery area · Ontogenetic habitat shift · Spatial distribution · Anadromous salmon · Coastal current

INTRODUCTION

Predation and environmental stress affect not only early mortality in coastal waters but also the abundance of the returning adult population of Pacific salmon *Oncorhynchus* spp. In anadromous salmon populations, mortality is often very high soon after juveniles enter the ocean (Pearcy 1992). Predation by fishes, birds, and mammals has been considered a major factor in early sea mortality of juvenile Pacific salmon (Bayer 1986, Beamish et al. 1992, Emmett 1997, Nagasawa 1998). Nevertheless, physical environmental stress, such as salinity and water temperature in coastal waters, also affects the abundance of adult chum populations (Mayama 1985, Blackbourn 1990). Mayama (1985) suggested that higher coastal water temperature and timing of fry release strongly affect the survival of Japanese hatchery-reared chum populations.

Anadromous Pacific salmon change their habitat between freshwater and marine environments with migration. Chum salmon alevin develop osmoregulatory ability, and their fry often migrate seaward soon after emergence (see reviews by Salo 1991, Clarke & Hirano 1995). Many fry released from hatcheries also migrate seaward soon after release (Mayama et al. 1982, Kaeriyama 1986). After entering the ocean, fry are distributed in estuarine and intertidal regions. At a size of 50 to 80 mm, fingerlings disperse in inshore regions of coastal water, and fingerlings larger than 80 mm eventually migrate offshore or northward around the coast of Japan (Mayama et al. 1982, Kaeriyama 1986, Irie 1990). With these ontogenetic habitat shifts, chum salmon increase salinity preference and tolerance (McInerney 1964).

Coastal waters have complex features caused by hydrodynamic effects, input from terrestrial ecosystems, and human activities. Riverine plumes are more productive than adjacent waters (Bode & Dortch 1996, Harvey et al. 1997). Many coho and chinook salmon smolts are caught in riverine plumes off Oregon and Washington (USA) (Pearcy & Fisher 1990, Fisher & Pearcy 1995). Chum salmon juveniles are also caught in low salinity

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*Present address: Subarctic Fisheries Resources Division, Hokkaido National Fisheries Institute, 116 Katsurakoi, Kushiro 085-0802, Japan. E-mail: fukuwaka@hnf.affrc.go.jp waters (<34‰) around the coast of Japan (Irie 1990). In frontal regions of riverine plumes, zooplankton and fish eggs are accumulated (Mackas et al. 1980, Govoni et al. 1989, Grimes & Finucane 1991, Fortier et al. 1992). The accumulation of prey in frontal regions can be utilized by Pacific salmon (Brodeur 1989). Production of Pacific salmon is affected by riverine discharges and coastal surface salinity in British Columbia and Washington State (Blackbourn 1990, Beamish et al. 1994). Coastal currents also influence recruitment of other fishes to coastal fisheries through the transport of fish larvae and organic and inorganic materials (Thomson et al. 1989, Fortier et al. 1992). Production of marine fishes is often influenced strongly by spatially and temporally variable environments in coastal waters.

To assess riverine plumes as a nursery area for chum salmon in early ocean life, we examined the relationship between spatial distribution of juveniles and oceanographic environment in the Japan Sea coastal waters off Honshu. This paper aimed to (1) detect the change in spatial distribution of chum salmon juveniles with ontogeny in neritic waters and (2) identify the association between juvenile distribution and riverine plumes or other oceanographic environmental factors.

MATERIALS AND METHODS

Study site. The Japan Sea coast of Honshu, Japan, is the southern limit of chum salmon distribution in the western Pacific (Salo 1991). The northern area of the coast is characterized by broad and open sand beaches and less developed estuaries (Coastal Oceanography Research Committee, Oceanographical Society of Japan 1985). Coastal waters in the Japan Sea are strongly affected by the Tsushima Current. Currents generated by tides are relatively small. The Tsushima Current is characterized by a high temperature (minimum 8°C at 100 m depth) and high salinity (>34.1 psu) water mass flowing alongshore and northward on the continental shelf (Kawabe 1982). Riverine discharges increase in the spring due to snow melting; these discharges result in the development of riverine plumes in nearshore regions (Coastal Oceanography Research Committee, Oceanographical Society of Japan 1985).

We set a line transect from the mouth of Gakko River to the southern edge of Tobishima Island off Fukura, Yamagata Prefecture, Japan (Fig. 1). The shoreline of the southern area of the river mouth is an open sandy beach and in the northern area a rocky shore. We placed 5 sampling stations on the line transect at 2 (A), 5 (B), 10 (C), 15 (D), and 20 (E) km offshore. At these stations, water depth was 10 to 200 m. The surface water current was observed to flow steadily northward during sampling in the study area.

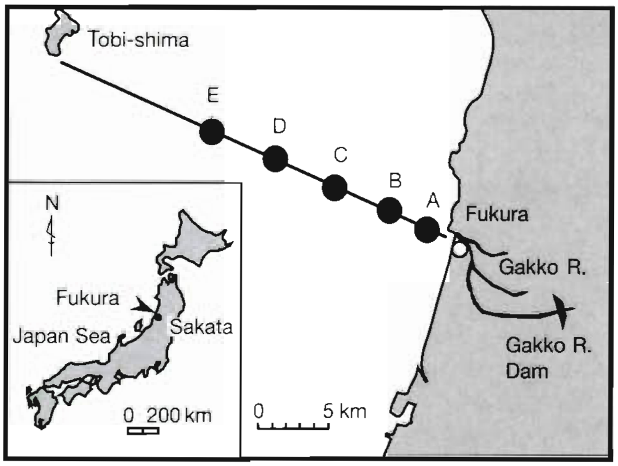

Fig. 1. Map of study site and stations for collections of chum salmon juveniles in 1993 to 1996 off Fukura, Yamagata Prefecture, Japan Sea coast

Sampling procedure. From March to May in 1993 to 1996, we collected chum salmon juveniles by surface trawls and simultaneously measured water temperature and salinity using a CTD at the sampling stations (Fig. 1). Surface trawls were towed at ca 4 km h^{-1} by 2 vessels parallel to the shoreline in 1 set of 30 min or 3 sets of 15 min at each station (Suzuki et al. 1994, Suzuki & Fukuwaka 1998). The net was 8 m wide and 4 m deep at the mouth and equipped with 25 to 34 mm (stretched) mesh in the body and 7.5 mm mesh in the cod end. Latitudes and longitudes of the position of net sets were measured by a GPS. The precise distance of each net set from the shoreline was estimated as the distance from the position of net set to the nearest position on the shoreline. Collected juveniles were fixed in 10% formalin and the fork length measured in millimeters. Catch per unit effort (CPUE) was calculated as the number of collected juveniles per 30 min net trawl.

Detection of the difference in distribution with fish size. To evaluate how fish size intervals influenced the distribution pattern, we sorted juveniles into 13 size classes in 5 mm length intervals (i.e. ≤40, 40–45, 45–50, 50–55, 55–60, 60–65, 65–70, 70–75, 75–80, 80–85, 85–90, 90–95, and >95 mm). Morisita's index of interspecific correlation was estimated for the relationships in spatial distributions among the 13 size classes of juveniles (Morisita 1959). The index is less affected by number of individuals than other indices evaluating the relationship with distribution. The index ranges from −1 (completely avoid each other) to 1 (completely attract each other), and 0 value indicates that their distributions are not correlated. Cluster analysis using the complete linkage method was used to combine size classes that showed a positive relationship in their distribution.

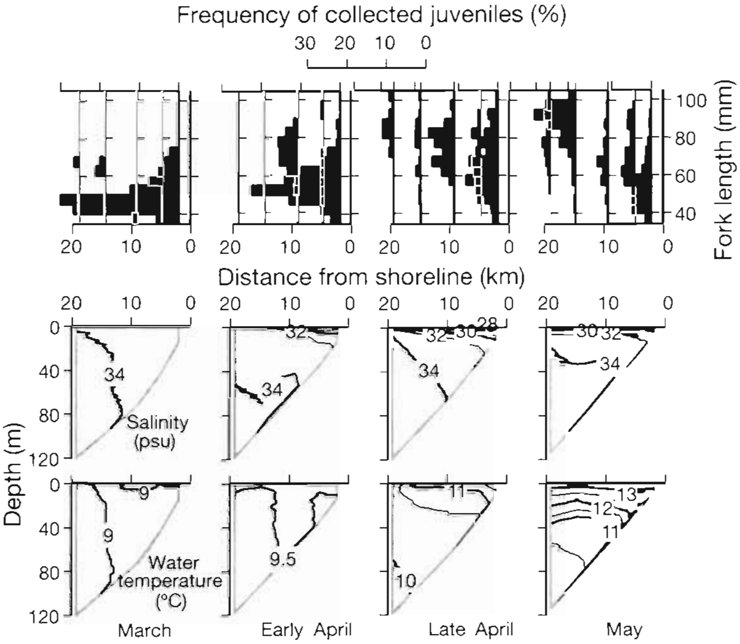

Fig. 2. *Oncorhynchus keta*. Size frequency distributions of collected chum salmon juveniles and vertical sections showing contours of salinity and water temperature in spring of 1993 to 1996 off Fukura, Japan Sea. Cumulative number of collected juveniles was 90 in March, 349 in early April (1 to 15), 249 in late April (16 to 30), and 403 in May

Relationship between distribution of juveniles and environmental factors. Correlation coefficients were used to identify associations between the surface salinity (0 m), mean outflow of Gakko River Dam, and mean daily discharge of Mogami River for 5 d prior to the sampling date. These variables were used because Kawai & Nagata (1993) found that the area covered by low salinity water was positively correlated with the sum of riverine discharge for 5 d prior to the observation date for 2 other rivers (Shinano and Agano) flowing into coastal waters of the Japan Sea. The relationship between riverine discharges and surface salinity was analyzed using stepwise multiple regression ($p \leq 0.05$ to add and $p \geq 0.10$ to remove; Sokal & Rohlf 1995). The significance of correlation coefficients and standard partial regression coefficients was tested using the *t*-test. Outflow data of the Gakko River Dam (15.6 km from the river mouth) were obtained from the Yamagata Prefectural Fisheries Experimental Station. The daily discharge of the Mogami River (the largest river closest to the study site) was obtained from the discharge table for Sagoshi Gauging Station, 11.1 km upstream from the river mouth (River Bureau, Ministry of Construction 1994–1997). For the structure of water masses, water temperature and salinity were averaged at 1 m depth intervals at each station in March, early April (1 to 15), late April (16 to 30), and May.

The randomization test of cumulative frequency was used for the difference in distribution between size classes and distance from shoreline, surface water temperature, and surface salinity (Perry & Smith 1994, Syrjala 1996). In this test, the Cramér-von Mises test statistics and 999 permutations of random combination of 2 variants were used for the significance (Syrjara 1996). The relationships between the distribution of juveniles and the environmental factors were tested by the randomization test for cumulative functions of CPUE and stations over environmental factors (Perry & Smith 1994). The relationships among distributions of size classes of juveniles were tested by that for cumulative functions of CPUEs over environmental factors.

RESULTS

Environmental factors and CPUE of juveniles in the coastal water

Low salinity water off Fukura originated from discharges of rivers near the study site. Surface salinity ranged from 18.5 to 34.3 psu in March to May, and surface water temperature ranged from 8.0 to 17.6°C (Fig. 2). Low salinity water below 32 psu was not observed in March, but was observed in the surface layer 0 to 15 km offshore in early April. Low salinity water reached 20 km in late April, and then expanded beyond 20 km in May. Outflow from the Gakko River Dam was positively correlated with discharge from the Mogami River (Table 1). Surface salinity was negatively correlated with outflow from the Gakko River Dam and discharge from the Mogami River, but was more closely related with outflow from the Gakko River Dam when we calculated by stepwise multiple regression analysis (Table 1).

Most chum salmon juveniles were collected in the riverine plume (Fig. 2). The total number of chum salmon juveniles collected by 63 net trawls was 1091 (Table 2). The mean CPUE of juveniles was 14.7 ± 24.7 SD (n = 63) per 30 min net trawl. In March, the riverine plume was insufficiently developed (<2 km) off Fukura, and most juveniles were collected in the most nearshore (2 km station). In early April, the riverine plume was developing offshore (<20 km), and some juveniles were collected at 10 km offshore. In late April and May, the riverine plume was sufficiently developed over 20 km offshore, and juveniles were collected at every station from 2 to 20 km offshore.

Table 1. Correlation coefficients and result of stepwise regression analysis of surface salinity off Fukura on outflow of Gakko River Dam (Japan) and riverine discharge of Mogami River (Japan) in 1993 to 1996. $^{***}p \le 0.001$; $^{**}p \le 0.01$; $^{*}p \le 0.05$

	Correlation coefficients		Standard partial regression coefficient
	Salinity	Gakko River	
Gakko River	−0.435***	–	−0.481**
Mogami River	−0.325*	0.626***	Not entered

Smaller juveniles were collected in nearshore regions and larger juveniles were collected in relatively offshore regions (Fig. 2). The mean fork length of collected juveniles was between 50.0 and 84.9 mm in March to May of 1993 to 1996 (Table 2). In March and early April, juveniles smaller than 70 mm formed a large proportion of collected juveniles (Fig. 2). In late April and May, many juveniles larger than 70 mm were collected. On 9 of 11 sampling occasions, fork length of collected juveniles was positively correlated with the distance from shoreline to the position of net trawl (Table 2).

Relationship between juvenile size and distribution

The cluster analysis with complete linkage method shows 3 groups of juvenile size classes that were not correlated in their distribution (Fig. 3). Two linkages were constructed below a value of 0 for the Morisita's correlation index. In each group linked at positive values of the index, juvenile distribution in every size class was positively correlated with that in another size class because of the complete linkage method. The group of small juveniles consisted of 3 size classes smaller than or of 50 mm in fork length. The group of medium-size juveniles consisted of 5 size classes from 50 to 75 mm in fork length. Another group of large juveniles consisted of 5 size classes larger than 75 mm in fork length.

Table 2. *Oncorhynchus keta*. Number of collected chum salmon juveniles, fork length (mean ± SD) and correlation coefficient between fork length and distance from shoreline off Fukura by sampling date in 1993 to 1996. $^{***}p \le 0.001$; $^{*}p \le 0.05$; NS: $p > 0.05$

Year	Date	Number of juveniles	Fork length (mm)	Correlation coefficient	*F*
1993	April 28	88	72.8 ± 13.7	0.460	23.1***
	May 18	24	59.8 ± 9.4	0.460	5.92*
1994	March 22	90	50.0 ± 8.4	0.378	14.6***
	April 7	81	56.1 ± 8.3	0.417	16.7***
	April 21	68	68.6 ± 9.6	0.527	25.4***
1995	April 12 and 14	71	52.4 ± 11.1	0.530	27.0***
	April 28 and 29	59	65.4 ± 15.8	0.132	1.01NS
	May 9 and 10	115	74.5 ± 13.6	0.140	2.70NS
1996	April 9	197	63.2 ± 11.1	0.597	108***
	April 23	34	84.9 ± 9.9	0.392	5.82*
	May 12 and 14	264	73.8 ± 18.9	0.889	984***
Pooled		1091	66.6 ± 16.3	0.674	906***

Relationship between distribution of juveniles and environmental factors

The distribution of small juveniles was largely restricted to the nearshore region off Fukura. A large portion of small juveniles (≤50 mm) was collected at the station nearest to the shore (Fig. 4A). The distribution of small juveniles was significantly different from the distribution of distance from shoreline to net trawls (Table 3). Most small juveniles were collected at below 13°C surface water temperature (Fig. 4B), but the distribution of small juveniles was not different from that of water temperature (Table 3). Cumulative frequency of small juveniles increased in a similar pattern as salinity (Fig. 4C, Table 3).

The distribution of medium-size (50 to 75 mm) juveniles was not significantly different from that of small juveniles (Table 4), but medium-size juveniles were collected in the offshore area more often than small juveniles (Fig. 4A). Most medium-size juveniles were collected within 0 to 10 km offshore (Fig. 4A). The distribution of medium-size juveniles was significantly different from the distribution of distance from shoreline to net trawls (Table 3). Most medium-size juveniles were collected in stations with surface water temperature below 14°C (Fig. 4B), but their distribution was not significantly different from that of temperature (Table 3). Cumulative frequency of medium-size juvenile CPUE increased in a similar pattern as salinity and as that of small juveniles (Fig. 4C, Tables 3 & 4).

The distribution of large (>75 mm) juveniles was restricted to a narrow range of salinity and was different from those of small (≤50 mm) and medium-size (50 to 75 mm) juveniles in relationships between distribution and environmental factors. The distribution of large juveniles was not significantly different from that of distance from shoreline to net trawls

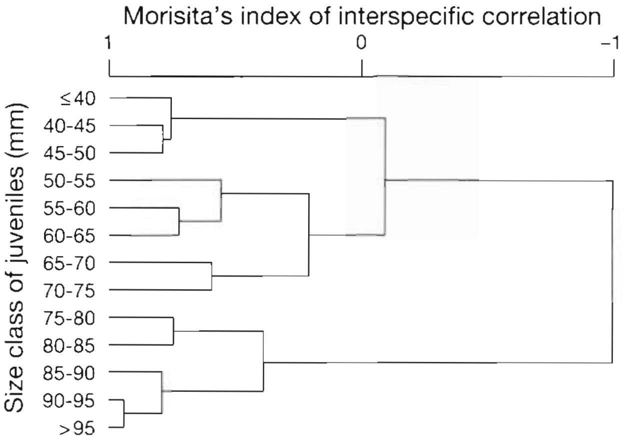

Fig. 3. Dendrogram constructed by cluster analysis of similarity among distribution patterns of chum salmon juvenile size classes. Morisita's index of interspecific correlation was used for the similarity

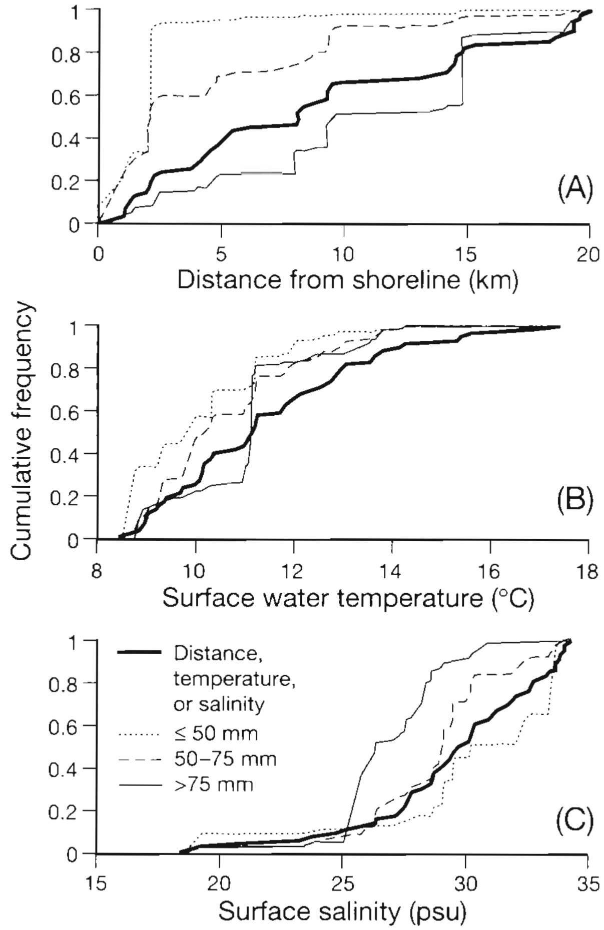

Fig. 4. Relationships between cumulative frequencies of chum salmon CPUE for 3 size classes and cumulative frequency of observed and fixed environmental factors for the stations: (A) distance from shoreline, (B) surface water temperature, and (C) surface salinity

(Fig. 4A, Table 3), and it was different from those of small and medium-size juveniles (Table 4). A large portion of large juveniles was collected in the range of surface salinity from 25 to 30 psu (Fig. 4C). The distribution of large juveniles was significantly different from those of salinity and small juveniles (Tables 3 & 4). Most large juveniles were also collected in stations with surface water temperature below 14°C, and many large juveniles were collected near 11°C (Fig. 4B). The distribution of large juveniles was not significantly different from those of water temperature, small juveniles, and medium-size juveniles (Tables 3 & 4).

DISCUSSION

Developmental stages and juvenile distributions

Distributions of fry and fingerlings of chum salmon differed off Fukura. We found 3 size groups whose distributions were not correlated with each other. Each group was sequentially linked to adjacent size classes of juveniles. One group included juveniles smaller than 50 mm in fork length, another group included juveniles of fork length from 50 to 75 mm, and the other included juveniles larger than 75 mm. In the early sea life of chum salmon, fry (30 to 50 mm in fork length) are distributed in estuarine or intertidal regions, small fingerlings of 50 to 80 mm disperse in inshore regions of coastal water, and fingerlings larger than 80 mm migrate offshore or northward (Mayama et al. 1982, Kaeriyama 1986, Irie 1990). The swimming ability of fishes increases with their size (Beamish 1978). Skeletal structure related to swimming ability is intensified considerably in the fingerling stage with 50 to 80 mm fork length, and is completed in the fingerling stage with 80 to 120 mm fork length of chum salmon (Kaeriyama 1986). Changes in juvenile distribution are attributed to an increase of swimming ability with development.

Table 3. CPUE (mean ± SD) and results (probability values) of randomized test for the associations between distance from shoreline, surface water temperature and salinity and distributions of 3 size classes of chum salmon juveniles collected off Fukura, Japan Sea. n: cumulative number of net trawls

Size class (mm)	CPUE (no./30 min trawl)	Distance from shoreline	Surface water temperature	Surface salinity	n
≤50	2.69 ± 8.4	0.001	>0.05	>0.05	63
50–75	7.94 ± 15.5	0.001	>0.05	>0.05	63
>75	4.33 ± 12.0	>0.05	>0.05	0.004	63

Table 4. Results (probability values) of randomized test for difference in associations between distribution and distance from shoreline, surface water temperature, and salinity among 3 size classes of chum salmon juveniles off Fukura, Japan Sea

Size class	Distance from shoreline			Water temperature			Salinity		
(mm)	≤50	50–75	>75	≤50	50–75	>75	≤50	50–75	>75
≤50	–	>0.05	0.001	–	>0.05	>0.05	–	>0.05	0.016
50–75	–	–	0.006	–	–	> 0.05	–	–	>0.05
>75	–	–	–	–	–	–	–	–	–

Chum salmon fry may find refuge from marine predators in the shallow onshore area, and fingerlings may select an appropriate habitat for feeding or growing in the relatively offshore area. Fry are distributed in estuaries or onshore regions of open coasts (Healey 1979, Mayama et al. 1982). Larger juveniles are distributed in more offshore regions in coastal waters (Kaeriyama 1986, Irie 1990, Suzuki et al. 1994). Juvenile size was often correlated with distance from shoreline off Fukura. Small juveniles (≤50 mm) and medium-size juveniles (50 to 75 mm) had a distribution that was significantly related to the inshore region, but they were not affected by surface water temperature and salinity. Medium-size juveniles were distributed relatively further offshore than small juveniles. The distribution of large juveniles was less affected by distance from shoreline and strongly affected by surface salinity. Salo (1991) reviewed that the offshore movement of chum salmon juveniles coincides with the decline of inshore prey resources when the fishes have grown to a size that allows them to feed upon larger neritic organisms and avoid predators. On the western coast of North America, the restriction of prey availability in estuaries limits chum salmon populations (Healey 1979, Wissmar & Simenstad 1988). Piscivorous fishes and birds prey extensively on juvenile salmon in estuaries (Parker 1971, Bayer 1986, Beamish et al. 1992). Although predation by birds on fish is greater in shallower depths, small prey fish are distributed in shallow waters because of predatory large fish (Safina & Burger 1985, Crowder et al. 1997). In some fishes inhabiting sand beaches, the positive relationship between fish size and depth reduceds the predation on smaller fishes by fish predators inhabiting deeper waters (Ruiz et al. 1993, Gibson et al. 1995). Chum salmon fingerlings obtain sufficient swimming ability to avoid fish predators, to search for prey organisms, and to select appropriate habitats.

Physical environment and juvenile distribution in the coastal water

The difference in juvenile distributions among size classes could be caused by differences in habitat selection. While smaller juveniles were restricted to inshore regions and were observed over a wide range of salinities, larger juveniles were distributed over a narrow range of salinities around 28 psu. Chum salmon have osmoregulatory ability in their early life and their juveniles increase salinity preference temporally, which relates to the ontogenetic habitat shift in their migration (see review by Clarke & Hirano 1995). While juveniles tolerate unusually high salinity waters (<48 psu), they prefer low salinity water below 12‰ Cl. (ca 22 psu in salinity) (McInerney 1964). Growth rates of juveniles of 1 g in body weight (ca 50 mm in fork length) decrease in highly saline waters of 32 psu (Koshiishi 1986). This indicates that highly saline water is not preferred by chum salmon juveniles and is inappropriate for their growth. Larger juveniles selected actively for water masses around 28 psu in salinity in the coastal water. Smaller juveniles stayed in inshore areas, and would have less ability of habitat selection in offshore regions of the coastal water.

The upper limits of water temperature for the distribution of chum salmon juveniles are determined by their physiological tolerance. Although a significant relationship between water temperature and juvenile distribution was not observed, most juveniles were distributed below 14°C surface water temperature off Fukura. Chum salmon juveniles have previously been observed to be mostly distributed in water masses below 14°C water temperature in coastal waters (Kaeriyama 1986, Irie 1990). Chum salmon juveniles decrease their feeding efficiency in rearing experiments in a water temperature of 15°C (Kaeriyama 1986). Mayama (1985) suggested that coastal water temperature at release time strongly affects the abundance of the hatchery-reared chum salmon population in Japan.

Function of riverine plumes

The riverine plume provides an appropriate habitat not only for salinity tolerance but also for higher concentration of food for juvenile chum salmon. The riverine plume developed from early April to May off Fukura. Juveniles dispersed offshore in the riverine plume. Primary production is higher in a riverine plume than in adjacent waters because of the input of nutrients originating from the land (Bode & Dortch 1996, Harvey et al. 1997). Zooplankton, fish eggs, and fish larvae are often accumulated in the frontal region of riverine plumes (Mackas et al. 1980, Govoni et al. 1989, Grimes & Finucane 1991). Pacific salmon juveniles and zooplankton are abundant in the frontal region of estuarine and riverine plumes, and juvenile salmon are attracted to the higher concentration of prey organisms (Brodeur 1989, St. John et al. 1992). Chum salmon juveniles prey on zooplankton and fish larvae off Fukura (Suzuki et al. 1994, Suzuki & Fukuwaka 1998). Large juveniles (>75 mm) were concentrated from 25 to 30 psu surface salinity off Fukura. Large juveniles selected frontal regions of riverine plumes where there is a high probability that juveniles encounter a patch of prey organisms.

The extension of the riverine plume might decrease the predation rate of juvenile chum salmon by marine predators. In British Columbia and Washington State, riverine discharge was negatively correlated with marine survival of chum, pink, and sockeye salmon (*Oncorhynchus keta*, *O. gorbuscha*, and *O. nerka*) (Blackbourn 1990, Beamish et al. 1994). River lamprey *Lampetra ayresi* prey extensively on juvenile salmon in the Fraser River plume (Beamish & Neville 1995). Off Fukura, a slightly digested juvenile of chum salmon was observed in stomach contents of masu salmon smolt *O. masou* caught using a trawl net (authors' unpubl. data). However, chinook salmon smolts *O. tshawytscha* released in the marine zone are exposed to more bird and fish predators than smolts released in transition, estuarine, and river zones (Macdonald et al. 1988). Hartt & Dell (1986) thought that the nearshore distribution of chum, pink, and sockeye salmon juveniles minimized the overlap with oceanic predators. In addition, Nagasawa (1998) concluded in his review that predation by fishes did not appear to be an important factor controlling Japanese chum salmon populations.

Chum salmon juveniles are transported northward by the Tsushima Current in the Japan Sea coastal water. Large juveniles (>75 mm) were distributed relatively offshore within the riverine plume. On the Hokkaido coast of Japan Sea, chum salmon juveniles around 70 mm have been observed to begin to migrate northward along the coast (Mayama et al. 1982). Off Fukura, surface water flowed alongshore and northward in every net set (pers. obs.). A branch of the Tsushima Current flows northward and alongshore in the region landward of 200 m depth on the Japan Sea coast (Kawabe 1982). The Shinano-Agano River plume spreads mainly northward and alongshore in the nearshore region within 10 km offshore and shallower than 100 m in depth, which was affected by the coastal current (Kawai & Nagata 1993). Off Oregon, coho and chinook smolts released in the Columbia River are transported in the riverine plume by the coastal jet during May and June (Pearcy & Fisher 1988, Fisher & Pearcy 1995). The migration route of Fraser River sockeye salmon has been explained by surface currents and random swimming behavior of fish (Walter et al. 1997). The alongshore coastal current acts as an alongshore conduit and cross-shore barrier to the transport of biomass and other materials over the continental margins (Thomson et al. 1989).

In summary, distributions of chum salmon juveniles in the Japan Sea coastal water differed among their developmental stages: fry (≤50 mm), small fingerlings (50 to 75 mm), and large fingerlings (>75 mm). Juvenile distributions were mostly within a riverine plume, and were determined by distance from shoreline or by surface salinity when surface water temperature ranged from 8 to 14°C. These oceanographic environments are affected by coastal water current, climate, and water utilization on the land. Our results suggested that juvenile distribution was affected by the tolerance to environmental stress (high temperature or high salinity) and by the refuge from fish predators. Functions of the distribution within the riverine plume are to avoid environmental stress, to search for prey patches, and to use less energy for migration.

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