Interaction Between Chum Salmon and Fat Greenling Juveniles in the Coastal Sea of Japan off Northern Hokkaido

Hiroshi Kawamura
Mashike Branch of Hokkaido Fish Hatchery, Yamanokami 1256,
Shokanzawamura Mashikecho, Mashikegun Hokkaido, Japan

Mahito Miyamoto, Mitsuhiro Nagata,
Hokkaido Fish Hatchery, Kitakashiwagicho 373, Eniwa,
Hokkaido, Japan

and

Kazuo Hirano
Hokkaido Central Fisheries Experimental Station,
Hamanakacho 238, Yoichigun Yoichicho, Hokkaido, Japan

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We examined potential interactions between chum salmon (*Oncorhynchus keta*) and fat greenling (*Hexagrammos otakii*) juveniles in terms of their distribution, abundance, growth and food habit in the Sea of Japan along the Mashike coast in northern Hokkaido. We captured the juveniles by a Sayori tow net from mid-April to mid-June in 1995. To compare the distribution patterns of both species, we calculated the point correlation coefficient (PCC, Dagneli's Φ) and Morisita's C_δ. We used Kimoto's C_π, as a similarity index of a stomach content composition between the two species, and SCI (Stomach Content Index, %). Although chum salmon juveniles were collected from mid-April to mid-June, fat greenling continued to inhabit till early May. Both species showed the highest abundance in early May and their distributions were restricted to inshore waters except for mid-April. There was a significant correlation of PCC in mid-April (PCC=0.75, χ^2=6.857, p<0.01), however, Morisita's C_δ remained at low levels (0.2~0.28) during the same period. Although there was significant difference in mean fork length between the two species in this period (t-test, P<0.05), frequency distributions of fork length were very similar. The mean values of SCI in mid- April ranged from 0.6% to 1.1% for chum salmon and from 0.8% to 1.8% for fat greenling among the sampling sites. The same food organisms, *Tortanus discaudatus* and *Themisto japonica* , were found in the stomachs of both species. Kimoto's C_π showed high values ranging from 0.34 to 0.58 in mid-April. It is suggested that there is potential competition between chum and fat greenling juveniles in terms of the food and habitat requirements during the early ocean life of chum salmon juveniles.

INTRODUCTION

It is hypothesized that the survival of salmon juveniles may be controlled by the competition for food and the predation during the early ocean life (Parker 1968; Healey 1982; Pearcy 1992).

Chum salmon (*Oncorhynchus keta*) stocks in Japan have been increasing, however, chum salmon stock along the coast of the Sea of Japan is smaller than those along the Pacific Ocean and the Sea of Okhotsk coasts in Hokkaido. It is considered that the lower level of chum salmon stock of the Sea of Japan is affected by the strength of Tsushima warm current in spring when chum salmon juveniles migrate to the sea and inhabit inshore waters. For the juveniles, Tsushima warm current brings about a higher water temperature for the residence and a change in zooplankton composition for their food (Seki et al. 1984; Kaeriyama 1989; Irie 1990).

However, little is known about the relation between chum salmon juveniles and other marine fish in terms of prey organism and distribution in inshore waters of the Sea of Japan. We hypothesized that chum salmon juveniles of the coastal Sea of Japan were more restricted to their resident time inshore for growth than those of the Pacific Ocean and the Sea of

Okhotsk coasts, and that timing of abundance of food organisms and competition with other fishes with a similar life strategy in feeding behavior were important for growth within a restricted time period.

The objective of this study was to clarify the relation between chum salmon and fat greenling (*Hexagrammos otakii*) juveniles in terms of their distribution, abundance, growth and food habit. Fat greenling juveniles are a common species that inhabits coastal waters of the Sea of Japan in spring (Sato 1991).

MATERIALS AND METHODS

Sampling Sites and Gear

We established fifteen sampling stations in the Mashike coastal area in the Sea of Japan of Hokkaido (Fig. 1). We captured the juveniles with a Sayori tow net at a speed of approximately two knots for thirty minutes at seven to ten stations, which were located with Global Positioning System, six times from mid-May to mid-June in 1995. Sayori tow net had a mouth that was eight meters wide, five meters deep and eighteen meters long with wing nets seven meters long, and towed by two fishing boats.

Stomach Content Analysis

Sampled fishes were fixed in five percent neutral formalin solution for several hours and then moved to seventy percent ethanol. In the laboratory, we measured fork length (FL) to the nearest 0.1 mm, body weight (BW) to the nearest 1mg and stomach content weight (SCW) to the nearest 1mg, and calculated stomach content index (SCI) as SCI = ((SCW/(BW-SCW))•100.

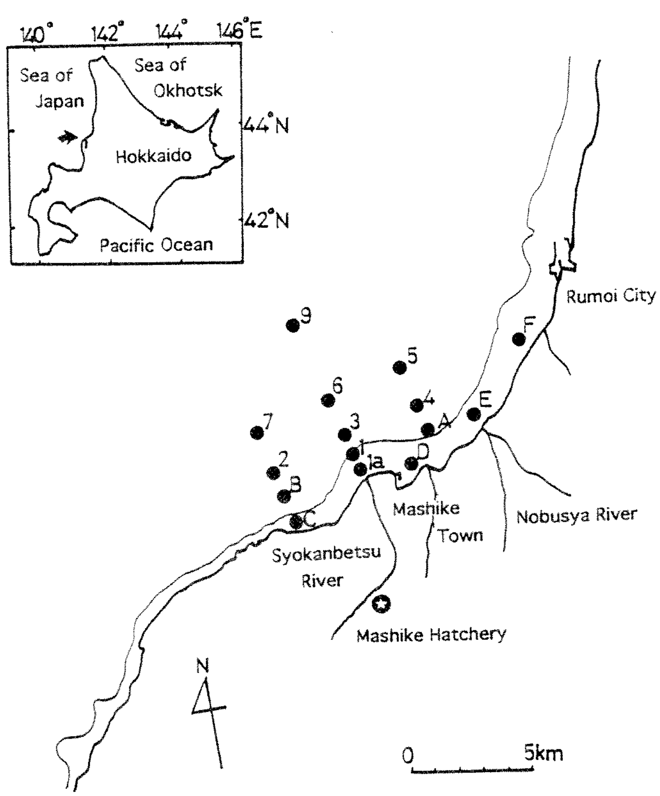
Prey items in each stomach were counted and identified to species whenever possible. A similarity index of stomach content composition was examined using Kimoto's Cπ (Kimoto 1967).

$$C\pi = \frac{2\sum_{i=1}^{s} n_{1i}\, n_{2i}}{(\Sigma\pi_1^2 + \Sigma\pi_2^2) N_1 N_2}, \quad \Sigma\pi_1^2 = \frac{\sum_{i=1}^{s} n_{1i}^2}{N_1^2},$$

$$\Sigma\pi_2^2 = \frac{\sum_{i=1}^{s} n_{2i}^2}{N_2^2}$$

where n_{1i} and n_{2i} are the number of a given prey species in the stomach content of fish group n1 and group n2, respectively, and N1 and N2 are the total of every prey species in the diet of fish group n1 and group n2, respectively. This results in an index ranging from 0 to +1, with 0 indicating no selection.

Fig. 1 Map showing the sampling stations along the Mashike coast of the Sea of Japan off Hokkaido, Japan.



Distributional Pattern Analysis

We examined an interspecific association between chum salmon and fat greenling juveniles with Dagnelie's ϕ (Dagnelie 1962), that is Point Correlation Coefficient and a distributional overlap with Morisita's C_δ (Morisita 1959).

$$\text{Dagnelie's } \phi \text{ (PCC)} = \frac{ad - bc}{\sqrt{(a+b)(a+c)(b+d)(c+d)}}$$

where a, b, c and d show four categories; a is the number of the sampling site where both chum and fat greenling are found, b or c is that collecting site where either chum or fat greenling occur and d is the number of sites where both species are absent. This correlation coefficient ranges from -1 to +1, with +1 showing preference for the same environment. Morisita's C_δ is written:

$$C_\delta = \frac{2\sum n_1 n_2}{(\delta_1 + \delta_2) M_1 M_2}$$

where n_1 and n_2 are the number of a given species at every sampling site and δ_1 and δ_2 show unbiased inference values of Simpson's λ (Simpson, 1949). M_1 and M_2 indicate a total number at every sampling site. This results in an index ranging from 0 to +1, with 0 indicating no distributional overlap.

RESULT

Abundance and distribution of sampled fishes

We captured nine species of fish by a Sayori tow net from mid-April to mid-June (Table 1). Chum salmon juveniles were numerically predominant through the survey period except for late-April. A lot of fat greenling juveniles were captured from mid-April to early-May except for late-April, when only few chum and fat greenling juveniles were caught. The other species, masu salmon (*O. masou*) juveniles, walleye pollock (*Theragra chalcogramma*) larvae, threespine stickleback (*Gasterosteus aculeatus*), Japanese needlefish (*Hemiramphus sajori*), needlefish (*Strongylura anastomella*), Temmink's surfperch (*Ditrema temnincki*) adults and Pacific sand lance (*Ammodytes personatus*) juveniles, were caught in few numbers from mid-April to mid-June.

Chum salmon juveniles distributed to inshore waters within one kilometer from the Mashike coast line except for mid-April, when the juveniles extend their distribution farther offshore. Also, the distribution of fat greenling juveniles spread to farther offshore waters in mid-April, however, they distributed to inshore waters in early-May. It seemed that both species of juveniles showed similar distributions. So, we analyzed interspecific association and degree of distributional overlap between chum and fat greenling juveniles with Dagnelie's ϕ and Morisita's C_δ, respectively.

Dagnelie's ϕ value was significantly high in mid-April (Table 2). Although Dagnelie's ϕ in mid-April was 0.75 (Chi square: 6.875, $P>0.01$), the values in late-April and early-May showed low levels (0.4 and 0.41), showing that chum and fat greenling juveniles preferred similar environments in mid-April. On the other hand, Morisita's C_δ values were low, ranging from 0.2 to 0.283 (Table 2), suggesting that every species of juvenile may have fine-scale habitat segregations.

Growth

We captured chum salmon juveniles in fork length ranging from 39 mm to 59 mm and fat greenling juveniles ranging from 30 mm to 55 mm in mid-April. The average fork length of chum and fat greenling juveniles in mid-April was 47 mm (N:244, SD: 4 mm) and 44 mm (N:101, SD: 6 mm), respectively. Although, there was significant difference of mean fork length between both juveniles (t-test, $P>0.05$), the frequency distributions in fork length of both juveniles were similar except for the class of small size in fat greenling (30~38 mm).

Table 1. Fish species and individual numbers captured with a Sayori tow net.

Species	April 14	April 25	May 9	May 16	May 31	June 13	Total
Oncorhynchus keta	244	5	3,356	1,061	112	22	4,800
Oncorhynchus masou				2	6		8
Hexagrammos otakii	103	8	236				377
Theragra chalcogramma		5					5
Gasterosteus aculeatus	6	2	9	2			18
Hemiramphus sajori			5				5
Strongylura anastomella					1		1
Ditrema temnicki			1				1
Ammodytes personatus			61				61

Table 2. Interspecific association and distributional overlap between chum salmon and fat greenling juveniles in the Mashike coast.

	April 14	April 25	May 9
No. of stations	9	10	8
C_δ	0.283	0.2	0.275
ϕ	0.75	0.4	0.41
χ^2	6.857	1.12	1.667
	p<0.01	ns	ns

C_δ from Morisita (1959) and ϕ from Dagnelie (1962).

Stomach Content Analysis

Stomach Content Index (SCI)

We compared the SCI of chum salmon with that of fat greenling in mid-April when both juveniles preferred similar environments. The mean values of SCI in mid-April ranged from 0.6% to 1.1% for chum salmon and from 0.8% to 1.8% for fat greenling among sampling sites (Table 3). At three sites where two species juveniles distributed sympatrically, there was no significant difference of mean SCI between the two species except for station B (t-test, P>0.05). Although SCI of fat greenling at station B showed a higher value than that of chum salmon, that may be caused by a higher prey catchability of the larger size juvenile than those of the other sites. This is supported by a higher value of SCI at station 6, where fat greenling juvenile were larger than at most other sampling sites (Table 3).

Stomach Content Composition

Table 4 represents the results of stomach content analysis and the numbers of prey item per fish at three stations where two species of juveniles were distributed sympatrically in mid-April. Although fat greenling juveniles preferred *Pseudocalanus minutus* and *Metridia sp.* (Copepodid), several prey items, such as *Tortanus discaudatus*, *Harpacticus sp.*, *Themisto japonica* and fish larvae were found in stomachs of chum salmon and fat greenling juveniles. Only at station B, zoea of *Anomura* occupied chum and fat greenling stomachs. It was evident that the same prey organisms were available for food of chum salmon and fat greenling juveniles.

Consequently, we calculated Kimoto's C_π as a similarity index of stomach content composition, comparing the individual size, because fish size may effect feeding behavior between individuals of different sizes. Kimoto's values showed higher levels ranging from 0.34 to 0.58 between the two species for similar body sizes (Table 5). However, Kimoto's value for individuals of different size showed a lower level (0.04). It was evident that there is potential competition for prey organisms between chum salmon and fat greenling juveniles of similar body size.

DISCUSSION

Our study showed that chum and fat greenling juveniles preferred similar environments, and that they might show fine-scale segregation in coastal waters of the Sea of Japan in mid-April. Moreover, it was observed from the analysis of their stomach content composition that several prey organisms were available for their food. There have been a number of reports on food habits of juvenile chum salmon during early ocean life (Kaczynski et al. 1973; Mason 1974; Healey 1979; Sibert 1979; Kaeriyama 1986; Irie 1990; Suzuki et al. 1994). Although Wissmart and Simenstad (1988) surmised that a balance between growth of juvenile chum salmon and abundance of prey organism could be evaluated with some growth efficiency level in an estuary, this is a possible food limitation in the early ocean life of growth of salmon juveniles.

Table 3. Comparison of stomach content index between chum salmon and fat greenling on April 14.

	Oncorhynchus keta			*Hexagrammos otakii*		
Station	N	FL(mm)	SCI(%)	N	FL(mm)	SCI(%)
St 1	99	45.3±3.4	0.60±0.71	12	38.6±4.2	0.91±0.62
St 3	62	46.0±3.3	0.29±0.54	-		
St 4	24	48.1±2.7	1.09±0.77	-		
St 6	-			45	46.5±4.3	1.57±0.88
St A	11	48.3±5.5	0.97±1.23	33	42.3±5.2	0.82±0.49
St B	45	51.7±4.1	*0.87±0.79	7	46.8±3.1	*1.78±0.821

Mean±SD
* : Student's t test (p<0.05)

Table 4. Comparison of stomach content composition of chum salmon and fat greenling juveniles off the Mashike coast in mid-April, 1995.

Station		St 1	St 1	St 1	St A	St A	St B	St B
Predator Species		*1 *O. k*	*2 *O. k*	*H. o*	*O. k*	*H. o*	*O. k*	*H. o*
Annelida	Polychaeta				0.1			
Mollusca	Gastropoda larvae						0.5	
Arthopoda	*Calanus plumchrus* (Copepodid)		0.2	0.8				0.1
	Eucalanus bungi bungi (Copepodid)		0.1					
	Paracalanus parvus							0.1
	Clausocalanus pergens					0.1	0.1	
	Pseudocalanus minutus			0.3	0.1	0.5		3.6
	Metridia sp. (Copepodid)		0.1	0.9		1.7		2.7
	Tortanus discaudatus	5.1	13.2	0.9	0.8	0.3	1.1	0.4
	Calanoida	0.9	0.8	2.2		0.6	0.7	1.6
	Oncea media		0.1					
	Harpacticus sp.	3.4	0.1		1.2	0.3	0.5	3.3
	Harpacticoida	0.1					0.1	
	Jassa sp.	0.1	0.1				0.2	
	Amphipoda						0.1	
	Tanaidacea (*Anatanais normanni*)	0.3						
	Themisto japonica	0.6	0.1	0.2	2.1	3.3	0.4	
	Zoea of *Anomura*			0.1			4.9	4.7
	Zoea of *Macrura*					0.2	0.1	
	Zoea of *Brachyura*							0.1
	Megalopa of *Brachyura*					0.1		
	Decapoda larvae	0.4						
Prochordata	*Oikopleura spp.*	0.1				0.2		
Vertebrate	Fish larvae	0.2	0.2		0.4	0.2	9.0	1.1

*1 shows larger size chum salmon (FL>50mm) and *2 indicates smaller size one (FL<40mm). The numbers of prey item represent individuals per fish.

Table 5. Comparison of Kimoto's C_n, as a similarity index of stomach content composition between chum salmon and fat greenling juveniles in the Mashike coast in mid-April, 1995.

Species	size	*H. otakii* middle	*H. otakii* small
O. keta	large	0.58(St A) 0.42(St 1)	0.04(St 1)
O. keta	middle	0.41(St B)	
O. keta	small		0.34(St 1)

Large, middle, and small chum salmon had mean fork lengths of, 58mm, 48mm and 41mm, respectively.
Middle and small fat greenling were 47mm and 39mm in mean fork length, respectively.

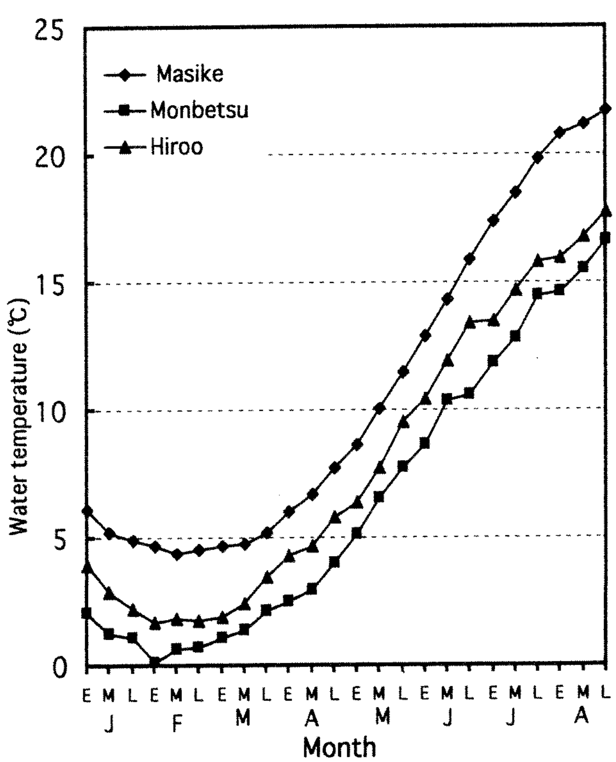
In this study, the size of chum salmon juveniles was similar to that of fat greenling and Kimoto's C_{π}, as a similarity index of stomach content composition, was highest between the two species when fished similar size were compared. However, severe competition for food did not occur, since there was no significant difference of stomach content index between both species. These results suggest that prey resources may be sufficient in the surveyed sites, however, a potential for competition may exist between the two species when prey are scarce.

On the other hand, it was observed that chum and fat greenling juveniles were distributed in narrow areas inshore along the Mashike coast. Distribution pattern of chum salmon in the Mashike coast was different from that of north American region, where juvenile chum salmon inhabit the marsh or estuary during a restricted time after the seaward migration (Kaczynski et al. 1973; Mason 1974; Healey 1979; Congleton et al. 1981; Pearcy et al. 1989). Although there has been a number of reports on the factors affecting the distribution in inshore waters of chum salmon, such as temperature, salinity, flow, prey abundance and predators (Bax 1981; Congleton et al. 1981; Kaeriyama 1989; Pearcy et al. 1989; Irie 1990), we consider that prey abundance and ocean condition are more important for the survival of juvenile chum salmon in the inshore waters of Mashike. Since it has been represented that juvenile chum salmon migrate offshore at a constant body size (approximately 70 mm in fork length), and that they are forced to move offshore at more than about 13°C of seawater temperature (Irie 1985, 1990; Kaeriyama 1989), chum salmon need to grow to a constant body size within a restricted time for survival. Growth of salmon juveniles is influenced by prey abundance, ocean condition and social interaction, such as competition and density-dependent effect (Pearcy 1992).

Strength of Tsushima warm current (TWC) implicates in a resident time of juvenile chum salmon inshore waters of the Sea of Japan, particularly through a higher temperature. Based on changes in surface temperatures of the three coastal regions of Hokkaido, the temperature of Mashike coast begins to increase earliest during the early spring (Fig. 2). As a result, juvenile chum salmon along the Mashike coast have to grow most quickly to reach an offshore migrating size among the three coastal regions. We observed, furthermore, that prey resources of Mashike coast were affected by the development of TWC, and that the change in ocean condition brought a decrease in stomach content (Kawamura and Hirano, unpublished data).

Consequently, it is important for survival that juvenile chum salmon have available good prey resources and grow to a offshore migrating size within a restricted time under a favorable coastal condition, such as lower temperature ranging 6°C to 12°C and lower salinity, before the development of TWC. Also, the interaction between chum salmon and fat greenling juveniles is thought to be important for our understanding the fluctuations in chum salmon stock of the Sea of Japan, because of their similar prey availability and habitat.

Fig. 2 Fluctuations in average surface water temperatures (1990-1996) of Masike, Monbetsu and Hiroo from January to August. Masike, Monbetsu and Hiroo are located along the coasts of the Sea of Japan, the Okhotsk Sea and the Pacific Ocean of Hokkaido, respectively.



CONCLUSIONS

We examined potential interactions between chum salmon and fat greenling juveniles in terms of their distribution, abundance, growth and food habit along the Mashike coast of the Sea of Japan off northern Hokkaido. In mid-April, chum and fat greenling juveniles preferred similar environments. Moreover, similar prey organisms were available for both chum and fat greenling juveniles' food. On the other hand, their distributions inshore were restricted to within one kilometer from the Mashike coast line except for mid-April. As a result, it is suggested that there is a potential for competition between chum and fat greenling juveniles for food and habitat requirements during the early ocean life of chum salmon juveniles.

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