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Effect of Salinity on Food Intake, Growth and Feed Efficiency of Chum Salmon, *Oncorhynchus keta* (WALBAUM), and Ayu, *Plecoglossus altivelis* TEMMINCK et SCHLEGEL

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Abstract

The salinity-growth responses of chum salmon fry and juvenile ayu were studied under an abundant food supply. A precipitous rise in the environmental salinity caused a loss of appetite, reduced growth, and a decreased feed efficiency of chum salmon. The daily feeding rate of chum salmon in seawater was resumed in the second week of the experimental period and thereafter exceeded the rate of that in freshwater. While a decreased daily growth rate and feed efficiency under high salinity was maintained throughout the 35 days of the experimental period, the higher the salinity provided, the lower the growth rate attained. Ayu, which migrate in an opposite direction from chum salmon, exhibited the same reduced growth rate under high salinity after an acclimatization period of 12 days. Contrary to the case of chum salmon, the daily feeding rate of ayu was higher in freshwater. With an increase in the salinity, both species showed decreased whole body protein and fat retention.

I. Introducuction

Studies on the effect of salinity on the growth of fish tend to show conflicting results. Excluding the differences in species (BRETT 1979), the size of fish and such other factors as temperature, light periodicity and the amount of food intake affect the salinity-growth responses (KINNE 1960 ; SHAW et al. 1975 ; CLARKE et al. 1981). In general, euryhaline fishes and postsmolt anadromous salmonids provided with an abundance of food show good growth in high salinities, near full-strength seawater level (BRETT 1979). On the contrary, the growth of chum salmon (*Oncorhynchus keta*) fry reared in seawater were inferior to those reared in freshwater when provided with an abundance of food (KOSHIISHI 1980).

The survival of chum salmon during their early marine-life stage was estimated to be rather low (KOBAYASHI 1977 ; BAKKALA 1970). The causes of mortality during early marine-life are little known. However, it is reasonable to consider the scarcity of food available to small fry and the

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presence of predators as being important causes of mortality. Changes in environmental salinity may also be important. Although chum salmon fry after their yolk sac absorption can survive direct transfer from freshwater to full-strength seawater (KASHIWAGI and SATO 1969), indirect effects of salinity on survival during this stage can not be excluded. Recently, IWATA and KOMATSU (1984) reported on the importance of estuarine residence for adaptation of chum salmon.

The present study was designed to gain information on the salinity-growth responses of chum salmon. Ayu (*Plecoglossus altivelis*) migrate upstream in spring in contrast with chum salmon. In fall they spawn in the streams and spend their marine-life stage during winter (MATSUBARA 1965). Since ayu receive the salinity change that is opposite to that of chum salmon, salinity-growth responses of juvenile ayu are also studied and compared with those of chum salmon.

II. Materials and Methods

Eyed eggs of chum salmon, fertilized at the hatchery of Miomote River Salmon Fisheries Cooperative, were transferred to our laboratory. The fry were reared in freshwater with a commercial salmon diet until the time of the feeding experiment. Artificially fertilized juvenile ayu were obtained from the Murakami Branch, Niigata Prefectural Fish Farming Centre, where they were reared in seawater.

Experiments were carried out in transparent acrylic tanks of 55-liters capacity (Fig. 1). Coastal seawater filtered with sand and city water dechlorinated with activated charcoal were used as water sources. The salinities of the experimental tanks with running water were adjusted by mixing the seawater and freshwater from constant head tanks with teflon valves. Mixed water was introduced to each tank at a rate of 800 ml per minute. The water temperature was controlled by means of water cooling units and quartz-glass heaters and kept equal in all tanks. Continuous aeration was provided in the experimental tanks. From the onset of preliminary feeding, both chum salmon and ayu were fed a synthetic diet as moist pellets (Table 1). Chum salmon were fed 4 times a day to satiation except Sunday until fish stopped caring for dropping pellets. Care was taken to ensure that no pellet remained un-ingested. Ayu were fed 3 times a day in the same manner.

Chum salmon fry of the same size, weighing about 1 g, were selected and divided into 5 lots of 60. They were fed in freshwater to accustom them to the experimental diet for 14 days of preliminary feeding. After an initial weighing, the salinity (0, 8, 16, 24 and 32‰) of each tank was adjusted within 6 hours. Body weights of the fish in each tank after 36 hours

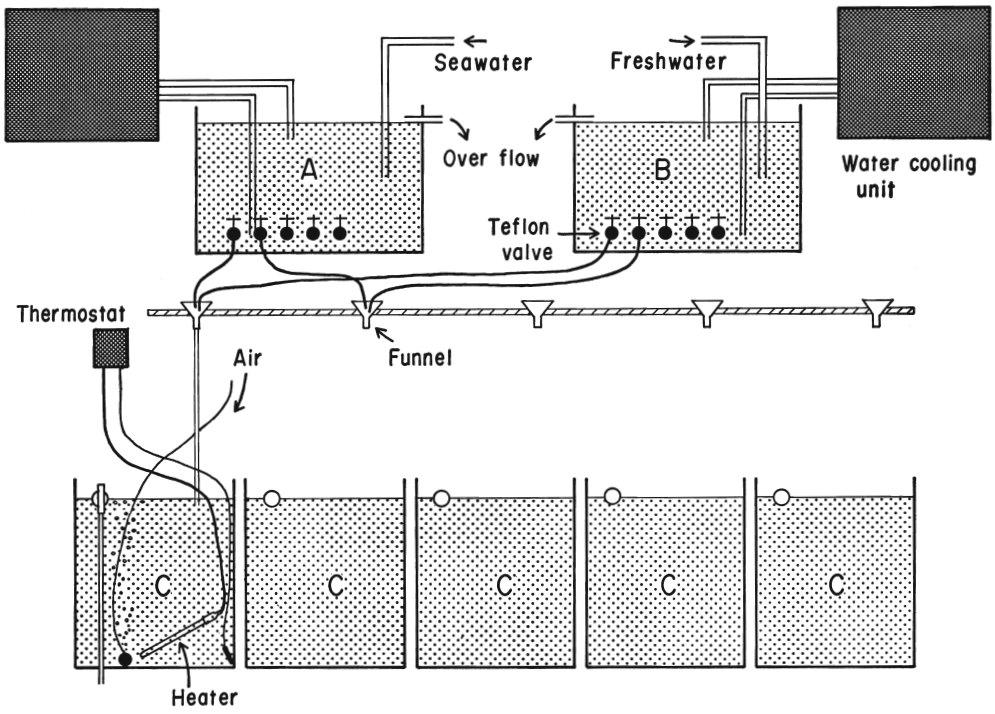

Fig 1. Schematic view of the experimental apparatus.
The salinities were adjusted by mixing the seawater and the freshwater from constant head tanks with teflon valves.
A : Seawater tank, B : Freshwater tank, C : Rearing tank

Table 1. Composion and proximate analyses of the experimental diet.

Casein [a)]	55
Dextrin	20
Cellulose powder	5
Carboxymethyl cellulose	5
Pollack liver oil [b)]	10
Mineral mixture [c)]	4
Vitamin mixture [d)]	1
Water	60
Moisture	37.4
Crude protein [e)]	55.6
Crude fat [e]	11.0

a) Supplemented with the following amounts of amino acids per 100g ; 3g L-Arg, 0.2g L-Try, 0.1g L-Lys · HCl, 0.5g L-His, 0.2g L-Met, 0.5g L-Cys. (Nose et al. 1979)
b) Contained vitamin A, 2000IU/g.
c) U.S.P. XII. salt mixture no.2 supplemented with trace minerals.
d) Supplied the following amounts per 1g mixture ; thiamin-HCI 6mg, riboflavin 20mg, pyridoxin-HCI 4mg, vitamin B_{12} 0.01mg, ascorbic acid 220mg, nicotinic acid 40mg, calcium pantothenate 10mg, inositol 220mg, biotin 0.6mg, folic acid 1.5mg, p-aminobenzoic acid 12mg, cholin chloride 400mg, cholecalciferol 4000IU, methyl naphthoquinone 5mg, α-tocopherol acetate 60mg. Cellulose powder was used as diluent.
e) % dry weight.

of food deprivation were determined on the 1st, 8th, 15th, 29th and 35th (final) days of the experimental period. All fish in each lot were dipped on a nylon net and excess water was blotted with a damp towel, and weighed in a bowl containing a known weight of water. Random samples of 4-8 fish of each lot were taken on the 1st, 8th, 15th and 35th days for the analyses of body composition.

Juvenile ayu reared in seawater were divided into two lots, seawater and freshwater. Acclimatization of the fish from the freshwater lot was accomplished within two days by a gradual decrease in the salinity. After 10 days of preliminary feeding, 28 fish of each were fed for 28 days. Weighing and sampling was carried out on the 1st and 28th days in the same manner as with chum salmon.

Daily feeding rates (f) and daily growth rates (g) were calculated by the equations :

$f = F / \{t \cdot (W_o + W_t)/2\} \times 100$, $g = (W_t - W_o) / \{t \cdot (W_o + W_t)/2\} \times 100$

where F=dry weight of food intake for t days, W=wet body weight at start and t days after. Feed efficiency (fe) was calculated as follows :

$$fe = (W_t - W_o) / F \times 100$$

Chemical analyses was carried out on the homogenized whole fish and diet. The dry weights were determined by drying the samples to a constant weight at 105°C. Crude protein was estimated by multiplying the value of micro-Kjeldahl nitrogen by 6.25. Crude fat was determined after extraction with chloroform-methanol mixture (2 : 1). The salinity was measured 2-4 times per week by an inductively coupled salinometer (Auto Lab Industries).

III. Results

1. Chum Salmon

The feeding experiment was carried out from April through May. Although the salinities were adjusted precipitously within 6 hours, no fish showed abnormal swimming activity, even when they received the change of 32‰. Results of the feeding experiment are summarized in Table 2. A slight mortality was observed in lot S100 after 15 days of feeding. The capacity of the cooling units was too small to keep the water temperature constant throughout the experimental period. However, the temperature was kept equal in all lots during each period (see Table 2 footnote), and the validity of comparing the relative effect of salinity is not doubted.

Maximun growth was attained with the freshwater lot (Fig. 2). The higher the salinity was adjusted, the lower was the growth shown. To simplify the description of the salinity effect on growth, the daily growth rates were transformed to relative values using those of lot F as 100 in

Table 2. Effect of salinity on feeding rate, growth rate and feed efficiency of chum salmon. [a)]

Lot	Feeding period (days)	Salinity Av (SD) (‰)	Percent weight gain	Daily feeding rate (dry/wet, %)	Daily growth rate (wet/wet, %)	Feed efficiency (wet/dry, %)	Mortality (%)
F	1- 7	0.00	36.4	2.39	4.39	184	0
	8-14		33.3	2.53	4.08	161	0
	15-28		78.5	2.47	4.03	163	0
	29-35		21.6	1.99	2.78	140	0
S 25	1- 7	8.23 (0.52)	30.7	2.34	3.80	163	0
	8-14		29.0	2.50	3.62	145	0
	15-28		78.7	2.54	4.03	159	0
	29-35		22.6	2.10	2.91	138	0
S 50	1- 7	16.42 (0.88)	23.6	2.30	3.02	131	0
	8-14		29.5	2.57	3.67	143	0
	15-28		73.0	2.72	3.82	140	0
	29-35		19.1	2.20	2.49	113	0
S 75	1- 7	24.35 (1.06)	12.5	1.75	1.68	96	0
	8-14		27.3	2.47	3.43	139	0
	15-28		74.5	2.79	3.88	139	0
	29-35		16.5	2.55	2.18	85	0
S100	1- 7	32.00 (1.13)	4.8	1.33	0.67	50	0
	8-14		20.8	2.49	2.69	108	0
	15-28		54.1	2.71	3.04	112	4.3
	29-35		17.2	2.63	2.26	86	2.3

a) Water temperature was kept at 12°C for 1-18 days, 13°C for 19-20 days, 14°C for 21-27 days and 16°C for 28-35 days of the feeding period.

each experimental period. In the first week, a striking decline in the relative daily growth rates was shown with an increase in salinity (Fig. 3). In this week, the growth rate of fish in full-strength seawater was shown to be only 15% of that in freshwater. Although the decline became more gentle thereafter, above 16‰, the growth rates never exceeded the rates in freshwater during the 35 days of the experimental period. In the 5th week, the only case in which the growth rate was higher than that in freshwater was shown in lot S25. The decreased growth rate in all lots in the 5th week (Table 2) may have been caused by the rise in temperature.

The daily feeding rates (Table 2) were also influenced markedly by the salinity, however this was in a somewhat different manner from that of the growth rates. Again, the relative values are shown as being the same as in growth rates (Fig. 4). In the 1st week, a decline in the relative daily feeding rates was shown with an increase in the salinity. The decline was heavy in lots S100 and S75. In the 2nd week, the relative daily feeding rates in these lots increased to about the same level as that in lot F. Above 8‰, the relative daily feeding rates beyond 100 were shown after the 3rd week. In the 5th week, the feeding rates in lots S75 and S100 were about 30% higher than that in lot F.

As with the growth rates, the highest feed efficiency was attained in the freshwater lot. A marked decline in the relative feed efficiency was shown with the increase in salinity in the 1st week (Fig. 5). Although the

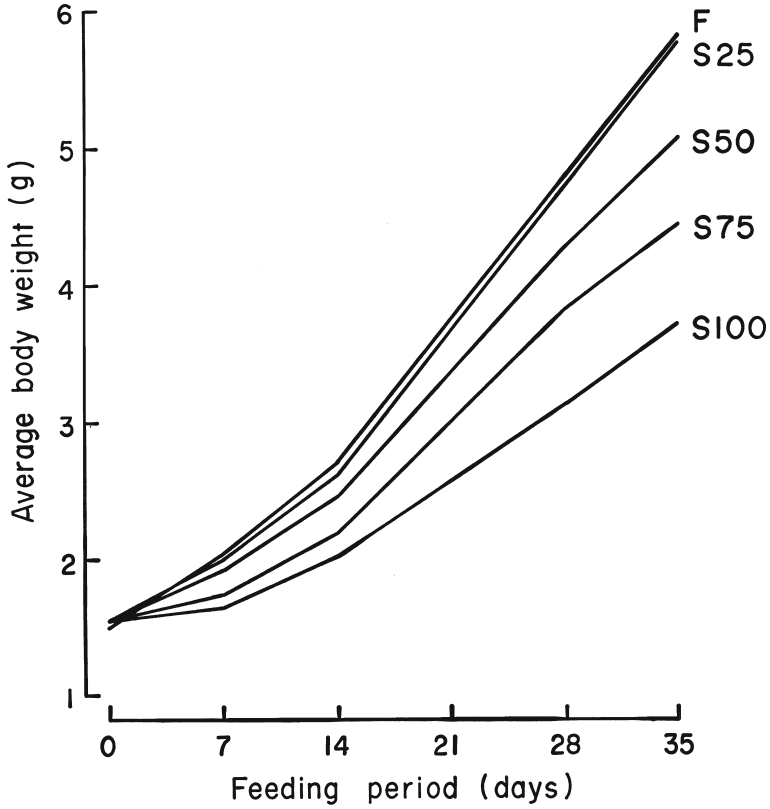

Fig 2. Growth of chum salmon fed under different salinity. Average salinity (‰) of each lot was ; F=0.00, S25=8.23, S50=16.42, S75=24.35, S100=32.00

decline became more gentle after the 2nd week, a consistent decline with the incerase in the salinity was shown. High feed efficiency and especially the values above 150 exhibited in lots F and S25 suggests a good growth performance with the experimental diet.

The proximate compositions of whole fish at prescribed days are shown in Table 3. As expected, the moisture content decreased with growth in all lots. However, slight differences were found among the lots on each sampling day. Crude protein increased with growth. Although somewhat higher crude protein contents were obtained in the lots above 8‰ than those in lot F, no trend related to the salinity among lots S25-S100. Crude fat again increased with growth, and a decreasing tendency was obtained with the increase in salinity on each sampling day.

2. Ayu

The feeding experiment was carried out in June. The acclimatization to freshwater and the experimental diet was performed smoothly.

As was the case with chum salmon, fish fed in freshwater exhibited

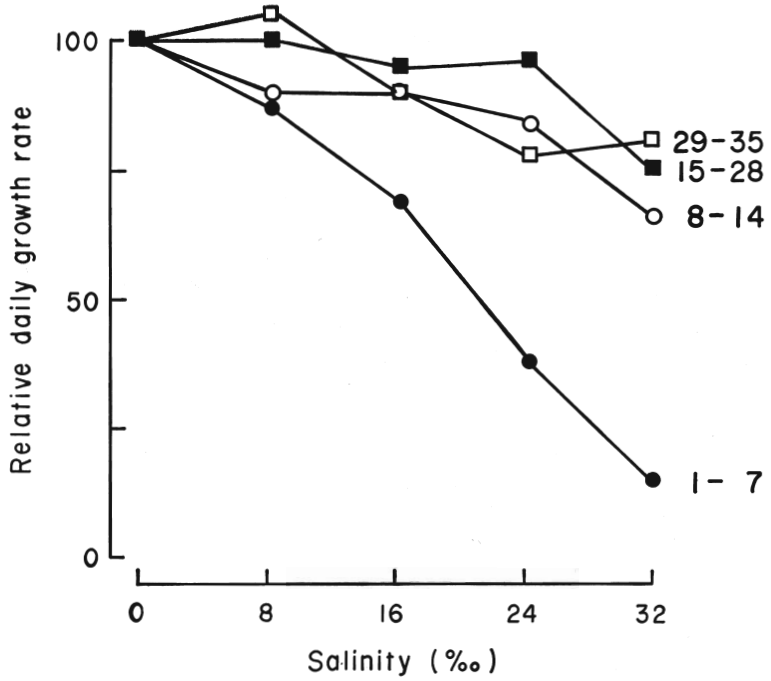

Fig 3. Change in the relative daily growth rate of chum salmon fed under different salinity.
Numerals on the right side represent the feeding period (days.)

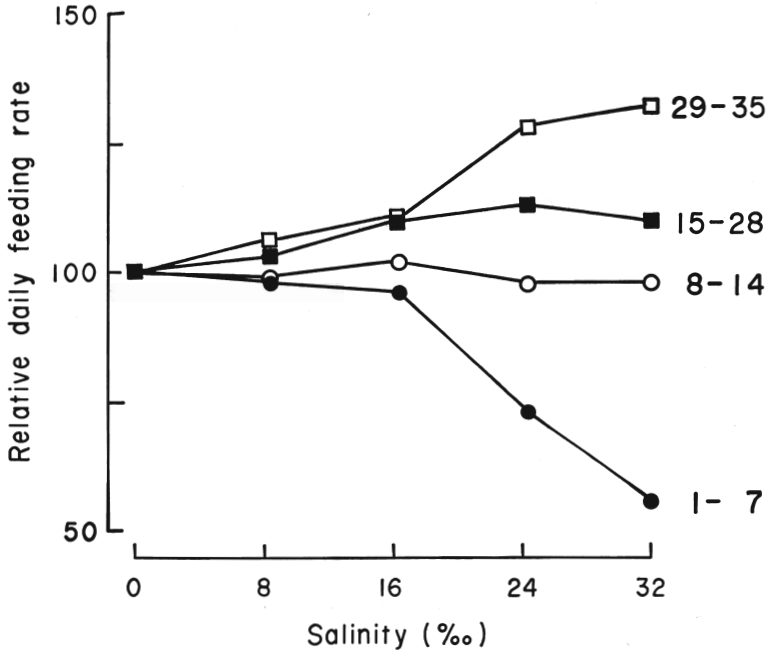

Fig 4. Change in the relative daily feeding rate of chum salmon fed under different salinity.
Numerals on the right side represent the feeding period (days).

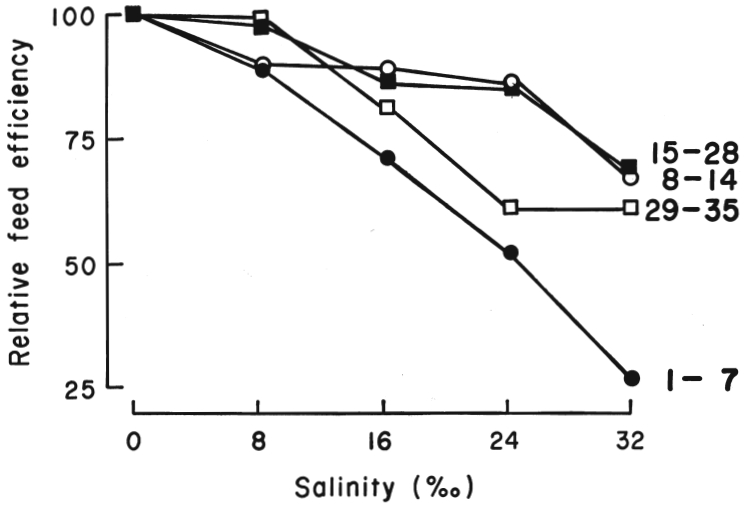

Fig 5. Change in the relative feed efficiency of chum salmon fed under different salinity.
Numerals on the right side represent the feeding period (days).

Table 3. Effect of salinity on proximate compositions [a] of whole body of chum salmon.

Feeding period (days)	Lot (Salinity, ‰)				
	F (0.00)	S25 (8.23)	S50 (16.42)	S75 (24.35)	S100 (32.00)
			Moisture		
Initial	80.6				
7	79.6	79.8	78.9	78.9	80.1
14	79.0	78.9	79.0	78.9	79.5
35	77.0	76.8	76.5	77.5	77.3
			Crude protein		
Initial	14.3				
7	14.5	14.8	15.2	15.3	15.0
14	14.5	15.1	15.0	15.3	15.2
35	15.8	16.6	16.3	16.2	16.4
			Crude fat		
Initial	3.97				
7	4.26	4.28	4.38	4.36	3.55
14	4.51	4.52	4.48	4.27	3.53
35	5.46	5.47	5.44	4.83	4.50

a) % wet weight

better growth than those in seawater (Table 4, Fig. 6). In freshwater, a higher daily growth rate was obtained in the latter half of the experimental period. In seawater, however, a constant daily growth rate was displayed. A slight mortality was observed in the seawater lot.

The daily feeding rate was higher in freshwater and an increase with time was shown in both lots.

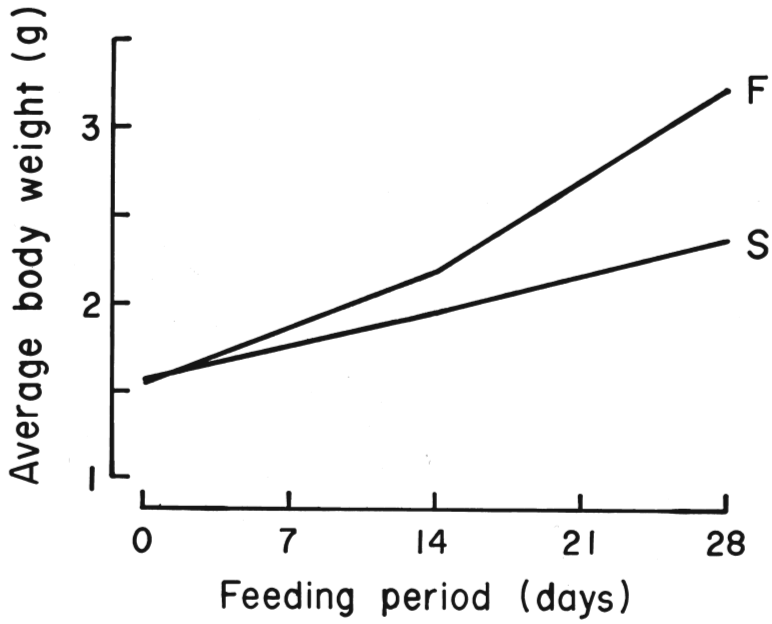

Fig 6. Growth of ayu fed in seawater (S) and freshwater (F).

Table 4. Feeding rate, growth rate and feed efficiency of ayu fed in seawater and freshwater. [a)]

Lot	Feeding period (days)	Salinity Av (‰)	Percent weight gain	Daily feeding rate (dry/wet, %)	Daily growth rate (wet/wet, %)	Feed efficiency (wet/dry, %)
F	1–14	0.00	41.1	2.80	2.44	87
	15–28		49.3	3.01	2.83	94
S	1–14	32.17	23.3	2.34	1.49	64
	15–28		23.1	2.38	1.48	62

a) Water temperature was kept at 21.5°C.

The feed efficiency was also higher in freshwater. In the latter half of the experimental period, a rising trend in the feed efficiency was shown in freshwater. The opposite trend was true in seawater. It appears that the relatively low values attained in feed efficiency, compared with those of chum salmon, can be attributable to the difference in the feeding habits of both species (MATSUBARA 1965) and difference in the experimental temperatures.

The proximate compositions of whole fish at the 1st and 28th days are shown in Table 5. In both lots, moisture contents decreased with time or with growth, and an especially clear decrease was observed in lot F. Although a somewhat higher protein content was shown in lot S of the initial sample, the protein contents of both lots were the same in the final sample.

Table 5. Proximate compositions [a] of whole body of ayu fed in seawater and freshwater.

	Lot (Salinity, ‰)	
	F (0.00)	S (32.17)
	Moisture	
Initial	76.7	75.5
Final	72.4	74.2
	Crude protein	
Initial	14.2	14.7
Final	14.2	14.3
	Crude fat	
Initial	6.07	6.89
Final	9.94	7.93

a) % wet weight

Crude fat increased with growth in both lots. The highest crude fat content of 9.94% was detected in lot F of the final sample.

IV. Discussion

The results of the present experiment indicate that an abrupt rise in the environmental salinity decreases the growth rate of chum salmon fry, in spite of their ability to survive a direct transfer to full-strength seawater after their yolk sac absorption (KASHIWAGI and SATO 1969). Within the first week of the experimental period, even when the fish recieved only an 8 ‰ change in the salinity a clear decrease in the daily growth rate was shown. A simultaneous decrease in the daily feeding rate, especially under high salinity, was shown in this week.

The daily feeding rates under high salinity resumed in the 2nd week and increased thereafter. On the other hand, the daily growth rates under high salinity never exceeded the rates in the freshwater lot during the 35 days of the experimental period. Moreover, after 60 days of preliminary rearing in seawater and freshwater, it had been observed that the growth rate of chum salmon fed to satiation in seawater was still lower than that in freshwater (KOSHIISHI 1980). From these findings, two distinct periods of salinity-growth response may be suggested, namely acute and sub-acute periods of the salinity effect corresponding to the 1st week and thereafter to the experimental period respectively.

A precipitous change in the salinity such as 32‰ may cause a severe physiological stress. The acute effect of salinity on chum salmon is characterized by the loss of appetite. Adjustive periods of osmotic concentration of chum salmon fry were reported to be one or two days, determined by whole body chloride (HOUSTON 1961) or plasma sodium concentration (IWATA et al. 1982). However, when fry experienced a change of 24‰ or more, appe-

Table 6. Protein efficiency ratio, protein and fat retained[a] in whole body of chum salmon fed under different salinities.

Feeding period (days)	Lot (Salinity, ‰)				
	F (0.00)	S25 (8.23)	S50 (16.42)	S75 (24.35)	S100 (32.00)
	Protein efficiency ratio				
1- 7	3.31	2.92	2.36	1.72	0.91
8-14	2.90	2.61	2.57	2.50	1.95
15-35	2.78	2.72	2.35	2.13	1.84
	Crude protein retained				
1- 7	49.8	48.1	44.9	40.1	26.8
8-14	42.1	42.1	36.9	38.2	31.5
15-35	46.9	48.6	41.2	36.3	32.8
	Crude fat retained				
1- 7	84.5	78.2	73.0	65.1	−23.8
8-14	77.1	70.5	62.8	49.8	33.8
15-35	88.0	86.2	75.4	57.8	52.9

a) (protein or fat increased)/(protein or fat intake), %

tite loss lasted at least one week. The fairly low feed efficiency and the negative value of crude fat retained (Table 6) as exhibited by lot S100 in the 1st week imply a rise in catabolic metabolism to cope with the severe change in salinity.

The sub-acute effect of salinity on chum salmon is characterized by the low feed efficiency. The low growth rates under high salinity during this period may be attributable to the low feed efficiency. Two mechanisms may be implicated to elucidate the cause of this low feed efficiency : a decrease in the absorption efficiency and an increase in the metabolic cost. It is not possible to clarify the cause of the low feed efficiency from the present study. Further work along a similar line would shed more light on this problem.

Reduced growth under high salinity is inconsistent with the fact that the larger mean size of fish which are found in both seawater and freshwater attained in the marine environment (CANAGARATNUM 1959), though the comparison seems to be difficult owing to the variables such as temperature and the amount and types of food. KASHIWAGI and SATO (1968) and SATO and KASHIWAGI (1968) reared chum salmon in a saltwater pond and freshwater pond for three years, and reported comparative growth, survival rates and some blood properties of the two fish groups. They reported that the growth was better in the saltwater group than in the freshwater group. However, the figure reported by KASHIWAGI and SATO (1968) illustrates that the growth would be better in the freshwater group than in the saltwater group if they were compared within 6-9th month after hatching. From their results it seems that the reduced growth rate under high salinity is not intrinsic but a passing phenomenon.

Table 7. Protein and fat retained[a] in whole body of ayu fed in seawater and freshwater.

	Lot (Salinity, ‰)	
	F (0.00)	S (32.17)
Crude protein retained	23.3	14.8
Crude fat retained	111.5	56.6

a) (protein or fat increased)/(protein or fat intake), %

Ayu migrate in an opposite direction from chum salmon and receive an opposite change in salinity under natural conditions. However, ayu showed the same reduced growth under high salinity as chum salmon. The result of the feeding experiment is comparable with that of chum salmon after 14 days since the feeding experiment was carried out after 12 days of acclimatization and preliminary feeding. There is a marked difference in the salinity effect on the daily feeding rate between the two species compared under the criterion mentioned above. Ayu showed an increased daily feeding rate in freshwater, in contrast to chum salmon. The activated metabolic rate controlled by the endocrine system arranged for migration (BAGGERMAN 1960) involving the environmental salinity change may demand the rise in food intake of both species. The feed efficiency and the protein and fat retained (Table 7) were lower in seawater. It is well known that the feed efficiency decreases with an increase in food intake. The higher food intake was attained in freshwater in the case of ayu, while the opposite result was found with chum salmon. Consequently, the reduced feed efficiency in seawater of both species seems to be affected by the salinity rather than the amount of food intake.

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サケおよびアユ稚魚の摂餌，成長ならび飼料効率に対する塩分の影響

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要　約

サケ稚魚の成長と塩分との関係を，0，8，16，24，32‰の5条件下で5週間の飽食給餌での飼育実験により調べた．飼育水塩分の急激な上昇により，第1週には摂餌率，成長率，飼料効率の低下が認められた．高塩分下における摂餌率は第2週には淡水区の水準まで回復し，その後これを上回った．一方，成長率および飼料効率は実験期間を通して淡水区の値より低く，塩分が高いほど成長が悪い結果を得た．

サケとは逆に海水から淡水への回遊を行うアユ稚魚について，海水および淡水でそれぞれ28日間の飼育を行ったところ，成長率はサケと同様に海水中で低かったが，摂餌率は淡水中で高くなった．全魚体への蛋白質および脂質の蓄積率は両種とも塩分の上昇により低下した．