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Effect of Feeding Level and Dietary Composition on Growth and Feed Efficiency of Chum Salmon, *Oncorhynchus keta* (WALBAUM), Fed in Seawater and Freshwater

YUICHI KOSHIISHI[1)]

Abstract

The detrimental effect of salinity on the growth of chum salmon fry was shown irrespective of the feeding level and type of synthetic diet, under laboratory conditions. Fish weighing about 1.4g were fed on two types of synthetic diets under two different feeding regimes for 28 days. Compared under the same other conditions of feeding level and type of diet, the daily growth rates in freshwater were 1.5 times higher than those in seawater. The low growth rate in seawater was brought about through the decrease in feed efficiency in seawater. A possible explanation of the low feed efficiency is the high rate of gastric evacuation in seawater which would cause a decrease in the absorption efficiency without any change in the rate of digestion. In seawater, decreses in the protein efficiency ratio and the protein and fat retention in whole fish were shown. Consequently, a rise in metabolic rate in fish in seawater is implied.

I. Introduction

It is well known that chum salmon (*Oncorhynchus keta*) fry exhibit a good adaptability to seawater (KASHIWAGI and SATO 1969) and seawater preference (BAGGERMAN 1960). However, the growth and feed efficiency of the fry fed an abundance of food in seawater was inferior to those fed in freshwater (KOSHIISHI 1980, 1985), or at least as reared under laboratory conditions for 4-5 weeks.

On the other hand, the growth of chum salmon in the early marine-life stage is estimated to be better than that in the stream-life stage (KOBAYASHI 1977). Many factors such as temperature, food types and amount, and the effect of confinement etc. must be checked in considering the opposite effect of salinity on growth under natural and laboratory conditions. Among these factors, the amount of food intake was studied in this paper.

Daily feeding rate is influenced by the frequency of feeding. Generally, the daily feeding rate increases and reaches an asymptote with an increase

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1) Japan Sea Regional Fisheries Research Laboratory. Suido-cho, Niigata 951, Japan.
(〒951 新潟市水道町1丁目5939-22 日本海区水産研究所)

in frequency (Ishiwata 1969 ; Kono and Nose 1971). Daily feeding rate is also influenced by changes in the satiation amount when different kinds of food are fed (Ishiwata 1968). Two feeding levels and two types of synthetic diets were introduced in the feeding experiment in this study. The effect of salinity on the rate of gastric evacuation was also studied to gain some information on the mechanism which controls the food intake and feed efficiency.

II. Materials and Methods

1. Feeding experiment

Eyed eggs fertilized at the hatchery of Miomote River Salmon Fisheries Cooperative were transferred to our laboratory. The fry were reared in freshwater and fed with beef liver for a week after the onset of feeding and a synthetic diet thereafter.

Eight rearing conditions, combinations of two salinities, two types of synthetic diets (Table 1) and two feeding levels were arranged (Table 2). The diets were fed as moist pellets. Experiments were carried out in transparent acrylic tanks of 55-liters capacity with running water and continuous aeration. Fry were fed 6 days a week, except Sunday. The water temperature was kept equal in all tanks.

Fry of the same size were selected and divided into two groups of 4 lots each. Seawater group fish received a gradual change in salinity from freshwater to full-strength seawater within a week. Then the fish of both

Table 1. Composition and proximate analyses of the experimental diets.

Ingredient	F	C
White fish meal	75	--
Casein [a]	--	55
Dextrin	5	20
Cellulose powder	5	5
Carboxymethyl cellulose	5	5
Pollack liver oil	5	10
Mineral mixture [b]	4	4
Vitamin mixture [b]	1	1
Water	65	65
Moisture	41.1	39.1
Crude protein [c]	51.5	55.6
Crude fat [c]	12.3	11.0

a) Supplemented with the following amounts of amino acids per 100 g ; 3 g L-Arg, 0.2 g L-Met, 0.5 g L-Cys. (Nose et al. 1979)

b) Same as the previous paper. (Koshiishi 1985)

c) % dry weight

Table 2. Rearing conditions of the eight experimental lots.

Lot	Water supply	Protein source of the experimental diet	Feeding level
SFS [a]	Seawater [b]	Fish meal	Satiated [d]
SCS	Seawater	Casein	Satiated
FFS	Freshwater [c]	Fish meal	Satiated
FCS	Freshwater	Casein	Satiated
SFR	Seawater	Fish meal	Restricted [e]
SCR	Seawater	Casein	Restricted
FFR	Freshwater	Fish meal	Restricted
FCR	Freshwater	Casein	Restricted

a) Abbreviated the rearing conditions as following : First letter (water supply) : S;Seawater, F;Freshwater. Middle letter (protein source of the diet) : F; Fish meal, C;Casein. Last letter (feeding level) : S;Satiated, R;Restricted.
b) Coastal seawater filtered with sand.
c) City water dechlorinated with activated charcoal.
d) Fed 6 times a day from 6 : 00 to 18 : 00 to satiation until fish stopped caring for dropping pellets at each time.
e) Fed twice a day with the restricted ration of 1.8% (dry/wet) of the body weight determined at the begining of each week.

groups were fed for 4 weeks to allow for experimental temperature and salinity acclimatization. After the second size selection, one more week of acclimatization was provied for the experimental diets.

Sixty fry, weighing about 1.4g, were assigned to each tank and fed for 28 days under the conditions prescribed. Body weights were determined weekly. The other procedures such as weighing, calculation of experimental data and chemical analyses were the same as described previously (Koshiishi 1985).

2. Gastric evacation

The rate of gastric evacuation in seawater and freshwater was determined by means of serial slaughter. After 90 days or more of rearing in seawater and freshwater with commercial diets, 40 fry of the same size were assigned to each tank. They were fed on the experimental diet (Diet C) once a day to satiation at 16°C for 10 days. Five fish from each tank were taken at prescribed times after the last feeding. Deeply anaesthetized fish were frozen until the time for dissection. The stomach contents were taken out as frozen bulbs. The dry weight of the stomach contents was determined and expressed as a fraction of the dry body weights.

III. Results

1. Feeding experiment

The experiment was carried out from April through May. Although

Table 3. Water temperature during the experimental period.

Lot	Temperature (Average(SD), °C)			
	1st week	2nd week	3rd week	4th week
SFS	10.2(0.2)	10.6(0.3)	11.2(0.7)	12.3(0.2)
SCS	10.2(0.3)	10.3(0.2)	11.1(0.9)	12.5(0.2)
FFS	10.3(0.2)	10.5(0.4)	11.1(0.4)	12.3(0.7)
FCS	10.2(0.3)	10.4(0.5)	11.1(0.9)	12.7(0.5)
SFR	10.3(0.2)	10.5(0.3)	11.1(0.7)	12.3(0.2)
SCR	10.3(0.4)	10.3(0.1)	11.2(0.9)	12.4(0.2)
FFR	10.5(0.6)	10.3(0.3)	11.1(0.9)	12.8(0.7)
FCR	10.3(0.4)	10.2(0.2)	11.1(0.8)	12.8(0.8)

Table 4. Results of 28 days feeding experiment of chum salmon under different rearing conditions.

Lot	Feeding period (week)	Daily feeding rate (dry/wet, %)	Percent weight gain	Daily growth rate (wet/wet, %)	Feed efficiency (wet/dry, %)	Mortality (%)
SFS[a)]	1st	2.60	23.1	2.96	114	0
	2nd	3.04	20.7	2.68	88	3.4
	3rd	3.19	20.1	2.61	82	1.8
	4th	3.04	14.1	1.88	62	1.8
	Average	(2.97)	(19.5)	(2.53)	(87)	
SCS	1st	2.36	18.8	2.45	104	0
	2nd	2.26	21.8	2.81	125	3.4
	3rd	2.38	22.7	2.91	122	0
	4th	2.34	15.4	2.04	87	3.5
	Average	(2.34)	(19.7)	(2.55)	(110)	
FFS	1st	3.00	35.8	4.34	145	0
	2nd	3.52	33.0	4.04	115	0
	3rd	3.66	31.9	3.93	108	0
	4th	3.60	24.0	3.06	85	0
	Average	(3.45)	(31.2)	(3.84)	(113)	
FCS	1st	1.94	36.9	4.45	229	0
	2nd	2.00	31.2	3.85	192	0
	3rd	2.29	28.8	3.60	157	0
	4th	2.26	23.7	3.02	134	0
	Average	(2.12)	(30.2)	(3.73)	(178)	
SFR	1st	1.38	8.3	1.14	83	0
	2nd	1.49	9.8	1.33	90	3.3
	3rd	1.55	7.3	1.00	65	3.4
	4th	1.51	6.4	0.88	59	1.8
	Average	(1.48)	(8.0)	(1.09)	(74)	
SCR	1st	1.39	12.3	1.66	119	0
	2nd	1.52	11.5	1.56	102	0
	3rd	1.55	10.1	1.38	68	1.7
	4th	1.53	7.2	1.00	65	3.4
	Average	(1.50)	(10.3)	(1.40)	(89)	
FFR	1st	1.35	12.4	1.67	123	0
	2nd	1.46	13.7	1.83	125	0
	3rd	1.48	12.8	1.71	115	0
	4th	1.44	10.4	1.41	97	0
	Average	(1.43)	(12.3)	(1.66)	(115)	
FCR	1st	1.37	16.7	2.21	161	0
	2nd	1.47	16.8	2.22	150	0
	3rd	1.49	15.7	2.08	139	0
	4th	1.45	14.9	1.99	137	0
	Average	(1.45)	(16.0)	(2.13)	(147)	

a) Abbreviation : See Table 2 footnote.

the water temperature (Table 3) of each lots was not exactly the same, the differences among the lots were within 0.15°C/day throughout the experimental period. Results of the feeding experiment are summarized in Table 4. A slight mortality was observed only in the seawater lots namely lots SFS, SCS, SFR and SCR. However, no clear trends in mortality among these lots were shown.

As a matter of course, the daily feeding rates in satiated lots in each week were higher than those in restricted lots, and ranged from 2.12 to 3.45% on the average of 4 weeks with the maximum of 3.66% in lot FFS in the 3rd week. The daily growth rates and the consequent percent gain were influenced primarily by the feeding level. The rate of those in satiated lots were higher than those in restricted lots. The highest value, 3.84% on the average of 4 weeks, was attained in lot FFS, though the highest average body weight was attained in lot FCS (Fig. 1). This reflects the difference between the initial body weights. The feed efficiency was primarily influenced by the salinity rather than the feeding level.

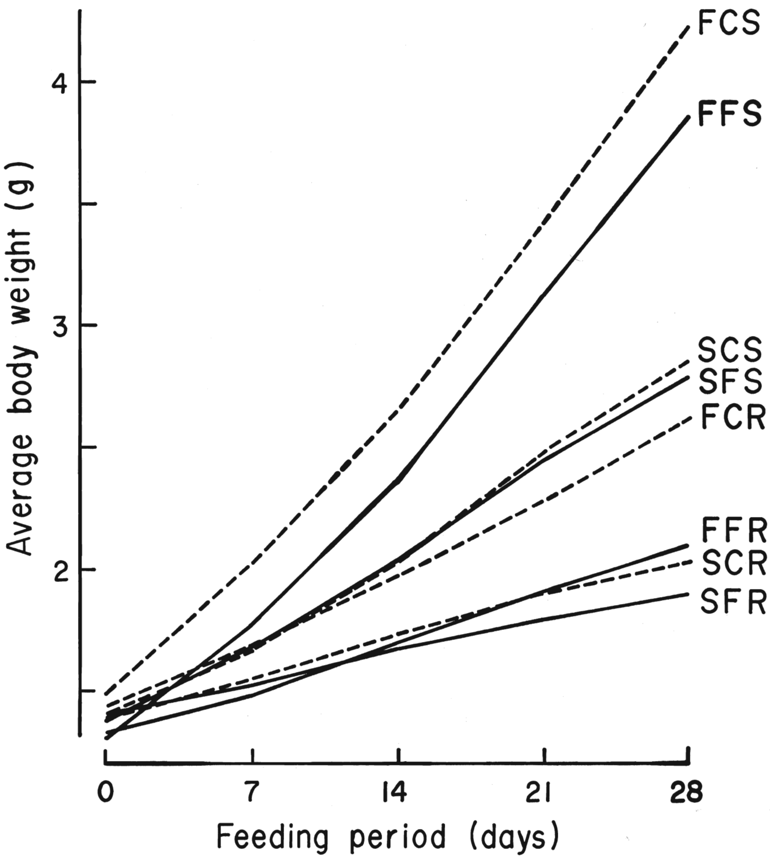

Fig. 1. Growth of chum salmon fed under eight different rearing conditions.
Abbreviation of each lot : See Table 2 footnote.

To simplify the description of the effect of the rearing conditions, the ratio of freshwater to seawater (Fig. 2), satiated to restricted (Fig. 3) and casein diet to fish meal diet (Fig. 4) under the same other conditions in turn were calculated on the average value basis as to the daily feeding rate, percent gain, daily growth rate and feed efficiency, respectively.

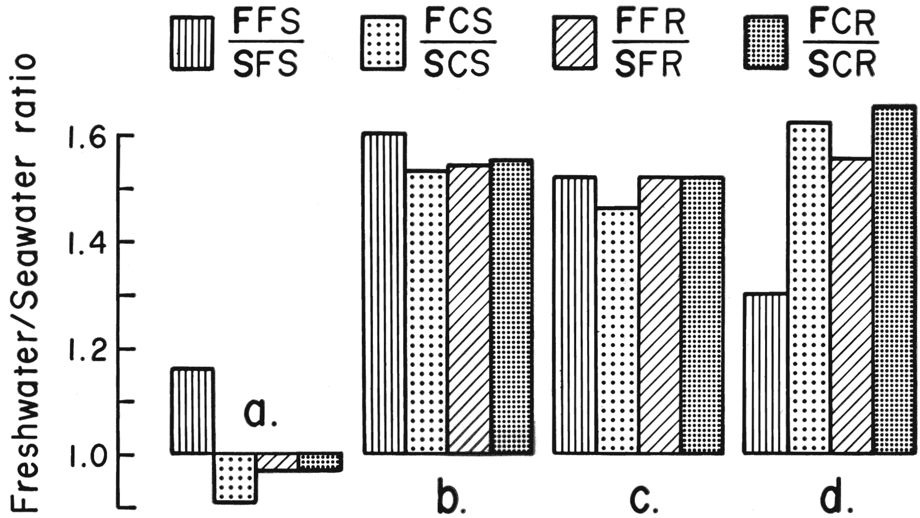

Fig. 2. Effect of salinity on daily feeding rate (a), percent gain (b), daily growth rate (c) and feed efficiency (d) of chum salmon represented as the ratio under the same other conditions.

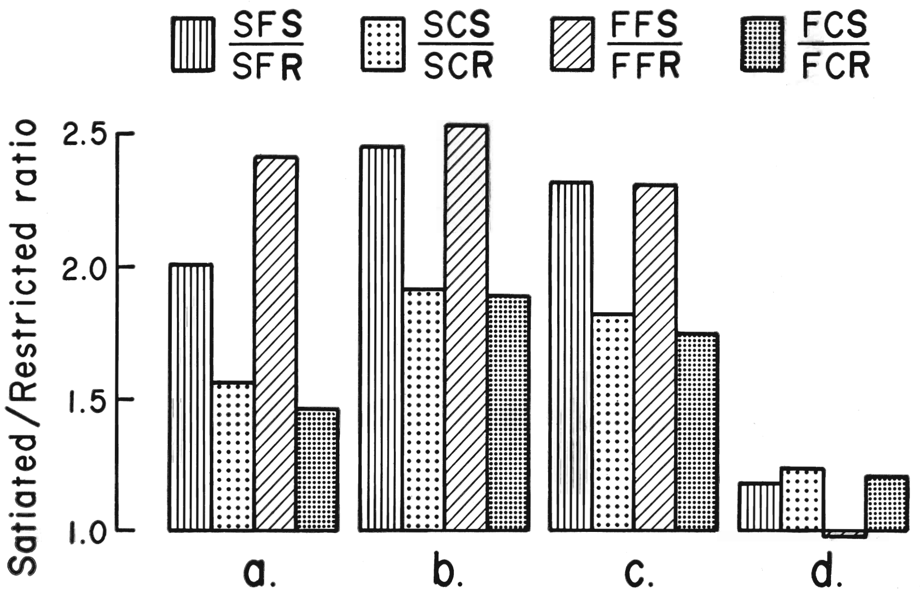

Fig. 3. Effect of the feeding level on daily feeding rate (a), percent gain (b), daily growth rate (c) and feed efficiency (d) of chum salmon represented as the ratio under the same other conditions.

Effect of salinity —— Growth rates were influenced markedly by salinity. The daily growth rates in freshwater were about 1.5 times higher than those in seawater (Fig. 2-c), while, the daily feeding rates were not so much affected as the growth rates (Fig. 2-a). When fed to satiation, the daily feeding rate with fish meal diet in freshwater was higher than that in seawater. On the other hand, the opposite was true with the casein diet. In all cases, the feed efficiency in freshwater was much higher than that in seawater (Fig. 2-d). A minimum ratio of 1.3 in feed efficiency was shown when fed to satiation with the fish meal diet.

Effect of the feeding level —— A more striking effect of the feeding level, irrespective of salinity, on the daily growth rates was shown with the fish meal diet compared with the casein diet (Fig. 3-c). This reflects the difference in the ratio of the daily feeding rates (Fig. 3-a). Relatively little effect of the feeding level on the feed efficiency was shown (Fig.3-d).

Effect of the types of diet —— When fed to satiation, a slight difference in the daily growth rates was shown between the casein diet and the fish meal diet (Fig. 4-c), while, the daily feeding rates with the casein diet were much lower than those with the fish meal diet (Fig. 4-a). Although the differences in the daily feeding rate among the lots under the restricted ration were not significant, the daily growth rates with the casein diet were about 1.3 times higher than those with the fish meal diet. Irrespective of the salinity or feeding level, the feed efficiency with the casein diet was

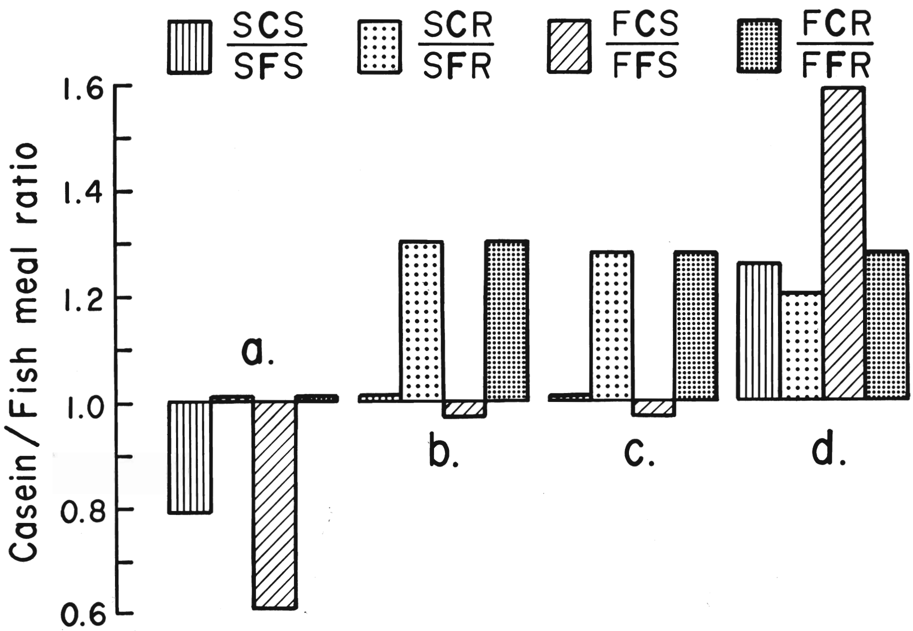

Fig. 4. Effect of the types of diet on daily feeding rate (a), percent gain (b), daily growth rate (c) and feed efficiency (d) of chum salmon represented as the ratio under the same other conditions.

higher than that with the fish meal diet (Fig. 4-d).

The proximate compositions of whole fish at the onset and the end of the experiment were shown in Table 5. Some effects on the proximate compositions attributable to the preliminary rearing conditions, the salinity and the types of diet, were detected at the onset of the feeding experiment, such as the higher moisture contents in the fish meal diet lots, the higher protein contents in seawater and the higher fat contents in the casein diet lots compared with those under the same other condions, respectively. At the end of the experiment greater differences between the lots were shown owing to the additional effect of the feeding level. The primary differences attributable to the difference in the feeding levels are the lower moisture

Table 5. Proximate compositions [a] of whole body of chum salmon reared under different conditions.

Lot	Moisture		Crude protein		Crude fat	
	Initial	Final	Initial	Final	Initial	Final
SFS	80.6	79.5	15.9	16.1	2.33	2.54
SCS	80.0	79.3	15.9	16.2	2.72	3.91
FFS	80.8	78.2	15.7	15.7	2.49	3.94
FCS	80.1	78.2	15.5	15.4	2.94	5.31
SFR	80.6	81.1	15.9	15.3	2.33	1.79
SCR	80.0	80.6	15.9	15.4	2.72	2.69
FFR	80.8	80.7	15.7	15.3	2.49	1.89
FCR	80.1	79.5	15.5	15.9	2.94	3.50

a) % wet weight

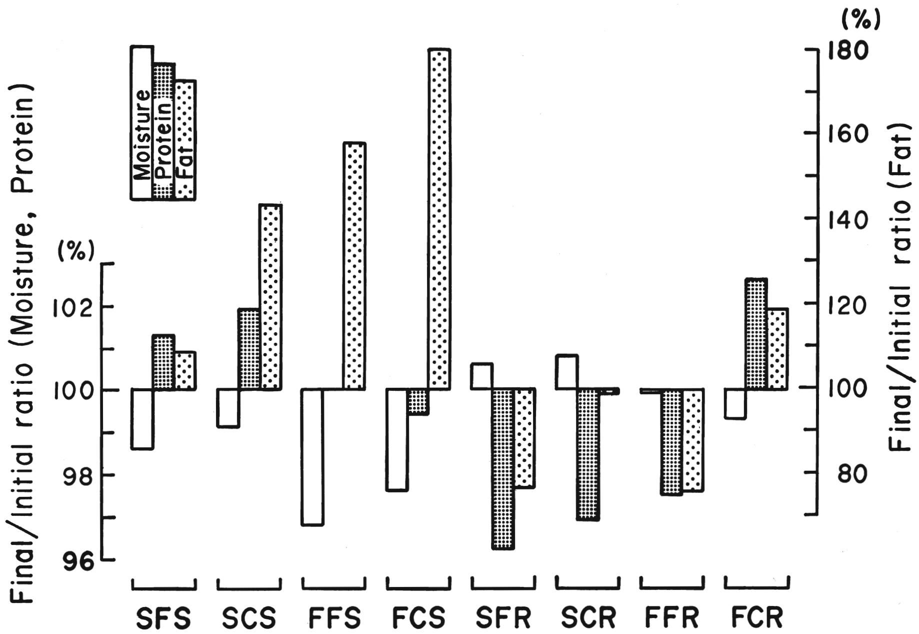

Fig. 5, Final to initial ratio of whole fish compositions of chum salmon fed under eight different rearing conditions.

content and the higher fat content in the satiated lots. Final to initial ratio of the composition (Fig. 5) illustrates that in satiated lots the effects of salinity on the protein contents and the effect of the types of diet on the fat contents were facilitated, and the effect of the types of diet on the moisture contents was suppressed. None of these effects, which were observed at the onset of the experiment, were facilitated in the restricted lots.

As in the case of the feed efficiency, the protein efficiency ratio and the protein retention in whole fish (Table 6) were influenced primarily by the salinity. A secondary effect on these was caused by the types of diet. Compared under the same other conditions the higer values were shown in freshwater than in seawater and with the casein diet than with the fish meal diet, respectively. Fat retention was influenced primarily by the feeding level (Table 6). It was also influenced markedly by the salinity and types of diet.

2. Gastric evacuation

The stomach contents were decreased exponentially with time in both seawater and freshwater. By plotting the logarithm of the stomach contents (dry/dry body weight, %) against time a straight line relationship was obtained (Fig. 6). The rates of gastric evacuation were represented by the slope of the regression lines (equation in Table 7).

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

Lot	Protein efficiency ratio	Crude protein retained	Crude fat retained
SFS	1.53	24.9	17.6
SCS	1.88	31.0	48.5
FFS	2.06	32.3	40.3
FCS	2.99	45.8	99.4
SFR	1.27	17.1	0.4
SCR	1.59	22.8	21.1
FFR	2.21	32.4	8.1
FCR	2.61	42.8	55.3

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

Table 7. Equation for the rate of gastric evacuation and the times to percent evacuation in seawater (lot S) and freshwater (lot F) at 16 °C.

Lot	Average body weight (g)	Satiation amount (dry/dry BW, %, Average (SD))	Time to % evacuation (hours)			Equation X : time in hour Y : dry/dry BW, %
			50%	75%	90%	
S	3.88	20.5 (6.0)	3.8	7.6	12.7	$\log_{10} Y=1.149-0.079X$
F	4.63	14.6 (3.2)	7.3	14.7	24.4	$\log_{10} Y=1.238-0.041X$

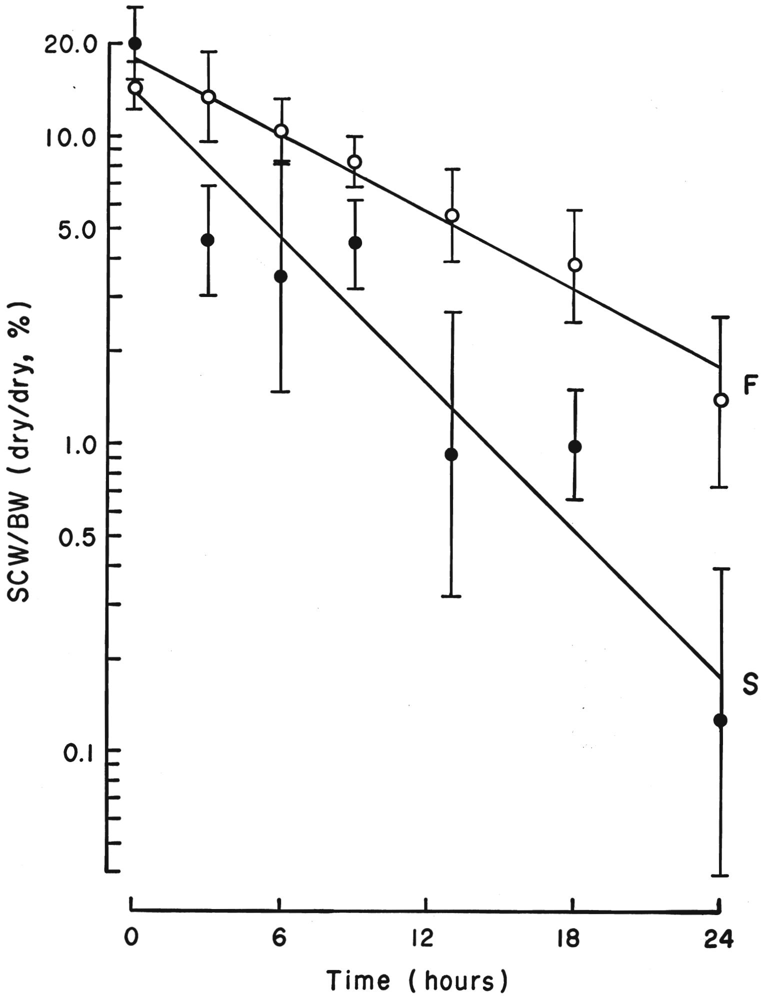

Fig. 6. Rate of gastric evacuation with the linear regression line of chum salmon fed in seawater (S) and in freshwater (F). Average and 95 % confidence interval were represented.

The satiation amounts and the rates of gastric evacuation were influenced noticeably by salinity (Table 7). The satiation amount, or stomach content just after satiation in seawater was 1.4 times larger than that in freshwater. The rate of gastric evacuation in seawater was shown to be about double that in freshwater. Accordingly, the evacuation time in seawater was calculated to be one half that in freshwater.

IV. Discussion

In this study it has been intended to re-examine the previously reported detrimental effects of salinity on the growth of chum salmon fry (KOSHIISHI 1980, 1985) with special reference to the amount of food intake.

To test the possibility of an insufficient food intake due to feeding methods, especially in seawater, the feeding frequency was increased from 3-4 times a day in the previous experiment to 6 times in the present experiment of satiated lots. The fasting period was reduced from 14 to 12 hours/day. These changes in feeding methods, however, have had no bearing on the detrimental effect of salinity on growth. Therefore, at least an insufficient food intake due to the feeding method is not a cause of the depressed growth.

In both satiated and restricted lots, irrespective of the types of diet, the daily growth rates were lower in seawater than in freshwater. This detrimental effect of salinity on growth is brought about through a decrease in the feed efficiency. The feed efficiency is known to depend on the amount of food intake (Paloheimo and Dickie 1966). Therefore, in the restricted lots where the daily feeding rates are approximately the same, the effect of salinity on feed efficiency can be evaluated more precisely. In these lots the feed efficiency were about 1.6 times higher in freshwater than that in seawater.

The higher rate of gastric evacuation in seawater is suggests itself as a cause of low feed efficiency. An increased rate of gastric evacuation without any change in the rate of digestion may result in a decrease in feed efficiency. This may be consistent with the observation of Macleod (1977) that the food absorption efficiency of rainbow trout decreased with a rise in salinity. An increased rate of gastric evacuation may also result with an increase in the daily feeding rate. This was true when fed to satiation with casein diet (Table 4). The rate of gastric evacuation with the fish meal diet seemed also to be higher in seawater than in freshwater. However, the daily feeding rate with the fish meal diet in seawater was lower than that in freshwater. Further work on the factors which control appetite may shed light on this problem.

Another cause of the low feed efficiency may be the increased metabolic cost in seawater. Using the nitrogen balance, Smith and Thorpe (1976) reported an increase in protein turnover in freshwater smolt and salt water rainbow trout. They reported that the processes which bring about the transformation of a stenohaline freshwater trout to a euryhaline trout increase its rates of protein metabolism. Chum salmon are known as a species which shows no smolt transformation (Hoar 1958). However, it seems reasonable that a metabolic rise may occur in chum salmon following the change in salinity. The lower retention in protein and fat in seawater are consistent with the increased catabolism. An especially marked difference in fat retention due to salinity may imply the higher metabolic cost in seawater, because the fat retention is known as a good index for energy expenditure.

Differences, primarily quantitative, in the effect of salinity on the daily feeding rate, daily growth rate and feed efficiency were shown between the two synthetic diets used in this experiment. ZEITOUN et al. (1973) reported that the minimum protein levels required for rainbow trout were increased with an increase in salinity. LALL and BISHOP (1976) also reported differences in nutrient requirements for rainbow trout fed in seawater and freshwater. LEBRASSEUR (1969) reported the growth of juvenile chum salmon fed on six different concentrations of size-selected zooplankton in seawater. The feed efficiency calculated from LEBRASSEUR's experiment, assuming that the moisture contents of prey in his experiment was 83%, were 243-284% and 188-197% when the daily feeding rates (dry/wet body weight) were 1.41-1.65% and 2.38-2.58%, respectively. These values are much higher than those observed in this experiment. Consequently, it would be reasonable to expect a much higher feed efficiency if they were fed on a more appropriate diet in seawater. Further work is required about the effect of the food types on the feed efficiency in order to clarify the conflicting effects of salinity on growth under natural and laboratory conditions.

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海水および淡水飼育サケ稚魚の成長ならびに飼料効率に対する給餌率，飼料組成の影響

輿 石 裕 一

要　約

海水および淡水で，体重約1.4gのサケ稚魚を飽食および制限食条件下で28日間飼育した．淡水飼育稚魚の日間成長率は給餌条件が同一の海水飼育稚魚の約1.5倍となり，塩分はサケ稚魚の成長に悪影響を及ぼした．

海水飼育稚魚では飼料効率の低下が認められ，成長率低下の原因となった．海水飼育稚魚の胃内容物排出速度は淡水飼育稚魚の約2倍であったが，消化速度が塩分の影響を受けないと仮定すれば，排出速度の増加は吸収効率の低下，したがって飼料効率の低下をもたらすと言える．また，蛋白質効率，蛋白質および脂質蓄積率はいずれも海水飼育で低い値を示し，海水中での代謝こう進が示唆された．