Comparison of the Growth of Juvenile Coho Salmon in Heated and Ambient Waters During Their Early Life Stages

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Fisheries and Marine Service

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March 1979

COMPARISON OF THE GROWTH OF JUVENILE COHO SALMON IN HEATED AND AMBIENT WATERS DURING THEIR EARLY LIFE STAGES

by

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ABSTRACT

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Coho salmon eggs were incubated and subsequent coho fry were reared at ambient and elevated temperatures to determine (a) at what stage an increase in rate of growth became apparent, and (b) whether faster growth rate was sustained after the fry were returned to ambient temperature. The treatments were:

	Temperature °C				
	Incubation	To hatching	To feeding	To 1-g fry	To termination
(a)	8.1	8.1	8.1	8.1	8.1
(b)	11.6	11.6	8.1	8.1	8.1
(c)	11.6	11.6	15.6	8.1	8.1
(d)	11.6	11.6	15.6	15.6	8.1
(e)	11.6	11.6	15.6	15.6	15.6

It was found that (a) a significant increase in developmental rate at 15.6°C was apparent even at the hatching stage and that in general increased growth was positively correlated with cumulative degree days; and (b) that growth rate after the temperature was lowered was not sustained, a possible exception being provided by fish which had been accelerated up to hatching.

RÉSUMÉ

Bilton, H. T., and D. W. Jenkinson. 1979. Comparison of the growth of juvenile coho salmon in heated and ambient waters during their early life stages. Fish. Mar. Serv. MS Rep. 1495: 10 p.

L'incubation d'oeufs de saumon coho et l'élevage des alevins ainsi obtenus se sont faits à des températures ambiantes et élevées afin de déterminer:

a) le stade auquel l'accélération de la croissance devenait manifeste; et b) si cette accélération persistait après le retour des alevins à la température ambiante.

Nature des traitements:

			Température en °C	
A l'incubation	Jusqu'à l'éclosion	Jusqu'à l'alimentation	Jusqu'à 1 g	Jusqu'à la fin

a) L'accéleration de la croissance, sensible à 15,6 °C, même au stade de l'éclosion, s'est généralement révélée fonction du nombre cumulatif de degrés-jours; b) et son rythme ne s'est maintenu après l'abaissement de la température, sauf peut-être dans les cas où elle s'était poursuivie jusqu'à l'éclosion.

INTRODUCTION

The authors were requested to conduct an experiment involving the incubation of coho eggs and subsequent rearing of fry, at ambient and elevated temperatures to determine (a) at what stage an increase in rate of growth becomes apparent, and (b) whether faster growth rate is sustained after the fry are returned to ambient temperature. This report presents the result of this experiment.

MATERIALS AND METHODS

A. DONOR STOCK

Coho eggs and sperm from the Big Qualicum River were transferred separately to the Rosewall Creek hatchery on December 3, 1973. Eggs were fertilized, and 100 eggs were placed in each of ten 10-gallon fiberglas tanks for incubation.

B. INCUBATION

Eggs were incubated in small wire-mesh baskets suspended in the water in each of the 10-gallon tanks. Heated water was used for incubation of eggs in eight of the tanks, and ambient water in the remaining two tanks. Throughout incubation tanks were covered to exclude light. Dead eggs were recorded.

C. FEEDING

Fish were offered Oregon moist pellet *ad libitum* throughout rearing.

D. EXPERIMENTAL APPARATUS

A series of ten 10-gallon circular fiberglas tanks was used for rearing. Water flow was the same in all tanks (1/2 gallon per min). Lighting in the experimental area was automatically controlled to give 12 h of light in each 24-h period. Both heated and ambient well water were provided. Water was heated to the desired temperatures using electric immersion heaters.

Groups of eggs were either incubated up to time of hatching in heated water at an average temperature of 11.6°C or in ambient water at an average temperature of 8.1°C. For the period following hatching up to termination of the experiment on June 10, 1974, ambient water temperatures averaged 8.1°C and heated water temperatures averaged 15.6°C.

E. EXPERIMENTAL DESIGN

The experiment was designed so that results could be statistically assessed by mixed model of analysis of variance (Simpson, Roe, and Lewontin 1960). Five treatments were conducted. These included the following:

	Temperature °C				
	Incubation	To hatching	To feeding	To 1 g fry	To termination
(a)	8.1	8.1	8.1	8.1	8.1
(b)	11.6	11.6	8.1	8.1	8.1
(c)	11.6	11.6	15.6	8.1	8.1
(d)	11.6	11.6	15.6	15.6	8.1
(e)	11.6	11.6	15.6	15.6	15.6

Each of the five treatments were replicated, giving a total of 10 trials. Of the two populations reared under each treatment, one was sampled every 2 wk, and the other only at termination of the experiment. Fish were sexed at the end of the experiment. Thus the effects of treatment, sex, and repeated sampling could be assessed. Fish were killed at the end of 6 mo on June 10, 1974. The design is given in Table 1.

F. EXPERIMENTAL POPULATIONS

At the beginning of the experiment 100 eggs were placed in each tank. As soon as eggs had hatched, the numbers of resulting alevins in each population were reduced to 40. Those reared in heated water were reduced in number on February 5, and those in ambient water on March 5.

G. SAMPLING

At the times of reduction in number, 10 fry from each population were measured for length and weight. This provided the starting point. Subsequent to this, 25 fish from each of half the populations (five populations) were sampled every 2 wk for fork length (millimeters) and weight (grams). At the end of the experiment, all fish in each of the 10 populations were sampled for length, weight, sex, and scales.

RESULTS

The length, weight, percent increase in weight per day and condition factor for fish sampled every 2 wk are given in Table 1.

Fish reared in heated water until termination of the experiment grew the most (Table 2), followed by those in heated water to 1-g fry, in heated water to feeding fry, eggs in heated water to hatching, and lastly in ambient water (there was a positive correlation between total number of degree days and final length, $r = 0.991$, $p < 0.01$). Comparison of the condition factors between those fish reared throughout in heated water with those reared in ambient water (populations 1 and 3, Table 2) indicated that the former were significantly heavier for the same length ($t = 3.3319$, 18 d.f., $p < 0.005$) than the latter.

The mean length, weight, and scale characters of fish by sex in each of the 10 populations at the end of the experiment are shown in Table 3.

Prior to analysis of variance, tests of homogeneity of variances were carried out on the data for length, weight, and scale characters. The tests indicated that the variances for all the measurements were close to being homogeneous except for weight and the condition factor which were clearly not the same. Therefore, analysis of variance was computed only on length, number of circuli and the scale radius. Treatment had the most pronounced effect on each of the three variances. There was not a significant effect ($p > 0.05$) from repeated sampling. However, there was a significant effect of sex. Hence, for length and total number of circuli there was a significant interaction between sex and treatment. In other words, males and females did not respond in the same way to the different treatments (Table 4).

DISCUSSION

The results of this experiment indicated that rearing eggs and/or fry at higher temperatures accelerated their development and rate of growth. The advantage in growth achieved by acceleration either during incubation and/or as fry was sustained to the termination of the experiment. Rearing in heated water up to even an early stage, such as to hatching, provided some advantage over rearing only in colder ambient water. There was no hard evidence to suggest that acceleration "triggered" a biological mechanism which resulted in fish continuing to grow at the same rate after water temperatures were lowered. In all populations, excepting those accelerated to hatching, there was a negative relationship between number of degree days and calculated growth rate. Only in the case where acceleration was continued to hatching, was there any suggestion that acceleration may have "triggered" subsequent growth rates. The growth rate among these fish remained constant even after they were introduced to ambient water.

Comparison of the condition factors for fish from the different experimental populations indicates a highly significant positive correlation ($p < 0.001$) between the total number of degree days and the average condition factor. It would appear that the longer fish were reared in heated water the heavier per unit of length they became. This suggests they either were able to more efficiently convert food to body tissue, or there was a greater tendency to store fats.

Mortality rate appeared to be related to temperature. The percentage of fish that died during the course of the experiment was highest (Table 3) among those reared throughout the experiment in heated water (34%) and lowest (4%) among those reared in ambient water. Even those fish reared for short periods in heated water suffered higher mortality rates (8-9%) than those reared in ambient water. Perhaps higher temperature imposes a stress on the fish making them more vulnerable to disease. Another explanation might be that the Oregon moist pellet diet, which was developed for rearing at cooler ambient temperatures, lacked something the fish needed at higher temperatures.

Although it had been expected that repeated sampling of the fish would have a significant adverse effect on the growth of the fish, analysis of variance indicated this was not the case. Fish from sampled and unsampled populations of a specific treatment attained similar sizes by the end of the experiment. However, there was some interaction between sex and treatment, suggesting the males and females did not respond consistently to the different treatments. Examination of the length data indicates that males of four of the treatments tended to be larger than the females, but in one case (heated egg to hatching, populations 5 and 6) the females tended to be larger.

It is of interest to note that fish reared throughout in heated water had the highest incidence of a check on their scales. This was probably related to their rapid growth rate (Bilton and Robins 1971).

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Table 1. Experimental design.

Treatment	Population	Dec. 3-31	Jan. 1-11	Jan. 12-31	Feb. 1-5	Feb. 6-28	Mar. 1-19	Mar. 20-31	Apr. 1-30	May 1-31	June 1-10	Sampling frequency
Heated water from egg to end	1	—	—	—	—	Heated	—	—	—	—	—	2 weeks
	2	—	—	—	—	Heated	—	—	—	—	—	End
Ambient water from egg to end	3	—	—	—	—	Ambient	—	—	—	—	—	2 weeks
	4	—	—	—	—	Ambient	—	—	—	—	—	End
Heated water from egg to hatch, then ambient water to end	5	— Heated	—	—	—	—	—	Ambient	—	—	—	2 weeks
	6	— Heated	—	—	—	—	—	Ambient	—	—	—	End
Heated water from egg to feeding fry, then ambient water to end	7	—	—	Heated	—	—	—	—	Ambient	—	—	2 weeks
	8	—	—	Heated	—	—	—	—	Ambient	—	—	End
Heated water from egg to 1-gram fry, then ambient water to end	9	—	—	—	Heated	—	—	—	—	Ambient	—	2 weeks
	10	—	—	—	Heated	—	—	—	—	Ambient	—	End

Table 2. Lengths and weights of fish in the five populations sampled every 2 weeks throughout the experiment.

Experimental population 1			Heated throughout				
Date	No. sampled	No. in pop.	Accelerated degree days	$\bar{x}$ length (mm)	$\bar{x}$ weight (g)	$\bar{x}^a$ gl %	Condition factor (K)
Feb. 5/74	10	40	766.3	34.2	0.35	-	0.883
Feb. 19/74	25	40	976.9	37.1	0.61	3.855	1.171
Mar. 5/74	25	39	1192.0	44.2	1.08	4.092	1.215
Mar. 19/74	25	39	1410.5	52.8	2.03	4.508	1.316
Apr. 2/74	25	39	1633.8	63.4	3.41	3.705	1.279
Apr. 16/74	25	38	1871.7	73.6	5.56	3.492	1.357
Apr. 30/74	25	35	2217.7	79.6	7.12	1.766	1.382
May 14/74	25	32	2439.3	81.3	7.70	0.599	1.402
May 28/74	25	29	2557.1	87.5	9.30	1.348	1.368
June 11/74	27	27	2912.7	90.5	10.70	1.001	1.353
$\bar{\bar{x}}$						2.71	1.273

Experimental population 3			Ambient throughout				
Date	No. sampled	No. in pop.	Accelerated degree days	$\bar{x}$ length (mm)	$\bar{x}$ weight (g)	$\bar{x}^a$ gl %	Condition factor (K)
Mar. 5/74	10	40	755.2	35.5	0.39	-	0.870
Mar. 19/74	25	40	874.2	37.7	0.51	1.920	0.944
Apr. 2/74	25	40	998.4	41.2	0.75	2.769	1.077
Apr. 16/74	25	40	1105.8	45.5	1.04	2.335	1.089
Apr. 30/74	25	40	1205.2	49.1	1.34	1.757	1.120
May 14/74	25	40	1305.1	53.3	1.72	1.837	1.122
May 28/74	25	40	1356.1	56.8	2.14	1.561	1.150
June 11/74	40	40	1572.5	60.8	2.65	1.561	1.165
$\bar{\bar{x}}$						1.96	1.067

Table 2 (cont'd)

Experimental population 5			Heated egg to hatch on January 11, then ambient				
Date	No. sampled	No. in pop.	Accelerated degree days	$\bar{x}$ length (mm)	$\bar{x}$ weight (g)	$\bar{x}^a$ gl %	Condition factor (K)
Feb. 5/74	10	40	658.9	31.5	0.29	-	0.936
Feb. 19/74	25	38	780.7	33.4	0.35	1.233	0.938
Mar. 5/74	25	38	901.8	36.4	0.46	2.044	0.932
Mar. 19/74	25	38	1020.8	39.2	0.64	2.350	1.014
Apr. 2/74	25	37	1145.0	42.9	0.92	2.585	1.074
Apr. 16/74	25	36	1252.4	48.8	1.43	3.134	1.153
Apr. 30/74	25	36	1351.8	52.8	1.75	1.443	1.152
May 14/74	25	36	1451.7	54.7	1.98	0.882	1.095
May 28/74	25	36	1502.7	58.5	2.49	1.637	1.142
June 12/74	36	36	1666.6	64.4	3.34	2.154	1.148
$\bar{\bar{x}}$						2.32	1.058

Experimental population 7			Heated egg to feeding fry on February 5, then ambient				
Date	No. sampled	No. in pop.	Accelerated degree days	$\bar{x}$ length (mm)	$\bar{x}$ weight (g)	$\bar{x}^a$ gl %	Condition factor (K)
Feb. 5/74	8	40	766.3	34.3	0.36	-	0.919
Feb. 19/74	25	40	898.1	36.2	0.47	1.959	0.987
Mar. 5/74	25	39	1019.2	39.9	0.67	2.560	1.043
Mar. 19/74	25	39	1138.2	43.9	1.02	2.959	1.171
Apr. 2/74	25	39	1262.4	49.6	1.39	2.211	1.122
Apr. 16/74	25	39	1369.8	52.9	1.75	2.543	1.152
Apr. 30/74	25	39	1469.2	55.4	2.01	1.200	1.136
May 14/74	25	39	1569.1	59.8	2.51	1.601	1.143
May 28/74	25	39	1620.1	62.9	2.98	1.002	1.160
June 12/74	39	39	1784.0	68.9	3.79	1.603	1.094
$\bar{\bar{x}}$						1.96	1.093

Table 2 (cont'd)

Experimental population 9			Heated egg to 1-gram fry on March 19, then ambient				
Date	No. sampled	No. in pop.	Accelerated degree days	$\bar{x}$ length (mm)	$\bar{x}$ weight (g)	$\bar{x}$[a] gl %	Condition factor (K)
Feb. 5/74	10	40	766.3	34.8	0.38	-	0.895
Feb. 19/74	25	39	976.9	36.7	0.59	3.162	1.173
Mar. 5/74	25	39	1192.0	43.9	1.01	3.876	1.155
Mar. 19/74	25	39	1312.0	48.4	1.45	2.583	1.231
Apr. 2/74	25	39	1436.2	54.4	1.96	2.153	1.172
Apr. 19/74	25	38	1543.6	58.8	2.55	1.880	1.204
Apr. 30/74	25	38	1643.0	62.5	2.99	1.161	1.208
May 14/74	25	38	1742.9	65.2	3.52	1.142	1.189
May 28/74	25	38	1793.9	67.6	3.84	0.621	1.186
June 12/74	37	37	1957.8	72.5	4.57	1.160	1.147
$\bar{\bar{x}}$						1.97	1.156

[a] Percent increase in weight per day.

Table 3. Length, weight, and scale measurements of fish in the ten populations sampled at the end of the experiment.

Experimental population number		Length (mm) ♂	Length (mm) ♀	Weight (g) ♂	Weight (g) ♀	Total no. circuli ♂	Total no. circuli ♀	Total scale radius × 254 ♂	Total scale radius × 254 ♀	Condition factor (K) ♂	Condition factor (K) ♀	No. circuli to 1st check ♂	No. circuli to 1st check ♀	Length (mm) ♂ + ♀	Weight (g) ♂ + ♀	Total no. circuli ♂ + ♀	Total scale radius × 254 ♂ + ♀	Condition factor (K) ♂ + ♀
1	N	15	12	15	12	14	12	14	12	15	12	7	7	27	27	26	26	27
	x̄	94.40	85.75	11.87	8.37	19.50	17.33	117.57	102.58	1.393	1.303	17.00	14.86	90.55	10.32	18.50	110.65	1.353
	SD	4.98	6.84	2.36	2.32	2.59	1.72	15.22	16.78	0.09	0.15	1.93	1.96	7.23	2.90	2.45	17.39	0.129
	t	3.798****		3.858****		2.472**		2.388**		1.930*		1.910*						
2	N	7	19	7	19	7	18	7	18	7	19	0	5	26	26	25	25	26
	x̄	95.57	90.74	12.43	10.09	20.00	18.22	125.57	115.11	1.383	1.318		16.00	92.04	10.73	18.72	118.04	1.335
	SD	9.01	6.31	3.84	2.93	1.53	2.34	28.98	15.18	0.14	0.12		1.09	7.28	3.29	2.26	19.90	0.124
	t	1.530		1.653		1.864		1.173		1.169								
3	N	23	17	23	17	22	17	22	17	23	17	0	0	40	40	39	39	40
	x̄	61.13	60.35	2.70	2.59	7.23	6.59	64.45	59.47	1.161	1.156			60.80	2.65	6.95	62.28	1.159
	SD	5.75	4.46	0.78	0.60	1.31	0.94	11.77	8.34	0.07	0.07			5.19	0.70	1.19	10.59	0.066
	t	0.465		0.485		1.704*		1.481		0.223								
4	N	19	18	19	18	19	18	19	18	19	18	0	0	37	37	37	37	37
	x̄	62.84	60.66	2.99	2.64	7.10	6.61	64.31	59.44	1.160	1.166			61.78	2.83	6.86	61.94	1.163
	SD	7.14	4.32	1.11	0.62	1.10	0.92	10.68	8.30	0.06	0.08			5.96	0.91	1.03	9.78	0.069
	t	1.116		1.175		1.466		1.543		0.259								
5	N	18	18	18	18	16	18	16	18	18	18	0	0	36	36	34	34	36
	x̄	62.39	66.50	2.96	3.72	7.94	8.17	72.37	76.05	1.104	1.197			64.44	3.34	8.06	74.32	1.151
	SD	10.45	9.26	1.25	1.34	1.29	1.54	9.83	14.62	0.14	0.06			9.95	1.33	1.41	12.55	0.120
	t	1.245		1.759*		0.469		0.850		2.590***								
6	N	18	19	18	19	18	19	18	19	18	19	2	0	37	37	37	37	37
	x̄	68.11	66.79	3.75	3.56	8.33	8.05	75.17	73.95	1.132	1.153	6.50		67.43	3.66	8.19	74.54	1.143
	SD	8.24	7.29	1.46	1.18	1.19	1.02	13.39	9.80	0.06	0.07	0.50		7.69	1.31	1.10	11.54	0.062
	t	0.517		0.436		0.770		0.317		0.977								
7	N	23	16	23	16	22	16	22	16	23	16	0	1	39	39	38	38	39
	x̄	69.04	68.75	3.85	3.67	9.54	9.00	78.18	74.06	1.123	1.051			68.92	3.78	9.31	76.45	1.094
	SD	7.59	8.22	1.33	1.38	1.68	1.03	14.47	10.96	0.07	0.14			7.74	1.33	1.45	13.11	0.106
	t	0.113		0.409		1.139		0.957		2.115**								
8	N	18	17	18	17	18	17	18	17	18	17	2	0	35	35	35	35	35
	x̄	67.72	67.06	3.75	3.67	9.44	9.06	78.28	77.29	1.142	1.176	8.50		67.40	3.71	9.26	77.80	1.158
	SD	9.73	7.23	1.58	1.14	1.72	1.25	14.64	13.21	0.06	0.05	0.50		8.49	1.36	1.50	13.77	0.059
	t	0.227		0.171		0.744		0.209		1.815*								
9	N	17	20	17	20	17	20	17	20	17	20	0	0	37	37	37	37	37
	x̄	76.82	68.95	5.30	3.95	11.76	11.55	90.47	81.30	1.134	1.159			72.57	4.57	11.65	85.51	1.147
	SD	7.87	7.96	1.59	1.41	1.39	2.16	10.65	15.21	0.07	0.06			8.76	1.62	1.83	13.93	0.066
	t	3.012****		2.737****		0.345		2.088**		1.169								
10	N	3	8	3	8	3	7	3	7	3	8	0	1	11[a]	11	10	10	11
	x̄	69.67	73.75	3.66	4.68	10.33	11.86	80.00	92.86	1.083	1.104			72.64	4.40	11.40	89.00	1.098
	SD	3.05	10.09	0.76	2.04	1.53	1.95	5.57	14.89	0.06	0.07			8.77	1.80	1.89	13.90	0.064
	t	0.689		0.844		1.209		1.453		0.460								

*Significant at 5%.
**Significant at 2.5%.
***Significant at 1.0%.
****Significant at 0.5%.

[a]The low number remaining was due to loss of fish from tank.

Table 4. Analysis of variance.

	Length			Total circuli			Scale radius		
	F ratio	d.f.	Sign.[a]	F ratio	d.f.	Sign.[a]	F ratio	d.f.	Sign.[a]
Treatment (A)	140.95	4,305	0.005	510.73	4,298	0.005	129.46	4,298	0.005
Sampling (B)	2.47	1,305	NS	0.36	1,298	NS	2.24	1,298	NS
Sex (C)	6.15	1,305	0.025	9.93	1,298	0.005	7.08	1,298	0.01
AB	1.13	4,305	NS	0.70	1,298	NS	1.50	4,298	NS
AC	3.17	4,305	0.025	3.73	4,298	0.005	2.10	4,298	NS
BC	0.00	1,305	NS	0.25	1,298	NS	0.64	1,298	NS
ABC	1.92	4,305	NS	0.66	4,298	NS	1.33	4,298	NS
Residual	0.44	4		0.64	4		0.93	4	

[a]Considered significant when $p < 0.05$.