Effect of Egg Size on the Characteristics of Embryos and Alevins of Chum Salmon*¹

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Relationships between the size of fertilized eggs and characteristics such as weight, length and stages of development of hatched embryos and emerged alevins in chum salmon were studied. Eggs weighing from 150 to 400 mg taken from chum salmon returning to the Tsugaruishi River in Iwate Prefecture were incubated at $11.0 \pm 0.5^\circ\text{C}$. The entire body weight, tissue weight, yolk weight, length, and developmental stages were compared among different size groups of the eggs at the hatching times and emergence. Irrespective of their differences in size at fertilization, eggs required almost the same duration for hatching and emergence. As was expected larger embryos gave larger alevins emerging at a less developed stage and with a greater condition factor while the smaller embryos gave smaller alevins emerging at a more advanced stage and with a lesser condition factor. Thus the larger alevins originating from larger eggs seem to have advantages in their early life history because of their energy rich condition. Disadvantages of the smaller alevins might be compensated by the relatively high fecundity and by their higher swimming activity at their emergence by more advance development.

Key words: chum salmon, egg size, alevin quality, condition factor

Fishes of the family Salmonidae show a wide variation in their mode of life and morphology even within a single species, e.g. age at maturity ranges from two to seven years, body weight at maturity ranges from one to ten kg, in chum salmon *Oncorhynchus keta*; age at smoltification varies from one to three years in masu salmon *O. masou*. The size of adult females largely affects the size of eggs and fecundity.¹⁻⁷⁾ In these studies, it was generally found that fecundity is positively related to the size and age of females. These reports dealt with quantitative measures of fecundity but did not consider qualitative features of salmon eggs. This qualitative evaluation is also important for stock enhancement of chum salmon. The present study aims to clarify the effect of egg size on the characteristics of hatched embryos and emerging alevins for stock enhancement of chum salmon.

Materials and Methods

Eggs from several dozen female chum salmon returning to Tsugaruishi River, Iwate Prefecture, on 13th Feb., 1990, were inseminated at Tsugaruishi hatchery and incubated at about 10°C to the eye stage embryos. On the 22nd of March, when 370 degree-days, about 20,000 embryos, weighing from 150 to 400 mg total weight per individual were transferred to a laboratory at the School of Fisheries, Kitasato University, Sanriku-cho, Iwate. They were classified into six size classes according to their weight and incubated at $11.0 \pm 0.5^\circ\text{C}$. Eggs were kept in six plastic net containers ($30 \times 30 \times 30 \text{ cm}^3$) immersed in an aquarium ($60 \times 60 \times 120 \text{ cm}^3$) without any incubation substrate. Fresh water was introduced at the surface about 5 l/min to each container and excess water drained from beneath the net containers. Embryos hatched from the 31st of March

to the 3rd of April (480 to 513 degree-days) and alevins swam up from the 1st to the 5th of May. Samples were taken on the 1st of April when about half of the embryos hatched out and on the 3rd of May when about half of the alevins swam up. The total length was measured to the nearest 0.1 mm using a caliper. The body of such alevins was divided into yolk and tissue, and the entire body and the tissue were weighed to 1 mg using an electronic balance. Yolk weight was estimated by subtracting tissue weight from the total weight. Length and weight were measured in a fresh condition immediately after sacrifice. Twenty individuals were measured from each size class at the times of hatching and emergence. Condition factor was calculated by the following formula:

$$\text{CF} = (\text{BL} / \text{TL}^3) \times 10^3 \quad (\text{BW: yolk-removed body weight})$$

Observation for fin rays and the pterygiophores was based on the specimens stained by alcian blue for cartilage and alizarin red S for ossified elements.

Table 1. Length of chum salmon at hatching and emergence, and its growth increment

egg size group (median)	sample size	mean total length at				growth increment*
		hatching	s.d.	emergence	s.d.	
375 mg	20	22.4 mm	.061	38.0 mm	.051	15.6 mm
335	20	21.8	.089	37.5	.048	15.7
295	20	21.3	.096	36.6	.033	15.3
255	20	21.2	.079	35.0	.043	14.6
220	20	19.5	.068	34.8	.050	15.3
175	20	20.6	.056	33.3	.036	12.7

* difference in length between hatching and emergence.

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Results

Mean of the total lengths with their standard deviations (sd) at the times of hatching and emergence are shown in Table 1. At hatching the length of the smallest egg-size group was 20.6 mm and its standard deviation was 0.056 mm. That of the largest group was 22.4 mm and sd was 0.061 mm. The mean total lengths of the intermediate groups fell between the two extremes. The mean length for the smallest group at the time of emergence was 33.3 mm (sd 0.026 mm) and for the the largest group was 38.0 mm (sd 0.051 mm). The mean of other groups fell between the two extremes. Thus the difference of the mean total length found between size groups became larger at emergence than at hatching, but the standard deviation for each size group became somewhat smaller at emergence than at hatching. Growth expressed as the difference between the mean total lengths at the time of emergence and that of hatching was larger in large egg-size groups than the small groups.

The mean total weight and growth expressed as the difference of total weight between emergence and hatching are shown in Table 2. The mean total weights of the larger-size groups at the times of hatching and emergence were much heavier than that of the smaller groups. The differences between the groups were highly significant ($P < 0.01$) except that between the second and the third groups at hatching. Growth in total weight was higher in larger-size groups and lower in smaller-size groups. Comparison of the tissue weights at the times of hatching and emergence and that of yolk weights were shown in Table 3. Like body weight, the tissue weight from larger-size eggs were heavier

than those from the smaller (90 mg vs 58 mg). The difference of 32 mg in tissue weights of the two groups increased to 162 mg at the time of emergence (400 mg vs 238 mg).

In order to get the conversion efficiency of yolk, tissue weight increment and yolk absorption for the six size classes were compared (Table 4). Both tissue weight increment and yolk weight absorbed varied greatly between the size classes but the conversion efficiency remained about 2.0 irrespective of size differences.

Table 4. Comparison of yolk conversion between egg-size classes

egg size group (median)	tissue increment	yolk absorbed	conversion efficiency
375 mg	310 mg	153 mg	2.03
335	285	124	2.30
295	250	143	1.75
255	238	116	2.05
220	216	112	1.93
175	180	91	1.98

Table 2. Total weight of chum salmon at hatching and emergence, and its growth increment

egg size group (median)	sample size	mean total weight at				growth increment*
		hatching	s.d.	emergence	s.d.	
375 mg	20	342 mg	8.16	487 mg	10.43	145 mg
335	20	273	6.54	432	9.38	159
295	20	278	4.86	380	4.04	102
255	20	230	6.22	349	7.81	117
220	20	203	5.53	303	8.45	100
175	20	164	6.61	252	3.42	88

* difference in weight between hatching and emergence.

Table 3. Tissue weight of chum salmon at hatching and emergence, and its growth increment

egg size group (median)	tissue weight at				growth increment*
	hatching		emergence		
	mean	s.d.	mean	s.d.	
375 mg	90 mg	.008	400 mg	.036	310 mg
335	75	.007	360	.035	285
295	76	.010	326	.021	250
255	71	.009	309	.033	238
220	59	.007	275	.025	216
175	58	.006	238	.031	180

* difference of tissue weight between hatching and emergence.

Fig. 1. Condition factor of each size class of just emerged alevin (at emergence) in chum salmon.

Bars indicate standard deviation.

Fig. 2. Schematic illustration of chum salmon embryo and alevin at hatching and the emergence from different egg sizes.

Bar indicates 10 mm. A: Embryo originating from the largest size group 22.1 mm TL, 335 mg BW. B: Alevin originating from the largest size group, 37.1 mm TL, 453 mg BW. C: Embryo from the smallest size group, 20.2 mm TL, 160 mg BW. D: Alevin from the smallest size group, 33.1 mm TL, 240 mg BW. Note slightly advanced state in smaller alevin (D) than larger alevin (B).

Condition factors at the time of emergence for the six size groups are shown in Fig. 1 and the general appearance of alevins at the emergence for the largest and the smallest groups are shown in Fig. 2. It is evident from the figure, that alevins originating from larger eggs showed more fat condition than the smaller eggs (Fig. 1). In outer morphology, embryos from larger eggs had retained more yolk (Fig. 2) and a robust body than those from smaller eggs.

In meristic feature, embryo at the time of hatching from larger eggs showed 11 dorsal and 14 anal pterygiophores, while embryo from a smaller egg showed more pterygiophores than those from larger eggs, i.e. 12 and 15. None of the rays of the dorsal nor anal fins were detected on hatched out embryos by alcian blue staining but in embryos from smaller egg showed several faint primordial rays on the dorsal. The modal number of pterygiophores of dorsal and anal fins are 13 and 15 in the population of chum salmon returning to Sanriku district (Hayashizaki *et al*, unpublished). The principal caudal rays were 10+9 and were stained by alcian blue, but the procurent rays were not formed in embryos at the time of hatching from every size group. Thus embryos from smaller eggs showed a slightly advanced condition in the formation of fin supporting elements at the time of hatching. Alevins at the time of emergence showed well ossified (alizarin red S stained) rays in dorsal (14), anal (16), pectoral (14), pelvic (10), and caudal (principal, 10+9) fins and their numbers were almost the same with the modal number of the population, i.e. 14, 17, 15, 10, 19, respectively (unpublished). Thus, alevins from different egg-size groups did not show a difference in the meristic feature at the time of hatching. But the degeneration of fin fold seemed to be slower in alevins from larger eggs than those from smaller eggs (Fig. 2. B and D).

Discussion

Alevins swam up about one week earlier than was expected based on the integrated water temperature (32 days vs 40 days at about 11°C). Usually earlier emergence or faster development may be caused by undesirable environmental conditions and results in over consumption of yolk. The earlier emergence of alevins in the present study might have been caused by the lack of incubation substrate or other environmental conditions. But judging from the general appearance of alevins, they did not show any morphological deficiency such as excessive consumption of yolk.

The range of weight of embryos in our samples at the eyed stage was more than 260% (150/400). A similar difference (255%) in the egg size within a single population of coho salmon, *O. kisutch* has been reported.³⁾ Between different populations of coho salmon, a difference of more than 140% in egg diameter (274 % in terms of weight) has been observed.⁸⁾ Usually, these variations are explained by a variation of parental size and fecundity and related to reproductive success. It is noteworthy that females belonging to a single population returning on the same day spawned a variety of egg sizes. One plausible explanation for this large variation is that it results from differences of their life span for maturation age which in turn may be a strategy for adaptation to an unstable river environment. Differences in age at maturity inevitably cause the differ-

ences in spawner size. Different age classes originating from a single year's cohort enhance spawning success under annually variable environmental conditions.

Irrespective of such large difference in weight, embryos showed little variation of duration for hatching and emergence. This means the difference in quantity of yolk did not affect the speed of development. Beachum and Murray⁹⁾ showed that the size of embryos was largely affected by egg size and the embryo size diverged largely at higher and lower water temperatures. Rombough¹⁰⁾ reported that embryos from large-size eggs required a longer period for attaining the maximum alevin weight in chinook salmon, *O. tshawytscha*, but he did not mention any variation of the incubation period.

Other than the initial swelling of eggs, immediately after fertilization, weights of embryos did not change until the time of hatching. Embryos absorbed about 30 to 70% of yolk available at hatching before emergence. The amount of yolk at emergence is greater in large-size eggs and is less in small-size eggs. Environmental conditions, such as water temperature, dissolved oxygen, and water current may affect the size of the embryo because of the variation of metabolic processes after hatching.

Both embryos and alevins from large-size eggs are richer or more efficient in using energy than those from small-size eggs. Under undesirable conditions such as high water temperature and excessive water flow, embryos waste more yolk and develop into smaller alevins.¹⁰⁻¹⁵⁾ In this respect, alevins from large size eggs would seem to have advantages over those from small eggs in their early life.

Helle¹⁵⁾ analyzed the relation between size at maturity and survival of progeny in chum salmon in Alaska, concluded that the size of parents and survival of progeny were positively related. His results suggests the size effect on survival affects not only in early life stage but also in the whole life history.

Berghe and Gross⁸⁾ reported breeding competition among wild female coho salmon in relation with their body size and explained the fitness value of size through the breeding success in three main ways: an increased initial biomass of egg production, the ability to acquire high-quality territory for egg development, and success in nest defense.

These reports^{8,10-15)} explain well the advantages of large sized adult producing large eggs but can not explain the persistence or appearance of small adults producing smaller eggs through the selective process. Most local strains of salmonids have a characteristic age composition with a wide variation in size. For example in chum salmon, age at maturity ranges from two to seven, and the equivalent range in weight is from one to ten kg. Smallness in the size of adults does not always result from stunted growth but results from earlier maturation age in most cases.

As shown in Fig. 2, alevin originating from larger-size eggs are robust while alevin from smaller sized eggs are slim. According to Kaeriyama¹²⁾, ossification of caudal vertebrae and fin rays is slightly delayed in alevins from larger eggs compared to alevins from smaller eggs, the result of the present study is almost identical. But it may be noted here that the formation of fin rays are slightly advanced in alevins from smaller eggs than those from larger ones and the difference may result in the difference in swimming abil-

ity.

With an abundant food supply, alevins from smaller-size eggs would not seem to be at any disadvantage, but in food-poor conditions, alevins from larger eggs would seem to have an advantage in early life stages over alevins from smaller eggs.

The disadvantages of energy-poor conditions for the alevins from smaller size eggs may be compensated by relatively high fecundity of females producing smaller eggs. Smaller eggs are, usually produced by smaller-sized females at younger ages at maturation than the larger (this point will be discussed in the following paper, for rainbow trout see Kato⁶). Advantages in producing larger eggs in relatively low fecundity with high survival and advantages in producing smaller eggs in relatively high fecundity with low survival need further experiments and discussion.

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