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A Genetic Analysis of Reproductive Traits of Masu Salmon *Oncorhynchus masou*

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A genetic analysis of reproductive characters of masu salmon at three year classes was described. The reproductive performance of masu salmon spawning at 2 years of age was analyzed using data collected over a period 3 years. Data were collected for post-spawning body weight, egg size, egg number, fertility, hatchability and growth traits to the juvenile stage. The phenotypic correlations among the traits were also estimated. It was determined that egg volume was the principal determinant of egg number and that the relationship of number to size was negative. It is recommended that selection for egg size be included in all selection programs and egg number be ignored in any selection program designed to increase body size. Phenotypic correlations between body size of parents and egg traits as well as between body size of offspring and egg traits were not significantly positive or negative magnitude at three year classes.

Key words : Masu salmon, *Oncorhynchus masou*, Reproduction, Egg size, Egg number, Phenotypic correlation

Introduction

Fish and Shellfish usually have a very high reproductive rate; salmonids have more than 1,000 eggs/kg body weight; channel catfish 5,000-10,000 eggs/kg; common carp more than 10,000 eggs/kg; tilapia 1000 eggs/kg; halibut 15000 eggs/kg; and oysters million eggs/spawn (Gjedrem, 1983). This makes the expense of maintaining brook stock quite low. Therefore, it is not important to consider egg number in a selection program for these species. One exception might be a production system where the eggs are the end product such as caviar and "Ikura". Eggs of salmon ("Ikura"in Japanese) are a favorite with Japanese, as well as reproduction. Egg size and egg quality could be important as selection criteria if they are correlated with early survival or growth rate. Moreover knowledge of this relationship is needed to study these important traits to avoid a negative correlation response when selection for other traits. In the present study, we estimate variances of reproductive traits and correlation between reproductive traits and growth traits of masu salmon, which is of great commercial importance in Japan.

Materials and Methods

Fish

The rearing procedures used for the study were described by Choe and Yamazaki (1998). Briefly, the parents of the fish studied consisted of females and males from a commercial brood stock which were spawned and randomly mated in September 1994, 1995 and 1996. The mating scheme produced 40 full-sib families and 85 half-sib families. Eggs and sperm were striped at the Mori of the Hokkaido Fish Hatchery and transported to a laboratory at the Faculty of Fisheries, Hokkaido University, Hokodate, Japan. The fertilized eggs were incubated in a 185-liter (185×50×20cm) tank. Each of the families was stocked separately within stainless baskets (19×15×6 cm) in the tank. The water circulated and maintained at 10℃.

Definition of the traits

Spawning body weight (g) was recorded immediately after the eggs were stripped. Total egg weight (g) was measured to the nearest mg. Average egg size (mm) was determined by measuring 20 eggs using caliper square. Fertility (%) was each expressed as percentage at the 4 cells stage and hatchability (%) was also each expressed as percentage of hatched fry to eggs set.

Analysis

The estimatical model used for the analysis of data was

$$Y_{ijk}=\mu+S_i+D_j+E_{ijk}$$

where Y_{ijk} is a measurement on the k th fish of the j th dam by the i th sire, μ is the population mean, S_i is the effect of the i th sire, D_j is the effect of the j th dam, and E_{ijk} is error term.

Means were calculated to estimate the mean performance for each trait. Coefficients of variance, also calculated using means, were used to compare variation among the traits.

Results

The number of families and the number of females with records are shown in Table 1, along with the mean, and coefficients of variation for all traits for the three years.

The variation of each trait was similar for all the three years while the coefficients of variation varied considerably among the various traits. The rank order of the variations was hatchability and total spawn egg weight; spawning body weight, egg weight and fertility; egg size.

Significant correlations were found for body weight of dam with spawn-total egg weight, but not egg size or egg weight (Table 2). No significant correlation

Table 1. The number of families and means, and coefficients of variation (CV) for growth and reproductive traits of masu salmon females-offsprings of three year-classes

Trait	1994 year class		1995 year class		1996 year class	
	Mean	CV	Mean	CV	Mean	CV
TL (mm)	40.2	5.9	418.7	5.7	452.8	17.4
BW (g)	782.6	16.8	902.2	17.2	1088.8	5.8
Gut-cutting BW (g)	523.5	17.8	632.0	18.8	745.9	19.2
EW (g)	194.4	20.0	202.7	7.0	242.4	20.3
ES (mm)	5.7	10.0	5.6	7.0	5.9	7.0
Fertility (%)	98.2	5.3	98.0	14.1	97.3	9.6
Hatchability (%)	85.6	24.9	83.3	24.5	85.9	17.4
Hatching BW (g)	0.2	13.8	0.19	19.7	-	-
			Alevin stage			
Mortality (%)	-	-	2.5	14.1	21.7	114.7
TL (mm)	-	-	32.1	4.5	-	-
BW (g)	-	-	0.3	5.6	-	-
			7 months old of Juvenile stage			
TL (mm)	75.1	9.0	-	-	-	-
BW (g)	4.7	31.9	-	-	-	-
			11 months old of Juvenile stage			
TL (mm)	126.9	11.0	-	-	-	-
BW (g)	24.6	32.3	-	-	-	-
No. female	30		50		44	
No. family	30		50		44	

*TL, Total length; BW, Body weight; Gut-cutting BW, Gut-cutting Body weight; EW, Spawn egg weight; ES, egg size; No. female, number of females studied; No. family, number of families studied; -, undetermined

Table 2. Phenotypic correlation between reproductive traits and growth-related traits of dam from the three years of masu salmon

Trait	Dam		
	TL	BW	Gut-cutting BW
	Spawn-total egg weight		
1994 year class	0.804*	0.838*	0.746*
1995 year class	0.703*	0.751*	0.552*
1996 year class	0.524*	0.591*	0.513*
	Egg size		
1994 year class	0.024	-0.050	0.096
1995 year class	0.310	0.361	0.169
1996 year class	0.441*	0.366	0.336
	Egg weight		
1996 year class	0.279	0.247	0.225

*P<0.05; TL, Total length; BW, Body weight; Gut-cutting BW, Gut-cutting Body weight

also was found for growth traits of parents with growth related traits of offspring (Table 3). Table 4 shows the correlations among reproductive traits estimated from the data of the three years in masu salmon. Significant correlation were found between egg size and egg weight, and between fertility and hatchability. The correlation between egg size and hatchability was significantly related in 1994 year class, but not 1995 year class. Significant correlations between egg traits and fertility were not found, and also between egg traits and hatchability at both years. These correlations were low and negative magnitude. Correlations between reproductive traits and growth traits were calculated. Fig. 1, 2 and 3 were described relationships between reproductive traits and growth traits. Significant correlation was found

Table 3. Correlations between reproductive traits and growth-related traits of parents estimated over three years for masu salmon

Trait	Dam			Sire			Parent		
	TL	BW	Gut-cutting BW	TL	BW	Gut-cutting BW	TL	BW	Gut-cutting BW
Fertility									
1994	-0.324	-0.383	-0.375	0.290	0.222	0.231	-0.015	-0.107	0.048
1995	0.210	0.253	0.158	0.155	0.095	0.041	-0.242	-0.312	-0.273
1996	-0.185	-0.117	-0.116	0.159	0.261	0.261	-0.060	0.011	0.042
Hatchability									
1994	0.047	0.030	0.059	0.092	0.082	0.086	0.085	0.073	0.115
1995	-0.268	-0.274	-0.269	0.152	0.150	0.086	-0.228	-0.289	-0.284
1996	0.085	0.103	0.141	0.127	0.275	0.311	0.010	0.079	0.097
Hatching BW									
1994	0.310	0.203	0.174	-0.151	-0.132	-0.129	0.104	0.125	0.003
1995	0.385*	0.377*	0.245	-0.096	-0.139	-0.094	-0.001	0.081	0.026
Alevin mortality									
1995	0.176	0.143	0.073	-0.201	-0.168	-0.148	0.179	-0.148	0.163
1996	-0.247	-0.218	-0.264	0.011	0.079	-0.125	0.022	0.026	-0.031
Alevin TL									
1995	-0.051	0.012	0.068	0.180	0.150	0.248	0.109	0.141	0.183
Alevin BW									
1995	0.209	0.222	0.144	-0.096	-0.221	-0.172	-0.173	0.148	-0.169
TL at 7 months old									
1994	0.086	-0.012	0.036	0.186	-0.159	-0.152	-0.057	0.171	-0.158
BW at 7 months old									
1994	0.018	-0.062	-0.073	-0.204	-0.167	-0.161	-0.151	-0.188	-0.192
TL at 11 months old									
1994	0.323	0.206	0.149	0.072	0.048	0.049	0.266	0.190	0.144
BW at 11 months old									
1994	0.288	0.179	0.123	0.128	0.091	0.092	0.274	0.219	0.164

*P<0.05; TL, Total length; BW, Body weight

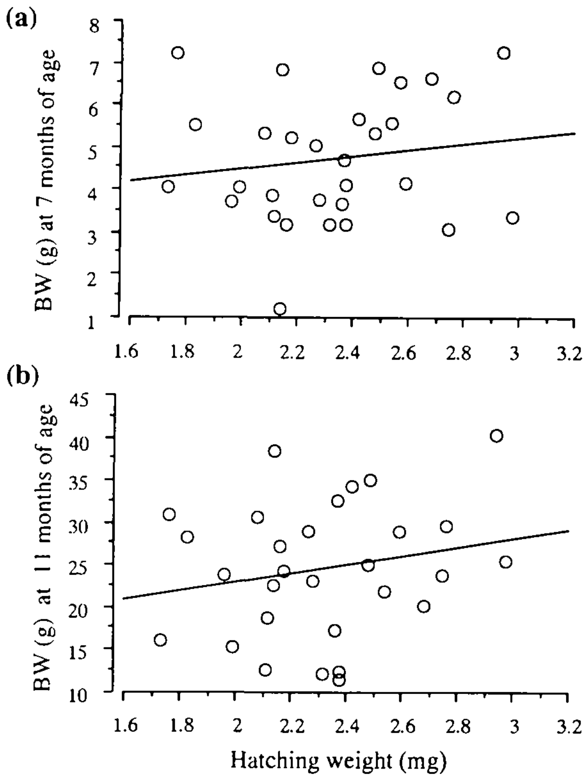

Fig. 1. Relationships between hatching weight (X) and juvenile body weight (BW) (Y) for masu salmon reared during 7 months (a), and 11 months (b) in 1994. The equations of linear regeressions are: (a) E(Y)= 3.084+0.708X(r^2=0.023, P>0.05); (b) E(Y)=12.518+5.192X (r^2=0.045).

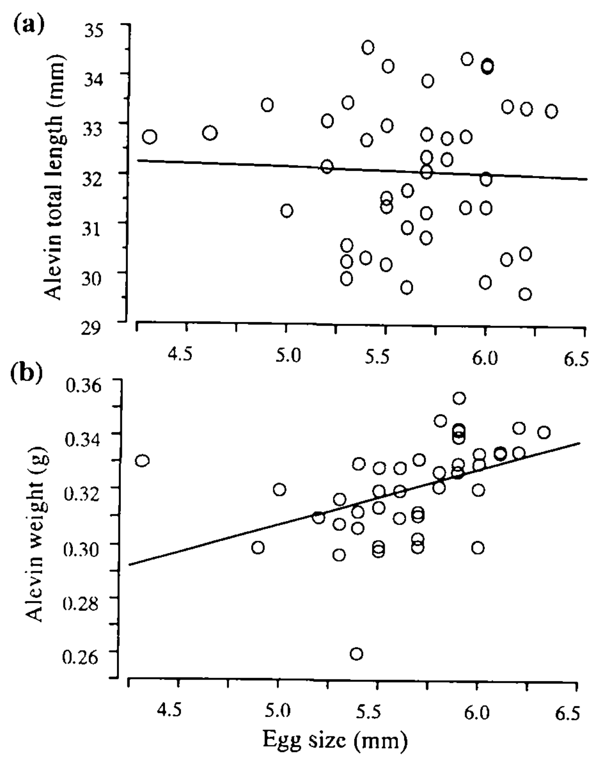

Fig. 2. Relationships between egg size (X) and alevin growthtraits (Y) for masu salmon reared in 1995. The equations of linear regeressions are: (a) E(Y)= 32.76-0.116X(r^2=0.001, P>0.05); (b) E(Y)=0.204+0.021X(r^2= 0.198, P>0.05).

Table 4. Phenotypic correlations among reproductive traits in masu salmon estimated from three years data

Trait	Egg size	Egg weight	Fertility	Hatcherbility
Egg size		0.724*	-0.175	-0.005
Egg weight	- -		0.277	-0.228
Fertility	-0.075 -0.185	- -		0.595*
Hatchability	0.810* 0.018	- -	0.229 0.505*	

*P<0.005; -, undetermined; Correlations of reproductive traits for 1994 and 1995 year classes in the upper and lower rows below the diagonal, and correlations of those traits for 1996 year class above the diagonal.

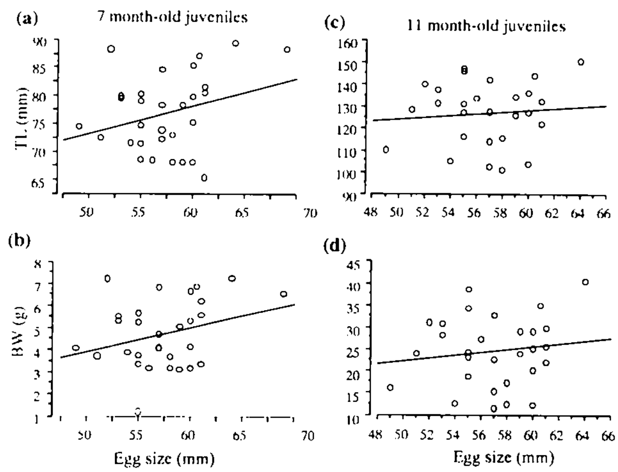

Fig. 3. Relationships between egg size (X) and juvenile growth traits (Y) for masu salmon reared during 7 months (a, b), and 11 months (c, d) in 1994. The equations of linear regeressions are: (a) E(Y)= 48.271+0.497X(r^2=0.086, P>0.05); (b) E(Y)=-1.586+0.11X (r^2=0.089, P>0.05); (c) E(Y)=104.511+0.393X(r^2=0.01, P> 0.05); (d) E(Y)=5.562+0.333X(r^2=0.022, P>0.05).

for egg size with hatching and alevin weight, but not other traits. A significant correlation was also found between hatching weight and alevin weight(Fig. 1). However, egg size was not significantly correlated with size and weight for juveniles(Fig. 2-3).

Discussion

The estimated correlation between spawning body weight and length of dams and spawn total eggs for the three years was almost positive in the present study, so that direct selection for egg production traits should result in favorable correlated responses.

In the present study, correlations between reproductive traits and growth traits were low, therefore selection method should be considered for the end product of selection. However, the efficiency and the application of this selection method in partial breeding needs further study, including the genetic correlations between spawning body weight and body weight at earlier age, and between body weight at market age and egg volume.

Although we did not calculate heritability in this study, heritability estimates for egg size, egg number and egg volume described by Su *et al.* (1997) in rainbow trout were higher than those found in some studies in rainbow trout (Gall 1975; Gall and Huang 1988). A high estimate for egg number was also obtained by Gall (1993) and the estimate (0.53-0.55) for spawning date by Su *et al.* (1997) was in agreement with the realized heritability reported by Siitonen and Gall (1989). In contrast, the estimated heritability of spawning body weight was low but similar to the estimate (0.15) obtained by Gall and Huang (1988) and by Su *et al.* (1997).

Gall (1974) reported a positive correlation in rainbow trout between egg size and egg quality measured as hatching percentage and also between egg size and growth up to 75 days of age. Similar results were reported by Pitman (1979). In both the experiments, confounding between the effect of age of female and egg size makes it difficult to separate the two effects. Chevassus and Blanc (1979), working with rainbow trout, reported a positive correlation between egg size and growth up to 1 and4 months of age, respectively. After that time, the correlation was not significantly different from zero. Similarly, Springate and Bromage (1985) found that in rainbow trout the significant correlation between egg and fry size at hatching was lost 4 weeks after the time of first feeding. They also reported no significant correlation between initial egg size and survival rates to eying, hatching and swim-up and as 3-month fed fry.

Gall (1975) has presented estimates of some genetic parameters, heritabilities and correlations, related to reproduction in rainbow trout: between body weight of dam, egg size, egg number, egg volume and eggs per 100g dam body weight. Coefficients of variation for the five traits ranged from18% to 30%. Gall and Gross (1978 a, b) described a similar experiment with rainbow trout: heritability estimates were generally higher (0.32-0.50) and the genetic correlation between egg size and egg number averaged -0.18. Gall and Gross (1978 b) pointed out that selection on body weight should result in a correlated increase in egg production.

Significant differences in egg size have been also reported between strains of Atlantic salmon(Pope et al. 1961; Aulstad and Gjedrem 1973; Glebe *et al.* 1979). These differences in egg size are believed to be mainly of genetic origin. However, the Atlantic salmon data were all recorded from wild fish caught in rivers. This means that no reliable conclusion can be drawn from these data because salmon from different rivers have followed various migration routes and have fed on different types of food. However, Gjerde and Refstie (1984) reported significant differences in egg diameter between strains of Atlantic salmon reared under the same farming conditions in cages in the sea.

Halseth (1984) and Haus (1984) analyzed extensive data on egg size, egg volume, egg number, and female body size in Atlantic salmon and rainbow trout. Except for egg size in rainbow trout, for which the sire component of variance was not significantly different from zero heritabilities for the egg traits studied varied between 0.13 and 0.44. Favorable or, at least, no strongly unfavorable phenotypic and genetic correlations were found between egg size, egg number, egg volume, and female body weight. It was concluded that at present there is no need to include any of these egg traits in the breeding objectives. However, the genetic correlation between egg size and growth rate should be investigated more thoroughly.

In fish, the observed phenotypic and genetic correlations between egg volume and egg number are large and positive. In contrast, the correlations between egg size and egg number are small (except for the genetic correlation in Atlantic salmon). As stated by Gall and Gross (1978 b), it can be concluded that egg volume is the principal determinant of egg number, and that body weight has a strong positive influence on egg volume. In rainbow trout, however, Hau (1984) found a small negative genetic correlation between egg volume and body weight.

In this present study, the phenotypic correlations between egg size and body weight were all found to be small but mostly positive. The genetic correlations in rainbow trout were also found to be positive or zero, while in Atlantic salmon a small negative genetic correlation was found. However, this negative correlation between egg size and body weight was not significantly different from zero.

In a selection program where selection for increased growth rate is practiced, there seems to bea need to select for increased egg volume and egg number. However, the genetic correlation between egg size or quality and growth rate should be more thoroughly investigated. Therefore, it may be necessary to take egg size and egg quality into account when determining a selection scheme for masu salmon.

Moreover, spawning date has an important influence on egg size which might be explained by the fact that the main increase in egg size and egg yolk formation is concentrated in a short period before spawning. Su *et al.* (1997) reported that variation in spawning date obviously exposes individual females to different environmental conditions which result in a greater effect on the variation of egg size than egg volume or number.

In the present study, it was determined that egg volume was the principal determinant of egg number and that the relationship of number to size was negative. It is phenotypic correlations between body size of parents and egg traits as well as between body size of offspring and egg traits were not significantly positive or negative magnitude at three year classes. Therefore, the selection for reproductive traits is not expected for improving growth rate in juvenile masu salmon.

An understanding of sources of variation and covariation for economically important traits is essential to the design of breeding programs and prediction of selection responses. Heritability and genetic correlation are two important parameters which measure the relative magnitude of additive genetic variation and covariation. However, estimates of the heritability for reproductive traits in the present study were not calculated. Therefore, we need to study providing further information of the genetic and environmental variation and covariation for improving growth rate and also reproductive capacity in masu salmon.

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