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EXPERIMENTS WITH SELECTIVE BREEDING OF ATLANTIC SALMON

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INTRODUCTION

In Norway rearing of salmonids has had growing interest during the last decade. Although the greatest interest has been on rainbow trout, Salmo gairdneri, significant quantities of Atlantic salmon, Salmo salar, are also produced.

Parent fish for salmon farming are in general caught in the sea or in the rivers, and the last years also first and second generation of farm-raised parent salmon have been used. The rate of growth, age and size at maturity are of great significance for salmon farming, and in nature the variations in these traits are well known. However, far less is known considering the influence of heredity and environmental factors on these traits, but it is reasonable to assume that the genetic potensialities of economic important characteristics are considerable, and that selective breeding could give strains which are better adapted to fish farming than the wild-caught salmon.

Besides variation in growth rate and size at maturity, genetic variation in other characteristics such as resistance to diseases, meat quality and weight/length ratio would be valuable.

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Experiments with selective breeding of salmon were started in autumn 1971 at the Institute of Marine Research, Bergen, Norway. In the first salmon generation the heritability of economic important characteristics are studied on material collected from several localities, and in the following generations this material will form the basis of selection experiments.

Another set of experiments were started in charge of Institute of Animal Breeding, The Agriculture College of Norway, approximately at the same time. In the present report a preliminary account of the methods and the results up to spring 1975 for the experiments at the Institute of Marine Research is given.

MATERIAL AND METHODS

Fertilized eggs were collected from several Norwegian rivers and two commercial fish farms in autumn 1971, 1972, 1973 and 1974 (see Figure 1.). In 1971 we also got material from two Canadian rivers and one Swedish river through cooperation with Quebec Wildlife Service and Salmon Council and Kvistforsens Laxodling, Skellefteå.

Normally two fishes from each sex were used at each locality. The eggs from each of the females were divided into two portions and each portion was fertilized with milt from one of the males. In this way four groups of fertilized eggs (a 2 x 2 factorial design) from each locality were obtained. The individuals of each of the groups were paternal half sibs to the individuals in one of the other groups, maternal half sibs to the individuals in another group and unrelated to the individuals in the third group.

The eggs were incubated and hatched at the hatchery of the research station Fisk og Forsøk, Matredal. The egg diameter of each group was measured at the "eyed" stage. The fry and parr were kept in plastic tanks at the station for one year, and afterwards transported to floating cages in brackish water near the station. After smoltification (mostly after two years) the young salmons were transferred to floating cages (4 x 4 x 3 m) in sea water at commercial fish farms.

The groups were kept separate in trays or tanks at least until

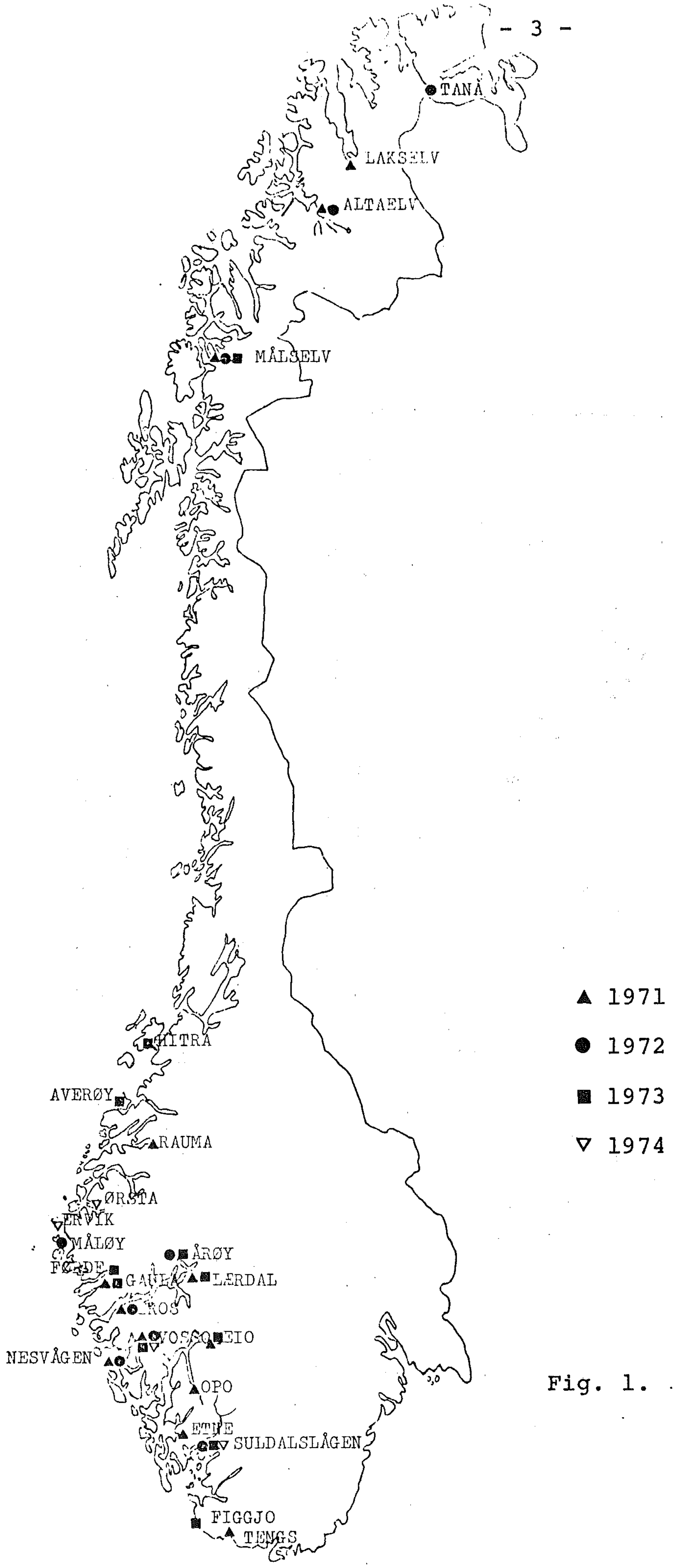

Fig. 1. Rivers and fish farms in Norway from which eggs were collected.

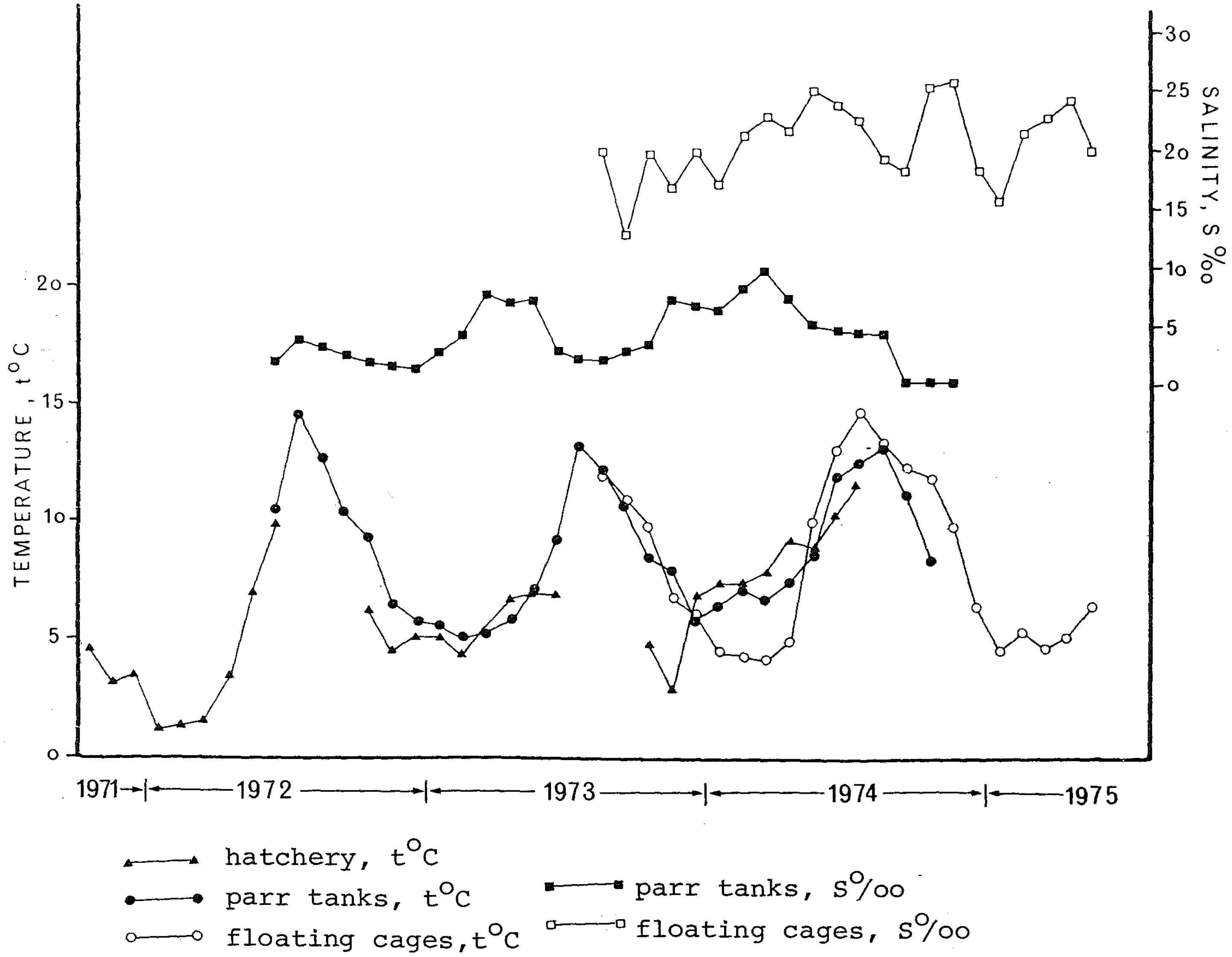

Fig. 2. Temperatures and salinity (monthly means) in the hatchery, parr tanks and floating cages at the research station Fisk og Forsøk. In the floating cages the measurements are taken at 2 m depth.

they were half a year. Then they were marked by removal of fins (Stuart 1958) and put together in greater tanks. By clipping different combinations of fins, up to seven groups could be kept together in the same tank.

One thousand smolts of the 1972 year-class were individually tagged with Carlin tags in spring 1974 and the rest of this year-class were tagged by FT-4 Lock on tags (Floy Manufacturing, Seattle) in spring 1975 and transferred to bigger floating cages (500 m^3). From 1975 on the smolt will be marked by cold branding.

The pH of the fresh water supply of the research station is too low to be used directly in the hatchery or in the rearing tanks. In the hatchery the water was passed through a tank filled with limestone thus adjusting the pH to about neutrality. In the parr tanks the pH was raised by adding sea water to a salinity of about 5 ‰. This caused no trouble even for the smallest fry, but it caused occasional outbreaks of vibriosis with heavy mortality in the salmon groups. From September 1974 on the pH of the freshwater therefore is adjusted by adding small quantities of lime powder to the water before it is distributed to the rearing tanks.

Heated water from an electric power station was used in the hatchery and in the rearing tanks keeping the water well above natural freshwater temperature. In Figure 2 the monthly means of temperatures and salinity from October 1971 to June 1974 are showed separately for the hatchery, the parr tanks and the floating cages.

Growth rates were recorded each half year (for the first two year-classes) or each year (for the third year-class) by total length measurements. During the growth stage in the sea also weights were recorded. Besides growth rate, smoltification in per cent after one and two years and maturation during the third year of life, were recorded.

As far as possible all groups were kept under identical conditions. However, due to differences in mortality there was some variation in density in the rearing tanks and also in the floating cages, which could have caused systematic errors when comparing groups. Especially the growth of the 1972 year-class during its first year in the sea may be suspected of being partly density dependent.

RESULTS AND DISCUSSION

To see whether growth rate at early life may be used as measurement of the fish's ability of growth at later age, correlation and regression coefficients between mean lengths for the same groups at different ages were calculated for the 1972 year-class. The coefficients are presented in Table 1, which shows that correlation is high between measurements which are taken at short intervals, but correlation is near zero for the earliest and latest measurements. Growth (measured as group mean lengths) at early life therefore seems to be of negligible value for predicting the growth at later stages, and selection for high growth rate cannot be based on presmolt growth rate. However, high growth rate on the presmolt stage may give high percentage of one-year smolts, which is of importance shortening the expensive fresh water stage.

Table 1. Correlation coefficients (above diagonal) and coefficients of regression (below diagonal) of mean length of sib groups of salmon measured at five different ages.

Age in months	6	12	18	24	30
6	-	0.75	0.27	0.00	-0.01
12	1.27	-	0.49	0.32	0.20
18	0.51	0.56	-	0.60	0.49
24	0.01	0.48	0.70	-	0.69
30	-0.03	0.87	1.72	2.04	-

In the 1972 and 1973 year-classes there were very few one-year smolts, and the material does not allow further studies on correlation between high growth rate during the first year and rate of smoltification after one year. But preliminary results of the 1974 year-class indicate that the groups which show the highest mean growth rate during their first year of life also give greatest per cent of one-year smolts under identical conditions.

In the 1972 and 1973 year-classes the proportion of parr varied between groups from zero to about 35% after two years. These parrs were put into seawater together with the smolts. They apparently survived the sea water during summer. Although the fishes were not tagged individually, it is reasonable to assume that they to a great extent mature as precocious parr during their first year in the sea, because a significant correlation ($r = 0.4$, $0.01 < P < 0.02$) was found for the 1972 year-class between proportion of parr after two years and proportion of precocious parr which also showed extensive variation between groups.

Except for precocious parr (all males) which spawned at a length of 15-20 cm, only two sexually mature fishes have been found in the material up to spring 1975.

To study the heredity of age (or size) at maturation and to obtain genetic improvement in this characteristic will be one of the main aims in the continuation of the present experiment.

The dependence of growth during first year of life on egg size was studied by calculating correlation coefficients between mean egg diameter and mean length after six months and twelve months of age. These calculations were made on the material hatched in 1972 and 1973. Table 2 shows a significant correlation between egg diameter and size after 6 months, but only about 20 per cent of the total variation between groups can be accounted for by this variation. After 12 months the per cent of variation accounted for by egg size is negligible and other factors are of far greater importance for growth. However, the maternal effect caused by variation in egg size may cause overestimation of the heritability factors calculated on maternal half sibs.

Table 2. Correlation between mean egg diameter (x) and mean length after 6 and 12 months (y).

Age	r_{xy}	P	% of variations accounted for by egg size
1972 year-class			
6 months	0.44	< 0.01	19.35
12 months	0.19	> 0.1	3.49
1973 year-class			
6 months	0.42	< 0.01	17.63
12 months	0.12	> 0.1	1.40

Bregnballe (1967) found a clear correlation between egg size and growth in rainbow trout, but the present findings only partly correspond to his results.

The relation between egg size and survival was studied by calculating correlation coefficient of the 1973 year-class between mean egg diameter and per cent survival (transformed to $\sin^{-1}\sqrt{\%}$) at six months of age. A correlation coefficient of 0.29 was found ($P \sim 0.05$) indicating that egg size may have some influence on survival (8% of the variation in survival rate could be accounted for by egg size), but that other causes (accidental or unknown) are of much greater importance.

The length measurements were used to calculate heritability factors (h^2) for growth at the presmolt stages. Factorial design and hierarchal design (Becker 1967) were used. The calculated factors varied greatly (Table 3), and clearly some of the values are overestimates.

Table 3. Account of calculated values of heritability for growth (measured as total length) of salmon parr and smolt. The letters S, D and A indicate that the factors are calculated from paternal half-sibs, maternal half-sibs and full-sib groups respectively.

			Hierarchal design			
	Factorial design		Paternal half-sib group		Maternal half-sib group	
Age in months	h^2_S	h^2_D	h^2_S	h^2_A	h^2_D	h^2_A
6	0.15	0.21	1.00	0.33	1.00	0.18
12	0.54	0.03	0.64	0.66	0.61	0.69
18	0.57	0.03	0.30	0.20	0.09	0.47
24	0.27	0.07	0.36	0.36	0.36	0.39

Generally the highest values were found for the youngest stages, indicating that unknown environmental factors (systematic errors) have some influence on the results. Maternal effect could account for part of the apparent overestimations. Aggresive behaviour could be another factor. Investigations concerning the influence of aggression on growth are started. Generally, however, the estimates based on maternal half sibs are not greater than estimates based on paternal half sibs or full sib groups.

Lindroth (1972) found a heritability factor of 0.60 for growth of parr. The present investigation indicates somewhat lower heritability, but higher than the heritability factors calculated for rainbow trout (Calaprice 1968, Aulstad, Gjedrem and Skjervold 1972) and brown trout (Calaprice 1968).

In any case, additive genetic factors seem to play a considerable part in growth of salmon at the presmolt stage, indicating that selection may give genetic improvement. However, for fish farming, the growth in the sea is of far greater importance, and considerable interest will be paid to this trait when continuing the experiments.

CONCLUSIONS

1. Mean growth rate of sib groups at early life seems to be of negligible value for predicting mean growth rate at later stages of Atlantic salmon.

2. The egg size seems to be of value for growth rate in the first month of life,and it also has some influence on survival rate during the first months.

3. The ratio of precocious parr varies between salmon groups of different origin, and seems to be correlated with proportion of parr after two years (late smoltification).

4. Additive genetic factors seem to play a sonsiderable part in growth of Atlantic salmon indicating that selection may give genetic improvement.

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