*FiskDir. Skr. Ser. HavUnders.*, *17*: 359–366.

# SOURCES OF VARIATION IN WEIGHT AND LENGTH OF ATLANTIC SALMON

By
GUNNAR NÆVDAL, RITA LERØY and DAG MØLLER
Institute of Marine Research, Bergen, Norway

## ABSTRACT

NÆVDAL, G., LERØY, R. and MØLLER, D. 1983. Sources of variation in weight and length of Atlantic salmon. *FiskDir. Skr. Ser. HavUnders.*, *17*: 359–366.

Variances of weight and total length of four year classes of farmed Atlantic salmon after two years in the sea were distributed on strain, family, maturing/immature (after two winters) and sex. Highly significant variations between families were found. Also significant variations due to sex and stage of maturity were evident. On an average males were heavier and longer than females, and maturing fish on an average were heavier and showed higher condition than immature within most groups. Differences in length between maturing and immature fish were not obvious. The higher condition factors of mature than immature fish were not caused by higher gonad weights.

## INTRODUCTION

For genetic improvement of salmonids for fish farming, the traits of growth rate and age at first maturity are of special interest. Concerning age at first maturity, it is important to omit from the broad stock salmon (*Salmo salar*) maturing after one sea-winter (grilse) and rainbow trout (*Salmo gairdneri*) maturing during their second year of life. It is widely discussed within the fish farming industry whether it is desirable to select for still higher age at first maturity, i.e., for salmon maturing after three sea-winters or later. The advantages are that large fish (15–20–25 kgs) may be reared, if wanted, and that the slaughtering may be conducted independently of the breeding season, hence is better adapted to the market situation. The main drawback will be production and handling of the brood stock, because in commercial fish farming it seems that the maturing process is more irregular for old spawners, and the egg quality is lower and more variable. Fish mortality due to handling of large fish is also a problem.

In rainbow trout it was found that fish maturing at 2+ were on average significantly larger than their immature sibs, and this difference could be traced back one year on individually tagged fish (NÆVDAL *et al.* 1979 b and unpublished). In a limited material of individually tagged salmon a similar, but not very obvious, tendency was observed (NÆVDAL *et al.* 1978). Earlier reports have suggested different growth rate between males and females.

In the present report interdependence of growth rate, sex and age at first maturity is studied on four year classes of sib groups of salmon. The study is part of a more extensive study on genetic variation in quantitative traits of salmonids. Observations from commercial production of salmon are also included.

## MATERIALS AND METHODS

The present study is based on year classes of salmon hatched in the years 1972, 1973, 1974 and 1975. The rearing methods are described in earlier reports (NÆVDAL *et al.* 1978, 1979 a) where the year classes 1972 and 1974 were described. The 1973 and 1975 year classes were made up in a similar way, except that the 1975 year class contained more sib groups from reared parents, while the other year classes mostly were based on brood stocks caught in rivers. Growth rates were recorded by length measurements during the rearing periods of half year or one year intervals. Maturing fish were recorded during the second sea-year. After two years in the sea the fish was slaughtered, except about 20 fish which were selected as brood stock from each sib group of the 1972 and 1973 year class. Lengths, weights, sex and stage of maturity were recorded for killed fish. The sex of immature fish could not be determined on the live broodstock fish. As the live fish were selected for size, no grouping according to sex was made on the first two year classes, because such data would have been biased. In the two last year classes all fish were killed because they were infected by IPN-virus and could not be used as broodstock. In the present analyses weight and total length were used as representing size. In order to confirm the results from the experimental fish, two groups of commercially reared salmon (A/S Bolaks, Eikelandsosen) were sampled. These fish were killed so early in the year (March) that the difference between immature and maturing fish could not be detected by visual inspection, but they gave, however, very good data for studying the relationship between sex and size. Standard analysis of variance were used for the analyses.

## RESULTS

### *COMMERCIALLY REARED SALMON*

Mean length and weights for the two groups of commercially reared fish are shown in Table 1. In both groups the males are on an average 0.8–1 kg heavier than the females. The difference between the two groups is probably due to their different origin. Group A was sorted out for high presmolt growth rate and B was the smaller ones when grading after one summer. This may also explain the difference in the proportions of grilse and sex ratio as higher presmolt growth rate for males than females is indicated and thus will give sex

ratio deviating from 1:1 proportions. The grilse were mainly males, and higher proportions of grilse may in this connection only indicate higher proportions of presmolt fast growing males. However, also the later maturing males showed significantly higher growth rate than the females.

Table 1. Observations from two groups of commercially reared salmon in the same plant after about 21 months in the sea. The grilse were omitted when the means were calculated.

| Group | Mean lengths (cm) | | Mean weights (kg) | | Grilse % | Sex ratio |
|---|---|---|---|---|---|---|
| | ♂ | ♀ | ♂ | ♀ | | ♂ : ♀ |
| A ..... | 78.1 | 73.9 | 6.0 | 5.0 | ~ 10 | 61:39 |
| B ..... | 80.9 | 76.4 | 6.4 | 5.6 | < 1 | 47:53 |

*EXPERIMENTAL FISH*

*Weights*

The weight data showed extensive variations in the total material. To reveal the sources of variation, the data were analysed by nested analyses of variance. The analyses are shown in Table 2.

In the three first year classes there is a significant influence of locality or sib groups within localities. This represents the genetic variation of the total experimental populations. The variation between sib groups within localities may be used for calculating heritability factors. In the present analyses reliable estimates cannot be made because the material includes both sib groups and groups of half sibs. Evidently there is much genetic variation which may be utilized for selective breeding. However, the main purpose of the present report is to study the influence of sex and age of maturation on growth rate. In order to eliminate the genetic effect on growth rate, the analysis of variance was made on a within-sib-groups-basis.

Significant differences were found between those fish maturing during their third year in the sea and those maturing later. From the calculated means it was clear that the maturing fish were on average the greater, although immature fish were also found among the greatest individuals. Similarly, there was a significant difference between the two sexes. On an average both among the maturing as well as among the immature fishes the males were the biggest.

The results correspond to the results of the commercially reared salmon, although the effects of sex were not so evident in the experimental fish.

However, some exceptions to the overall rules were observed. In some groups, especially from some river populations, there were very small differences between males and females, and occasionally females were on average the greatest. Concerning age at maturity, also some exceptions were observed.

Table 2. Analysis of variance of salmon weights distributed on localities, sib groups and mature/immature after two winter in the sea.

| Source of variation | 1972 year class | | | 1973 year class | | | 1974 year class | | | 1975 year class | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d.f. | Mean square | P | d.f. | Mean square | P | d.f. | Mean square | P | d.f. | Mean square | P |
| Between locality ..... | 10 | 37,9 | <0.05 | 5 | 39.4 | >0.05 | 10 | 86.0 | <0.01 | 4 | 227.9 | >0.05 |
| Between sibgroups .... | 21 | 9.9 | >0.05 | 10 | 30.0 | <0.01 | 29 | 4.2 | >0.2 | 29 | 84.6 | >0.05 |
| Between mature/ immature..... | 32 | 9.0 | <0.01 | 16 | 5.3 | ~0.05 | 39 | 29.3 | <0.01 | 31 | 42.8 | <0.01 |
| Between sex..... | | | | | | | 76 | 4.3 | <0.01 | 68 | 4.9 | <0.01 |
| Residual..... | 1 198 | 1.6 | | 695 | 2.7 | | 1 762 | 1.1 | | 2 922 | 1.8 | |

Table 3. Analysis of variance of salmon lengths distributed on localities, sibgroups and mature/immature after two winters in the sea.

| Source of variation | 1972 year class | | | 1973 year class | | | 1974 year class | | | 1975 year class | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d.f. | Mean square | P | d.f. | Mean square | P | d.f. | Mean square | P | d.f. | Mean square | P |
| Between locality ..... | 10 | 16029 | <0.01 | 5 | 294.4 | >0.2 | 10 | 1877.0 | <0.01 | 4 | 3926.3 | >0.05 |
| Between sibgroups .... | 21 | 225.0 | >0.05 | 10 | 504.6 | ~0.01 | 29 | 301.1 | <0.01 | 29 | 736.0 | <0.01 |
| Between mature/ immature..... | 32 | 123.3 | <0.05 | 16 | 112.6 | <0.05 | 39 | 102.5 | >0.2 | 31 | 176.0 | >0.05 |
| Between sex..... | | | | | | | 76 | 118.1 | <0.01 | 60 | 171.3 | <0.01 |
| Residual..... | 1 198 | 72.8 | | 695 | 50.4 | | 1 762 | 37.4 | | 2 922 | 30.2 | |

*Lengths and conditions*

Similar analysis of variance concerning total length were also carried out (Table 3). The effects of locality or family within locality were significant in all year classes. However, the effect of maturation was much less evident on lengths than on weights, as significant differences ($P < 0.05$) were found only for two year classes. This probably reflect the fact that in nearly all groups the calculated condition factors were higher for maturing than for immature fish of both sexes. No special gonad weights were recorded, but the differences cannot be due to gonad weight at this stage because the gonads were just starting to develop when the samples were taken, and they were negligible compared to the total weights of the fish. The differences in condition thus reflect real differences in body proportions between maturing and immature fish. According to lengths there was a significant sexual difference.

*Co-variations within families*

The relationship between mean size of males and females, respectively maturing/immature fish within sib groups were also studied by calculating correlation and regression coeffisients between mean lengths and weights. The results are summarized in Table 4. In all but one case, high and very significant correlations were found showing that in spite of the clear difference between maturing and immature fish and males and females respectively, the sib groups possessed inherent growth characteristics.

Table 4. Correlation coeffisients (above diagonal) and regression coeffisients (below diagonal) between mature and immature males and females within salmon sib groups. Left:mean weights, right: mean lengths.

| Sex and stage of maturity | Immature | | | Maturing | | |
|---|---|---|---|---|---|---|
| | ♂ | ♀ | Sum | ♂ | ♀ | Sum |
| Immature ♂ | | 0.93/0.93 | | 0.77/0.19 | | |
| ♀ | 0.64/0.62 | | | | 0.81/0.80 | |
| Sum | | | | | | 0.75/0.81 |
| Maturing ♀ | 0.80/0.0 | | | | 0.82/0.87 | |
| ♀ | | 0.78/0.85 | | 0.66/0.73 | | |
| Sum | | | 0,87/0,96 | | | |

## DISCUSSION

This paper mostly deals with variation in growth rate in farmed Atlantic salmon not directly genetically controlled. The main purpose of the study is to reveal genetic variation to be utilized for selective breeding, but information on non genetic variation also are important for understanding the variations observed.

In a previous paper NÆVDAL *et al.* (1978) found small, although statistically significant, variations in growth rate related to age at first maturity on a limited number of individually tagged fish (partly in the same material as the 1972 year class on the present study). However, in that study also grilse were included and found responsible for the main part of the variation. Effect of sex was not clear.

In a comparative study of subsequent growth rate of one and two year smolt of the same sib groups (NÆVDAL *et al.* 1979) the incidences of grilse were highest among the one year smolt (the fast growing individuals at the pre-smolt stage), but in contrast to the results from the commercially reared salmon in the present study, no surplus of males could be found among the faster growing fish on the pre-smolt stage. DALZIEL and SHILLINGTON (1966), however, found surplus of males among one year smolt of Atlantic salmon, and HAGER and NOBLE (1976) observed the same tendency in coho salmon, *Onchorynchus kisutch*. In three year old fish, however, the same authors found nearly the same mean lengths for males and females, but there was a significant higher variance for males than for females as both the biggest and smallest fish usually were males. Corresponding weight data showed slightly higher mean weight for females than for males.

KATO (1975) found that the mean body length of maturing rainbow trout was larger than for the immatures before the spawning season, and NÆVDAL *et al.* (1979 b) and NÆVDAL, LERØY and MØLLER (1981) found the same both in weight and length on individually tagged fish. Fish maturing at 2+ (about 31 months) were bigger than those maturing later even at 18 months of age. The effect of sex on growth rate was not very clear. It could, however, be revealed when variations due to other known sources were excluded.

However, the results of the present report contradict several investigations on growth of wild salmon. By backcalculating of growth zones in the scale of Scottish and Canadian salmon, COLDERWOOD (1925) and MENZIES (1925) found that the earliest maturing fish showed lower growth rate during the first seayears than the later maturing fish, i.e. salmon maturing as two-winters fish were shorter than salmon maturing as three-winters fish at the end of their second winter in the sea. Also ALLEN, SAUNDERS and ELSON (1972) found that the length of two-winters spawners were on an average less than the corresponding length of three-winters or older spawners after two years at sea, because the growth rate of the spawners already had slowed down at that time. Similarly, SCHAFFER and ELSON (1975) found a positive correlation between mean age at first spawning and marine growth rate after the grilse stage on a large material of wild Canadian salmon, i.e. high growth rate subsequent to the grilse stage is assosiated with delayed reproduction.

This discrepancies of the results of observation of wild salmon growth rate and the main results in the present study, may reflect differences between natural and fish farming conditions. Reared fish are usually given food in excess, and the fish are prevented from migration, and thus probably the

growth patterns are influenced. Differences in growth patterns between strains may also be an explanation, and this is indicated in the present study.

The obvious variation between strains or sib groups is in accordance with results of GUNNES and GJEDREM (1978) who found great variations in weights and lengths between strains from Norway, and also quite high heritability factors for these traits on a within-strain-basis.

ACKNOWLEDGEMENT

The authors are grateful to the staff of the research station at Matre, to the Svanøy Foundation for keeping the fish during the rearing periode, and to several river owners and commercial fish farms for providing the material.

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Received 14 September 1982
Printed 15 June 1983