

Breeding programmes of Salmonid fish with Arctic charr as a case study

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No farmer would consider raising wild boars and jungle fowls for producing ham and eggs. Instead they grow the domesticated pig and hens which has been bred for centuries to increase the production and level of domestication. Breeding programs of farmed fish aimed for consumption are as necessary as breeding were and still are for our most important farmed animals like chicken, egg laying hens, pigs and cows to increase production (Fig 1).

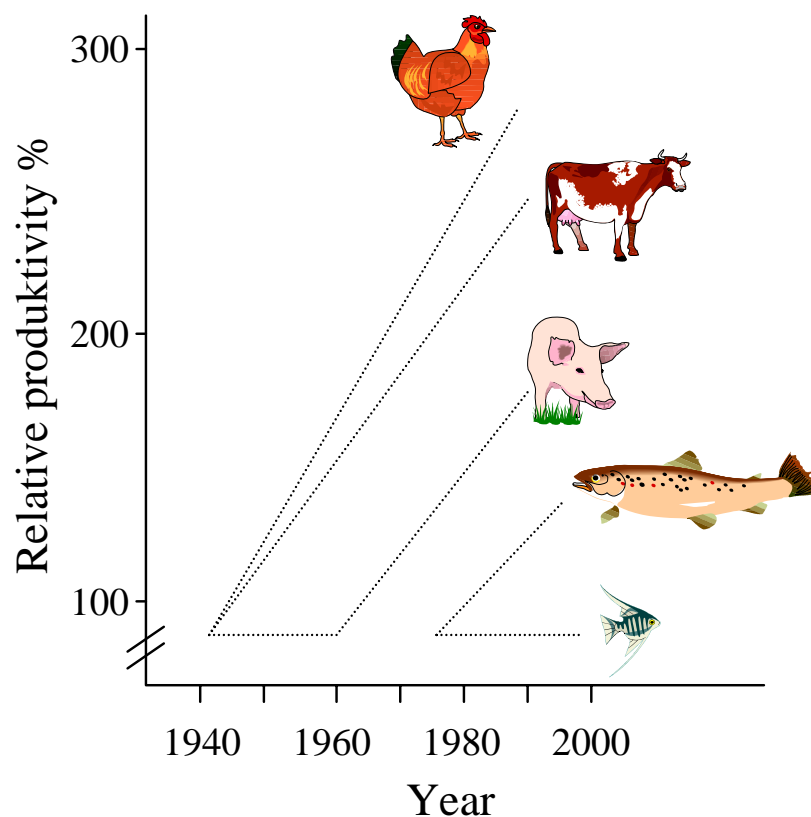


Figure 1. Example of the productivity increase by breeding of domesticated animals, including salmon. Tropical aquaria fish are used as a comparison (modified after Gjedrem 1995).

Breeding programs of fish is not a new occurrence as carp, goldfish and rainbow trout have been bred for centuries either for production or ornamental purposes. In Norway, however, the first major national breeding program on salmonid fish started in the late 1970: th to support the increasing aquaculture industry of mainly salmon and rainbow trout. This was a result of a close connection between aquaculture and agriculture in Norway which made the transfer of knowledge and routines from husbandry breeding to fish breeding quick and easy.

The advantage with breeding programs on fish is that high selection intensity can be achieved as their fecundity is high compared to farmed warm blooded animals with few offspring. A high fecundity makes it possible to produce offspring groups with many individuals in each and therefore, desirable traits can be tested in full-or half sib groups more efficiently in fish compared to most other domesticated species.

Gjedrem (1983) described that most of the investigated traits in fish has a high variation and that even traits with a low heritability can be selected for if full-and half sibs are used in the selection process as the number of offspring is high.

A standardized breeding program is a stepwise event with stepwise goals (Gjedrem 1995; Refstie 1990).

1) Breeding goal

What are the most important traits for the industry and consumers? These are traits of economic and quality importance and must show phenotypic and genetic variation in the population.

For salmonid fish the traits listed below are the most important ones:

- Growth rate
- Food conversion efficiency
- Survival rate
- Age at maturity
- Meat quality

2) Selection of strains.

Salmonids, including Arctic charr have distinct geographically separated population with different ecology and performance in farming conditions. When starting a selection program it is important to compare the performance of these strains in farming conditions as the selection can be based on the best genetic material. There are several examples of differences in performance between strains of several species (review Kinghorn 1983). It is sometimes recommended that when starting a selection program of a new species, crossing of the strains with the best performance in farming condition may be the best strategy to ensure a broad genetic basis for selection.

3) Estimation of genetic parameters

A simple selection scheme only requires that the trait show a genetic variation. However, an optimized breeding scheme requires that the responses to selection can be predicted which require reliable phenotypic and genetic parameters. This requires data collected from the individual itself, its siblings, half-siblings and parents. The most important phenotypic parameters are: mean values, standard deviation, phenotypic correlation and relative economic value of each trait. The most important genetic parameters are heritability and genetic correlation.

Commonly, several economically important traits are included in the breeding goal as in salmon. Theoretical genetics states that the highest breeding effect is done by selecting all desired traits at the same time instead of one at a time. Also, the relationship between additive and non-additive inheritance have to be studied. If additive variation is the case, then selection can be initiated but if the traits are non-additive, a combination of selection and crossbreeding has to be done. Also, it is important to investigate the relationship between environment and genotype. If the environment have a large impact of specific strains, e.g. if some strain perform poorly in warmer water whereas other perform excellent, the consideration of two or more breeding lines must be considered.

Finally, each single trait will have a heritability ranging from 0-1 where 0 is a trait with no heritability and 1 where 100 % of the variability of a trait can be explain by genetic factors. The breeding value of each animal can be estimated if the performance on the individual itself is combined the performance of siblings, half-siblings, parents etc. into a BLUP (Best Linear Unbiased Prediction) index.

The calculations of these parameters are described in textbooks of selective breeding. There are also several programs available on the internet for calculating BLUP index (i.e. Pedigree Viewer).

4) Selection method

Individual based selection and *family based* selection are the two most important selection methods in fish.

Individual based selection or mass selection is based on the individual fish's criteria and performance. This method was the most common method before the national breeding programs was initiated in Norway on salmon. Individual selection requires that the heritability of a particular trait is high and that the trait can be measured on the animal itself without having to kill it. The advantage with an individual based selection program is a low cost.

Growth rate has a heritability factor of 0.20-0.30 and is easily measured in Atlantic salmon and is the most common trait used in individual selection of salmonid fish in general.

Traits, like resistance to deceases, age at sexual maturity or meat quality are as economically important traits as growth rate but not suitable for individual based selection as these trait can not or are difficult to measure on living fish.

An efficient individual selection programme relies on standardized environmental conditions throughout the fish's life span. Differences in light, temperature or feeding conditions between groups aimed for selection reduced the reliability of individual selection. This is especially important if individuals from more than one farm are used in a selection scheme.

A risk with individual selection of fish of which the kinship is not known is the risk of inbreeding. Inbreeding in fish have resulted in growth depression and reduced survival (Gjedre et al. 1983)

Family based selection is based on measured criteria of siblings and half-siblings that will strengthen the estimation of genetic heritability of different traits. Fish has large family groups and the effect of kinship is in mean a 50 % similarity of the genetic material in siblings and 25 % in half-siblings. Family based selection is particularly efficient for traits like resistance to deceases and age at sexual maturity that has a low heritability factor or is difficult to measure as the environmental factor is high. The disadvantage is a high cost as the families have to be kept in separate units until they can be marked and put together in larger groups to avoid environmental or “tank” effects.

The most efficient program is a combination of an individual and a family based selection as individual selection strengthen the estimation of heritability of traits after family selection and also avoids inbreeding

A summary of a one generation schedule where a combination an individual and family based selection are used and includes measurement of the important traits in at least one test station and in the breeding station. Families are first ranked according to performance and then individuals (Fig 2).

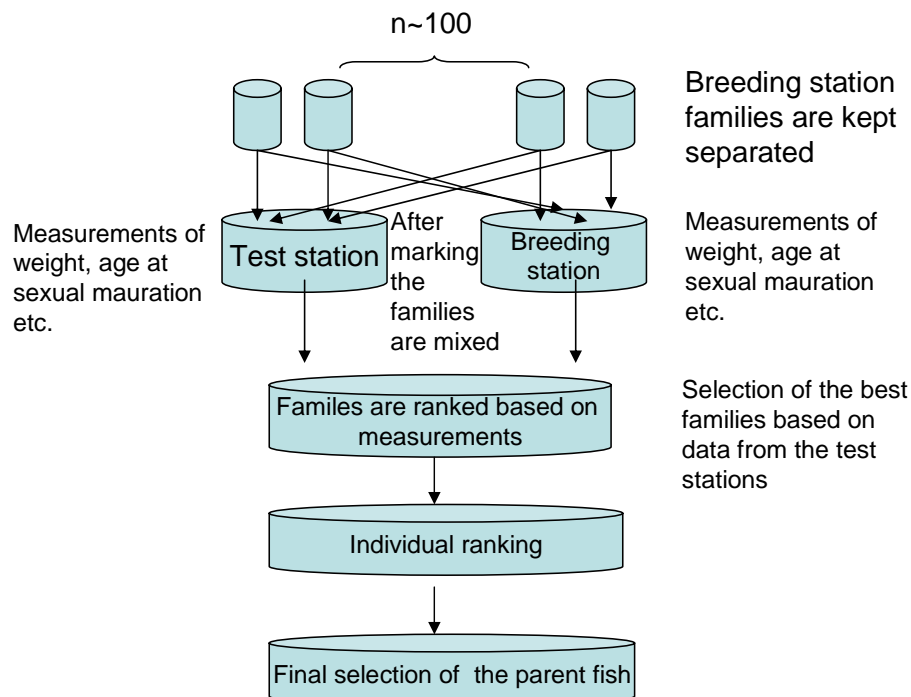


Figure 2. A selection schedule based on a combination of family and individual selection (modified after Gjedrem 1995).

New techniques in selective breeding

At present most breeding programs are done in a traditional way but there is a tremendously fast development in using new DNA markers when selecting broodstock. The goal is to identify a set of genes or markers that is important for growth or other important traits. The efficiency of selecting broodstock with specific genetic traits can then be considerably increased. So far markers have been identified for body weight and condition factor in Atlantic salmon, Rainbow trout and Arctic charr (Reid et al. 2004; Tao and Boulding 2003). Identification of a temperature tolerance genetic markers in Arctic charr and rainbow trout is also in progress (Ildiko et al. 2003). In fact, the entire genome of Arctic charr is presently being mapped in Canada at the Fraser University in Vancouver, Canada (www.....can)



Case study of a breeding program on Arctic charr:

Arctic charr have a great potential in coldwater aquaculture but they had to be improved genetically to be suitable in commercial fish farms. The Swedish breeding program of Arctic charr was the first national breeding program on Arctic charr and it followed the steps outlined by the national Norwegian selection program on Atlantic salmon.

1. The **breeding goals** were identified and mainly aimed to improve growth rate, increase age at first sexual maturation, pigmentation and resistance to fungal infection.

2. The selection program started 1982 by comparing three **different strains** of Arctic charr raised in net-pens under standardized commercial conditions. Growth rate and age at sexual maturation were measured during three growing seasons. Hornavan charr had the highest growth rate (Fig. 3) and the lowest frequency of early sexual maturation during the second growing season.

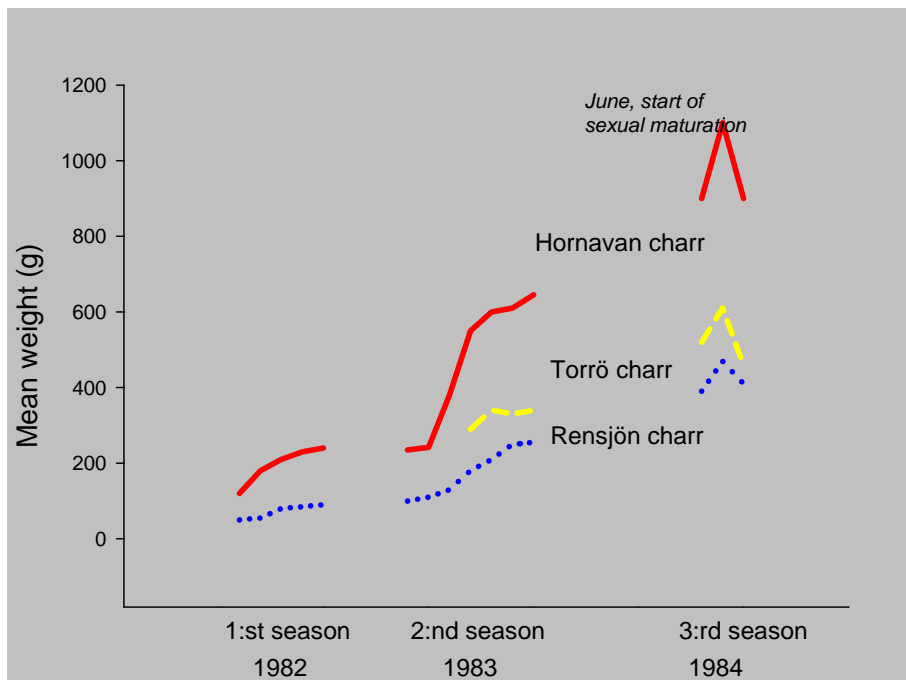


Fig 3. Growth rate of three of the most important Arctic charr population in Sweden reared in net pens in Lake Storuman during three growing seasons. The measurements started in May-June and ended in November during the season 1 and 2.

The Hornavan charr was the strain with the best performance for a selection program. In 1984, ninety-six full-sib families were formed by stripping and mating randomly chosen males and females. Genetic parameters were estimated and the heritability was significant for growth characters, age at first sexual maturation (Nilsson 1992; 1994) and resistance to fungal infection (Nilsson 1992).

Each selected generation started by selecting the best individuals and crossing these with non-siblings. The eggs are kept in separate egg-trays and reduced to 150 individuals in each family to be raised in separate trays (Fig 4).



Fig 4. From left to right; the stripping of parent fish, incubation and raising families in individual units.

3. The progeny are kept in separate family units until they are large enough to be marked (> 15 g). In this case, a combination of fin-clipping and freeze-branding are used (Fig 5.).

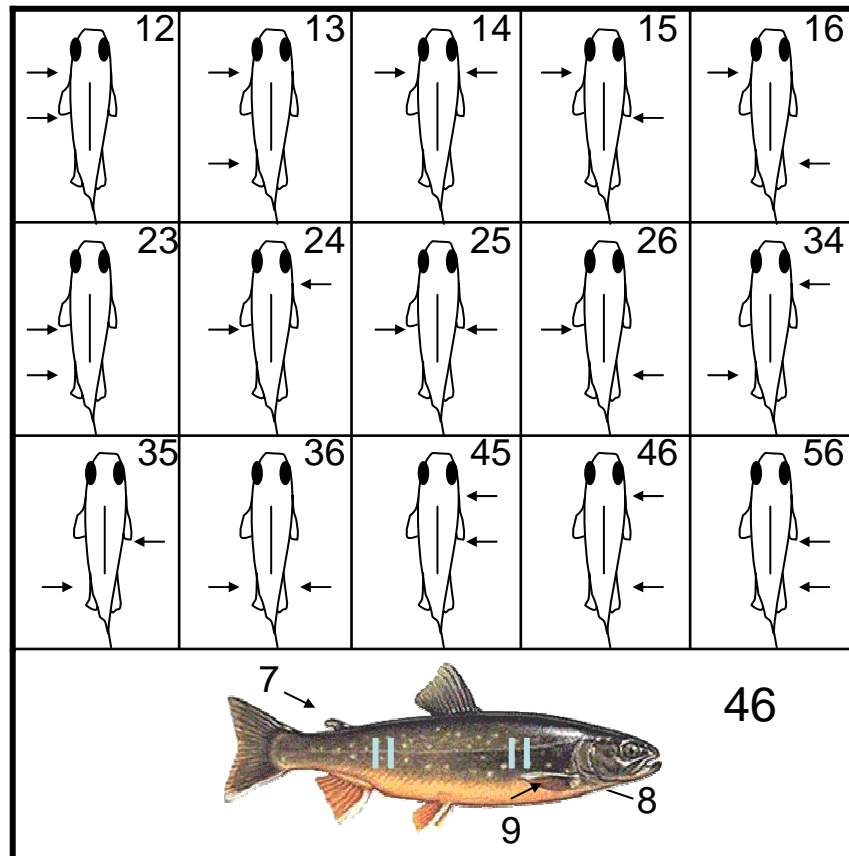


Fig 5. A combination of freeze-branding and fin-clipping can be used to mark fish according to family groups. By freeze branding each fish on two positions of the body 15 groups are created and by adding groups with the fat fin or the left or right pectoral fins cut increases the possible combination to 120. If the fish below would have its fat fin cut of the family is 746, if the left pectoral fin is cut the id is 846 and if the right pectoral fin is cut the id is 946 (modified after Gjedrem 1995).

After marking the fish according to family these are mixed and divided into two and more groups, one is kept in the breeding station (left) and the other(s) group(s) is kept in one or more commercial farm (right). Regular measurements on performance is made and noted according to family. When the groups are reduced, all individuals are marked with PIT-tags. BLUP-index for each family is calculated and a crossing schedule is made on the best individuals and avoiding inbreeding.



In October-November 2004, the sixth generation of the national breeding program was stripped and new families incubated. Each generation has in mean been estimated to be improved by 10 % at least by mean of growth rate. A comparison of the farming performance of the “original” Hornavan charr and the selected Hornavan strain, the *Arctic superior*® is summarized below (an improved rearing technique is also responsible for the improvement:

Arctic charr farming 1985	Arctic charr farming 2004
Production cycle of 3-4 years from a 2-year fish of 50 g.	2 -3 year production cycle, from eggs
Slow growth, low feed utilization	Fast growth, high feed utilization
High frequency of early sexual maturation (40-100% before 500 g)	Low frequency of early sexual maturation (0-10% at 500 g)
Variable quality	Low variability in quality
Production cost of 40-60 Skr / kg	Production cost of 25-35 Skr / kg

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