View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Aquatic Com

Breeding Programs On Atlantic Salmon In Norway – Lessons learned

Jørn Thodesen[1] and Trygve Gjedrem[2]
[1]AKVAFORSK Genetics Center AS, 6600 Sunndalsøra, Norway
[2]AKVAFORSK, Institute of Aquaculture Research AS, 1430 Ås, Norway

Abstract

An early establishment of selective breeding programs on Atlantic salmon has been crucial for the success of developing efficient and sustainable salmon farming in Norway. A national selective breeding program was initiated by AKVAFORSK at the beginning of the 1970s, by collecting fertilized eggs from more than 40 Norwegian river populations. Several private selective breeding programs were also initiated in the 1970s and 1980s. While these private programs were initiated using individual selection (i.e. mass-selection) to genetically improve growth, the national program was designed to gradually include all economically important traits in the breeding objective (i.e. growth, age at sexual maturation, disease resistance and quality traits) using a combined family and within-family selection strategy. Independent of which selection strategy and program design used, it is important to secure and maintain a broad genetic variation in the breeding populations to maximize selection response. It has been documented that genetically improved salmon from the national selective breeding program grow twice as fast as wild Atlantic salmon and require 25 per cent less feed, while salmon representing the private breeding programs all show an intermediate growth performance. As a result of efficient dissemination of genetically improved Atlantic salmon, the Norwegian salmon farming industry has reduced its feed costs by more than US$ 230 million per year! The national selective breeding program on Atlantic salmon was commercialized into a breeding company (AquaGen) in 1992. Five years later, several private companies and the AKVAFORSK Genetics Center (AFGC) established a second breeding company (SalmoBreed) using breeding candidates from one of the private breeding programs. These two breeding companies have similar products, but different strategies on how to organize the breeding program and to disseminate the genetically improved seed to the Norwegian salmon industry. Greater competition has increased the necessity to document the genetic gain obtained from the different programs and to market the economic benefits of farming the genetically improved breeds. Both breeding companies have organized their dissemination to get a sufficient share of the economic benefits in order to sustain and improve their breeding programs.

Introduction

Norway is producing about 540,000 t of Atlantic salmon per year. More than 95 per cent of the production is exported and Norwegian salmon supply 45 per cent of the world market. An early establishment of selective breeding programs on Atlantic salmon has been critical for the success of salmon farming in Norway, and now the farming industry is depending on genetically improved seed from commercial breeding programs to remain competitive. In the following paper, we will give a brief summary of lessons learned from developing selective breeding programs on Atlantic salmon in Norway. A special attention will be given to the situation of today; how different breeding companies have organized their breeding programs and dissemination of genetically improved seed.

A national breeding program

A national selective breeding program on Atlantic salmon was initiated by AKVAFORSK at the beginning of the 1970s. Since Atlantic salmon has a four-year generation interval with a high death rate after spawning, four base populations ("year-classes") were established to supply genetically improved seed each year.

Base populations

Fertilized eggs representing a total of 400 full-sib families (FS-families) were collected from more than 40 Norwegian river populations to secure a broad genetic variation in all base populations. While different river populations were equally represented in the base populations, this changed dramatically after two to three generations of selection. Genetic material from the Namsen River dominated the first year-class (72%), together with five other river populations, and genetic material from a mixed population representing several river populations dominated the second year-class (55%), together with genetic material from seven pure river populations. Genetic material from a mixed population from the Nidelv River and Gaula River populations dominated the third year-class (90%), together with genetic material from two other populations, and, finally, all genetic material in the last year-class originated from a mixed hatchery population (the Mowi breed). The genetic variation has been maintained in the year-classes, however, because the genetic variation among individuals within the same population is found to be much larger than the genetic variation between populations.

Breeding objective

Initially, the breeding candidates were selected based on their growth performance of breeding candidates and the test fish were kept in cages from the time of stocking as smolt until harvesting. The breeding objective has become more complex by gradually including more economically important traits; age at sexual maturation (1981: 1st generation), resistance to Furunculosis (1993: 4th generation), resistance to Infectious Salmon Anemia, ISA (1994: 4th generation), filet color (1994: 4th generation), fat content (1995: 4th generation), fat distribution (1995: 4th generation), growth in freshwater (2001: 7th generation), body shape (2001: 7th generation) and, finally, resistance to Infectious Pancreatic Necrosis, IPN (2001: 7th generation).

Selection strategy

Only body weight at harvest and body shape can be recorded for the breeding candidates since these need to be kept alive until production of the next generation of families. Other traits, such as disease resistance and quality traits, require that relatives of the breeding candidates (e.g. full-sibs and half-sibs) be sacrificed to obtain the data. The national selective breeding program on Atlantic salmon has, therefore, used a "combined family and within-family selection" strategy to simultaneously improve all traits included in the breeding objective.

Accurate breeding values

The breeding candidates are ranked and selected based on their total (aggregated) breeding value, which combines breeding values for each trait defined in the breeding objective according to their economic importance (i.e. index selection). Breeding values are estimated using advanced statistical programs that combine all sources of information (i.e. about the breeding candidates themselves and their brothers, sisters, and cousins). This requires an optimal breeding design, in which both full-sib and half-sib families are produced, and where the pedigree of all breeding candidates and test fish are recorded and stored in a database.

Genetic gain

Genetically improved Atlantic salmon of the 7th generation are now being disseminated to Norwegian farmers. Results from studies with offspring of the 5th generation suggest a selection response of 14 per cent per generation for growth and a correlated response of 4-5 per cent per generation for feed utilization. It follows that the farmed Atlantic salmon in Norway today grow twice as fast as their wild counterparts and require 25 per cent less feed. As a result of the national selective breeding program, the Norwegian salmon farming industry has reduced its feed costs by 1.5 billion NOK (more than US$ 230 million) per year! The increased growth rate has also shortened the production time (reduced from 40 months in 1975 to only 20 months today), which increases the turnover rate, increases the survival rate and reduces the need for expensive medication. The frequency of early sexually maturing fish has been reduced by 12.5 units, equal to a selection response of 8 per cent for each generation. It has been more difficult to estimate selection responses in resistance to different diseases due to the testing regime used. However, a high correlation between family ranking in challenge-tests and a natural outbreak of Furunculosis (a bacterial disease) in cages suggest that the testing regime is effective to study the genetic variation of disease resistance in Atlantic salmon. A recent study, in which extreme groups (high and low resistance) and a wild control group were challenged with ISA-virus, confirmed that selective breeding is an effective strategy to improve the disease resistance of Atlantic salmon. In this experiment, where the extreme groups had been produced using breeding candidates with very high (HR) or very low (LR) breeding values for ISA-resistance, the wild control group had a survival rate of 58 per cent while the HR and LR groups had a survival rate of 71 and 23 per cent, respectively.

Private breeding programs

Several private breeding programs on Atlantic salmon were initiated in the 1970s and 1980s, such as Bolaks, Mowi, Jakta and Rauma. Owing to a lack of resources (know-how and research facilities), these programs were initiated using individual selection (mass-selection) as the strategy to genetically improve Atlantic salmon. Individual selection, which utilizes information about the breeding candidates, is only effective to improve traits that can be recorded on live animals and have a medium to high heritability. Therefore, the breeding objective of these private programs has only included growth (recorded as harvest weight) and, in some cases, age at sexual maturation.

Comparison of improved breeds

A study was conducted by one of the largest feed companies in Norway to evaluate the growth performance of different wild and domesticated breeds of Atlantic salmon. Twelve full-sib families were produced to represent each of four domesticated breeds: the national breeding program, Bolaks, Mowi and Jakta, and two major river populations in Norway, namely the Namsen River and Alta River. The study confirmed that salmon of the national breeding program (offspring of the 5th generation) grew twice as fast as offspring of wild Atlantic salmon. Test fish representing the private breeding programs all showed an intermediate growth performance, confirming that mass-selection (with a restricted accumulation of inbreeding) can also be effective to genetically improve the growth performance of aquaculture species.

Breeding companies

The maintenance of selective breeding programs not only requires a lot of resources (both human and financial resources), but also has the potential to generate considerable profit for the owners. Since most aquaculture species have a high reproduction capacity, the costs of maintaining a breeding program can be divided according to the large number of seed produced. In breeding programs for farm animals, the cost/benefit ratio has been estimated to vary from 1:5 and up to 1:50. This ratio is much more favorable for Atlantic salmon and other aquatic species since the production cost of brood stock is considerably lower than that of farm animals.

The national breeding program on Atlantic salmon in Norway was commercialized in 1992. Private companies have also become more active in recent years to develop alternative breeds of Atlantic salmon in Norway. More competition has put strong pressure on the breeding companies to reduce their maintenance costs and improve the quality of their products – service and genetically improved seed.

At present, there are two major breeding companies providing genetically improved seed of Atlantic salmon in Norway – AquaGen and SalmoBreed. These companies have similar products, but different strategies on how to organize the breeding program and dissemination of genetically improved seed to the Norwegian salmon industry. AquaGen and SalmoBreed have similar market shares in Norway. Companies controlling other breeds (Marine Harvest and Rauma Group) have marginal market shares.

AquaGen was established in 1992 when the national breeding program on Atlantic salmon was commercialized. Initially, the company maintained its four year-classes by producing 300 FS-families each year. The company has continued to include more traits in the breeding objective, which today accounts for ten economically important traits. The importance of different traits in the breeding objective has changed over time and is now ranked as follows: quality traits (40%), disease resistance (30%), growth (25%), and age at sexual maturation (5%). To face increasing competition from SalmoBreed, efforts have been made to reduce costs and improve the genetic quality of the seed. First, the generation interval has been reduced from four to three years to speed up the genetic gain. Secondly, the four year-classes are combined in one breeding population of 400 FS-families to standardize the genetic quality of the seed (and perhaps to reduce the costs of family production). Subsequent to these changes, FS-families will be produced every three-year. The company will use freeze-stored milt to produce commercial seed other years.

Several private companies (Bolaks, Jakta, Erfjord Stamfisk and Osland Havbruk) joined forces in 1999 to establish a new breeding company – SalmoBreed. The company operates a cost-efficient breeding program on Atlantic salmon by using existing facilities provided by the cooperating companies and services provided by the AKVAFORSK Genetics Center (AFGC). The breeding program WAS initiated by using breeding candidates originating from the Bolaks-breed. The company, however, is operating an "open" breeding population, which means that superior genetic material from other sources can be tested and included in the breeding populations in the future. The breeding program is maintaining four year-classes by producing 300 FS-families each year. The breeding objective is similar to that of AquaGen.

Dissemination

The strong competition between breeding companies ensures that any genetic gain obtained in the selective breeding programs on Atlantic salmon is rapidly disseminated to the farms. The salmon farming industry in Norway is divided into specialized producers of brood stock/eggs, hatcheries that produce fingerlings/smolts, and large farms that feed the salmon in sea cages until they reach a suitable harvest weight. The breeding companies usually control several brood stock stations that are used as multipliers to increase the quantity of genetically superior seed. Two alternative organization models can be used to disseminate the genetically improved seed to the farms, either a centralized or decentralized organization.

Centralized organization

In a centralized organization (Figure 1), the breeding company keeps strict control of the breeding candidates and decides what kind of products are disseminated to the customers – commercial hatcheries or large production companies. Usually, the breeding candidates are kept at two locations in case of a disease outbreak. The genetically superior breeding candidates are used to produce the next generation of families in the breeding program, from which some individuals are again used as breeding candidates and others as test fish. The test fish are transferred to test stations (e.g. bio-secure facilities, commercial farms) to be tested for different traits (e.g. disease resistance, quality traits, growth performance in different test environments) as specified in the breeding objective. All test fish are killed after testing and only data are collected to estimate the breeding value of the breeding candidates. The breeding candidates are selected and ranked according to their total (aggregated) breeding worth. The available breeding candidates produced each year will usually be too few to produce enough commercial seed (i.e. fertilized "eyed-eggs") for dissemination. Therefore, the breeding company will make a special arrangement with other brood stock stations to function as multipliers. These brood stock stations will receive fertilized "eye-eggs" or smolts from the breeding company and use these for three or four years later to produce commercial seed ("eyed-eggs") for dissemination to the salmon farming industry.

Decentralized organization

In a decentralized organization (Figure 2), the breeding candidates are kept at several cooperating broodstock stations. The genetically superior breeding candidates at one or several brood stock stations are used to produce the next generation of families in the breeding program. These families are transferred to the breeding station as fertilized "eye-eggs". A random sample of individuals from each family produced will be used as either breeding candidates or test fish. The breeding candidates are distributed to the cooperating brood stock stations, while the test fish are transferred to test stations (e.g. bio-secure facilities, commercial farms) to be tested for different traits (e.g. disease resistance, quality traits, growth performance in different test environments) as specified in the breeding objective. The test fish are killed after testing and all breeding candidates are selected and ranked according to their total (aggregated) breeding values, based on collected data from the brood stock stations and test stations. However, the available breeding candidates that have been distributed to the cooperating brood stock stations might be too few to produce enough commercial seed (i.e. fertilized "eyed-eggs") for dissemination. Special female lines are, therefore, produced at each brood stock station to increase their capacity for the production of commercial seed ("eyed-eggs").

Customized seed

The next generation of families in the breeding program is produced by superior breeding candidates that have been selected based on their total (aggregated) breeding value, which combines the breeding value for each trait in the breeding objective according to their economic importance to the entire farming industry in Norway. Some salmon producers might, however, place a different importance to the traits included in the breeding objective. Therefore, the breeding companies arenow also disseminating "customized seed" produced by breeding candidates that have been selected according to a different combination of recorded traits from those used in the breeding program.

Conclusions

Based on the experience of developing breeding programs on Atlantic salmon in Norway, the following general conclusions can be made:

- The early establishment of selective breeding programs is crucial for the success of developing an efficient and sustainable aquaculture production.
- The selective breeding programs can become more advanced as more traits are included in the breeding objective (i.e. it is possible to develop simple breeding programs into advanced multi-trait selection programs).
- It is important to secure and maintain a broad genetic variation in the breeding populations by restricting inbreeding.
- The genetic gain obtained in breeding programs should be effectively disseminated to the farming industry without much delay to maximize the benefits of the programs (i.e. to secure a low cost-benefit ratio).
- Commercialization of national breeding programs into breeding companies might be necessary to limit their dependency on international and/or governmental financing/support.
- Breeding companies need to document the genetic gain obtained in the programs and market the economic benefits of farming genetically improved aquaculture breeds.
- Breeding companies should organize their dissemination to obtain a sufficient share of the economic benefits in order to sustain and improve their breeding programs.

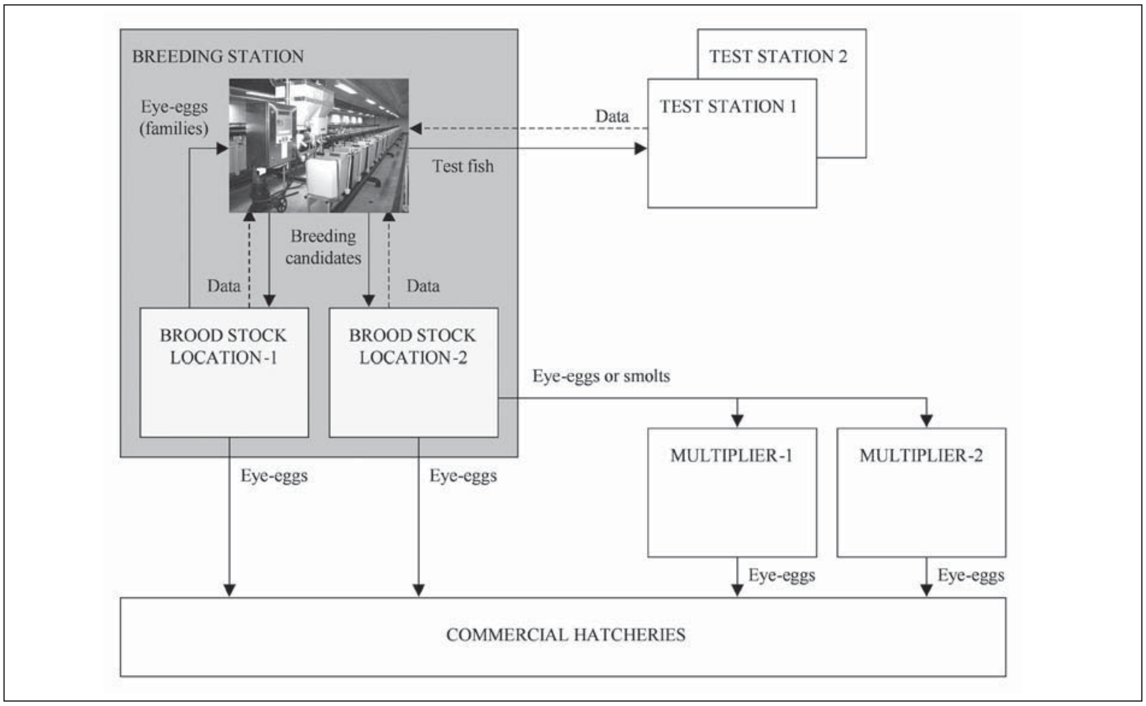

Figure 1. Centralized organizations used to disseminate genetically improved seed of Atlantic salmon to commercial hatcheries.

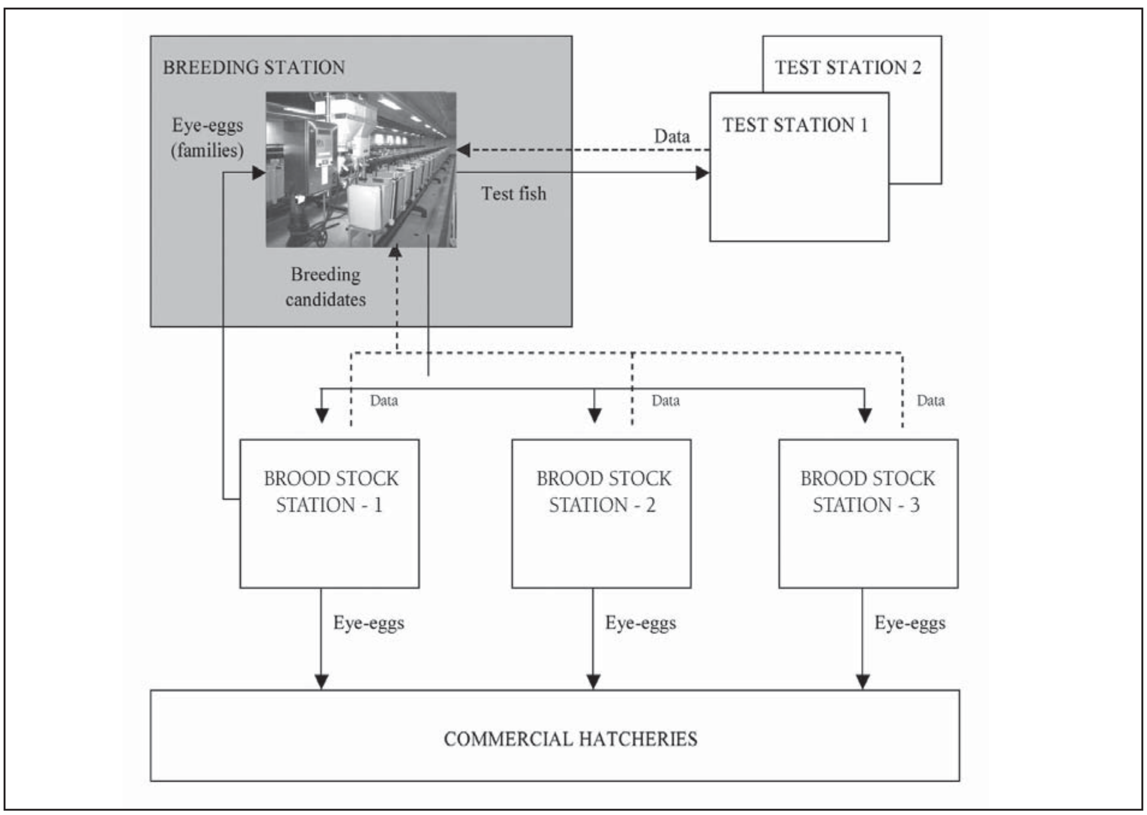

Figure 2. Decentralized organizations used to disseminate genetically improved seed of Atlantic salmon to commercial hatcheries.