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Integrating quantitative genetics and practical aspects in a fish breeding network in Denmark

K. Meier[1], A.C. Sørensen[1], E. Norberg[1] and B. Thomsen[2].

[1] Center for Quantitative Genetics and Genomics, Department of Molecular Biology and Genetics, Aarhus University, Denmark, [2]Danish Aquaculture Organization, Denmark

ABSTRACT: A breeding network has been established in the Danish aquaculture industry. The network is a collaboration between the Danish Aquaculture Organization, the farmers and Aarhus University with the aim of accommodating farmers different needs to intensify breeding efforts. Two examples of stochastic simulations are given to show how different practical aspects of a breeding plan can be optimized. By combining quantitative genetic theory with current breeding practice we are able to optimize different breeding plans increasing genetic gain while controlling the level of inbreeding and building up knowledge within the network.
Keywords:
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Introduction

In traditional livestock production, genetic selection has been applied for decades and it has resulted in a tremendous increase in most production traits. Until now, only few fish breeding programs have utilized the genetic potential, and there is room for increasing the genetic gain in many aquaculture species. Fish are characterized by a high reproduction capacity and a lot of genetic variation exists, meaning there is a great opportunity for genetic improvement. Although Denmark has a long tradition of fish breeding there is a need to implement research based breeding programs within the aquaculture industry to make the most of the potential for improvement. The aquaculture industry in Denmark is fragmented and consists of small scale fish farms with some being part of larger companies, while others operate independently. The main species of the aquaculture industry is rainbow trout (*Oncorhynchus mykiss*) and production is focused on large- or portion size trout, fillets, or roe. Thus, a central approach with common breeding goals and one breeding program for the whole industry is not possible. Instead a decentralized approach with tailor made breeding programs is more suitable, and as a result, a breeding network has been established. The network is a collaboration between the fish farmers, the Danish Aquaculture Organization and Aarhus University. The network has been established to accommodate the different needs and ambitions of the individual farms ranging from small scale breeding optimization to implementation of breeding programs. In this study we will give two examples of systems, where optimization of the current breeding program has been implemented and the network has obtained knowledge and competences available for other members of the network. One is on optimization of all-female production and the other on optimization of the breeding plan.

One practice for many farmers is to apply all-female production. In this production all individuals are females and a small proportion of fish larvae are hormone treated to become phenotypic males (XX males). These males cannot be used for production and do not provide any economic value. As a result, their quantity has been kept low and establishment of males from different families have been used to prevent mating of full-sibs. To optimize the use of XX males, stochastic simulation was applied to evaluate the consequences of family origin of males compared to females and the use of optimal contribution selection and minimum coancestry mating to control inbreeding.

Roe and fillet production is carried out in saltwater. However, there is a risk of transferring diseases from saltwater to freshwater farms, which is the reason farmers have only carried out breeding in freshwater. Hence, indirect phenotypic selection is carried out at the freshwater farm where the breeding stock is maintained. Thus, there is no direct link between the selection candidates and the traits of interest. To optimize the current breeding schemes, stochastic simulations was applied to evaluate the consequences of carrying out phenotypic selection directly in saltwater or indirectly in freshwater and increasing the number of males and selection among them.

Materials and Methods

To evaluate different strategies we applied stochastic simulations with the software ADAM (Pedersen et al. (2009)). Genetic parameters for weight in freshwater and saltwater at the age of 2 years were obtained from Kause et al. (2005).

Optimization of all-female production. We designed six scenarios based on the family design and breeding programs. XX male and female lines where either based on the same 130 families with a skewed sex ratio (77% females) or different full-sib families with only one sex represented in each family (100 female and 30 XX male or 65 female and 65 XX male families). Each of these scenarios was evaluated for two breeding programs: 1) Truncation selection (TS) with Random mating (RD) or 2) Optimal contribution selection (OCS) with minimum co-ancestry mating (MC) assuming knowledge of the pedigree. Breeding was carried out as indirect selection in freshwater and the selection criteria was weight at age 2 years (h^2=0.26). The simulated population structure was characterized as a small closed breed with discrete generations. In each generation 130 families where established with 1000 full sib offspring per family. OCS based on phenotypes was performed with the software EVA (Berg et al. (2006)), which is integrated in ADAM. Optimal genetic contributions were predicted with an evolutionary algorithm. A function combining genetic merit and inbreeding for the population was optimized based on individual genetic contributions. Individual genetic contribution determines how many times an animal is mated. Preliminary simulations were used to determine appropriate weights for genetic merit (w_{merit}) and average relationship ($w_{relationship}$). A value of 1 for w_{merit} and -20 for $w_{relationship}$ was used in the subsequent analyses.

Genetic gain and the rate of inbreeding were calculated as the average across generations 6 to 10 and 50 replicates. Significance level was determined with a t-test (level of significance 5%).

Optimization of sea farm breeding plan. Eight different scenarios were compared in order to evaluate different breeding scenarios. The population structure was simulated with discrete generations. Each generation consisted of 300 families with 1000 full-sib offspring and a sex ratio of 0.98 females. 300 females were selected for breeding based on their freshwater or saltwater phenotype. Ten or 150 XX males were selected either randomly or with truncation selection on their phenotype. Heritabilities for weight in freshwater and weight in saltwater at age 2 years were set to 0.26 and 0.22, respectively. Genetic gain for weight in saltwater and the rate of inbreeding were calculated as the average across generations 6 to 10 and 50 replicates. Significance level was determined with a t-test (level of significance 5%).

Results and Discussion

The network relies on the interaction of the individual fish farmers with the university, which allocates a member of the staff as a full-time consultant. In practice, the fish farmers formulate their challenges to the consultant, and the consultant interacts with the academic staff at the university in addressing solutions to the specific challenges. The consultant draws on his own experience as well as that of the rest of the academic staff and the other fish farmers in the network. Hence, the knowledge is gathered and used. Both examples given rely on all-female production. Hence, the knowledge gathered for optimization of all-female production has also been implemented in the optimized sea farm breeding plan

Optimization of all-female production. Table 1 presents values of using separate or the same families in all-female production and compares different selection and mating strategies. Focusing on TS and RM there is little differences between the different family designs. The optimal design is using equal number of different families for XX male and female production. Using different families but with a lower number of XX male families increases inbreeding and reduces genetic gain. The level of inbreeding in using the 130 same families compared to 30 XX male and 100 female families is the same. However, the genetic gain is higher using the same families to recruit males and females. Using EVA and MC mating the highest genetic gain is obtained by using the same 130 families for both XX males and females. The lowest level of inbreeding is obtained by using equal number of separate families (65/65). From a practical point of view using an equal amount of separate families is not possible because the XX males are of little production value. Hence we argue that using OCS and MC mating one should use the same families to recruit males and females in order to obtain the highest genetic gain, while controlling the rate of inbreeding.

Optimization of sea farm breeding plan. In Table 2, results for indirect and direct selection with different numbers of XX males and different selection methods are presented. Comparison of genetic gain and inbreeding for direct and indirect selection reveals that a higher genetic gain is obtained with the same level of inbreeding for direct selection independent of number of XX males and selection method. Hence, direct selection in saltwater is more effective to increase weight in saltwater. The gain obtained by indirect selection is a result of the positive correlation between weight in freshwater and weight in saltwater. Before implementing direct selection, the higher gain obtained with this method has to be compared to the disease risk with transfer of fish from saltwater to freshwater farms. Independent of indirect and direct selection, increasing the number of XX males will reduce inbreeding, and selecting among the males will increase the genetic gain. Thus, the optimal breeding plan would involve using a higher number of XX males for breeding and selecting among these instead of selecting randomly.

Conclusion

The establishment of a breeding network within a fragmented industry is working. By using stochastic simulation we have given two examples of production systems where the practical aspects of the breeding plan can be optimized by using quantitative genetic theory. As more aspects of the current breeding strategies are optimized knowledge and resources within the network are increased and this will benefit all members of the breeding network in the future.

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Table 1. Genetic gain and rate of inbreeding for different family designs compared to different selection/mating designs in all-female production

Selection and mating	Familiy design		
	Same 130	Separate 30/100	Separate 65/65
	ΔG		
EVA and MC	1.242^{A}	1.158^{B}	1.198^{C}
TS and RD	1.251^{AD}	1.209^{C}	1.269^{D}
	ΔF		
EVA and MC	0.0044^{A}	0.0049^{C}	0.0037^{D}
TS and RD	0.0093^{B}	0.0099^{B}	0.0078^{E}

Different superscript letters denotes significant differences between groups within the delta F and G sub tables, respectively (p<0.05).

Table 2: Genetic gain and rate of inbreeding for Indirect/direct selection compared to Male number and selection method: random- (RS) or truncation selection (TS)

Male selection	Male Number	Selection method			
		ΔG		ΔF	
		Direct	Indirect	Direct	Indirect
RS	10	0.649^{A}	0.373^{B}	0.018^{A}	0.018^{A}
RS	150	0.716^{C}	0.438^{D}	0.003^{B}	0.003^{B}
TS	10	1.129^{E}	0.705^{FC}	0.024^{C}	0.026^{C}
TS	150	1.110^{E}	0.692^{F}	0.005^{D}	0.005^{D}

Different superscript letters denotes significant differences between groups within the delta F and G sub tables, respectively (p<0.05).