INBREEDING LEVELS AND INBREEDING DEPRESSION IN A FARMED POPULATION OF RAINBOW TROUT (*Onchorhynchus mykiss*)

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SUMMARY

A farmed population of rainbow trout under selection for over six generations from the Norwegian Salmon Breeding Company, Ltd. was investigated for levels of inbreeding and occurrence of inbreeding depression for body weight. The average percent inbreeding levels and percent of individuals with inbreeding greater than zero (in parenthesis) were 2.9 (59.3), 2.8 (49.8), 8.5 (87.1), 8.0 (82.8) and 6.6 (81.4) for generations 2, 3, 4, 5 and 6, respectively. The coefficients of inbreeding ranged from zero to 30%. The rate of increase in inbreeding coefficient was non-linear. The average increase in inbreeding was 1.3% per generation. The inbreeding depressions for body weight at harvest per generation were: -1.2%, -0.3%, +0.03%, -0.2% and +0.1% per 1% unit increase in inbreeding coefficient. Over all generations, inbreeding depression was -0.2% per 1% inbreeding. These results suggest there is no cause for concern over the current inbreeding trend and inbreeding depression for this population.
Keywords:*Onchorhynchus mykiss*, rainbow trout, inbreeding coefficient, inbreeding depression, growth.

INTRODUCTION

In populations under selection, inbreeding produces negative effects such as increased homozygosity, which leads to increased chance of expression of lethal recessive genes, inbreeding depression and reduction of genetic variance (Falconer 1989). The few inbreeding studies in fish show in general the detrimental effects of inbreeding; reduced growth, viability and survival and increased numbers of abnormalities. In commercial farming of carp species, wild-caught individuals are often added to the broodstock population to avoid inbreeding depression (Eknath and Doyle 1990). In rainbow trout, Aulstad and Kittelsen (1971) observed a high occurrence of fry deformities with an inbreeding coefficient of F=0.25. Kincaid (1976a; 1976b) reported increased fry deformities, decreased feed conversion efficiency, decreased fry survival and decreased fish weight at 147 and 364 days of age at inbreeding levels of F=0.25 and F=0.375. Gjerde *et al.*(1983) found decreased survival of eyed eggs, alevins and fry and growth rate to 18 months in seawater at three levels of inbreeding (F=0.25, 0.375, 0.50).

In any breeding program, minimization of inbreeding has always been emphasized. However, there are no investigation of the actual inbreeding levels in closed populations of fish such as rainbow trout. The objective was to analyze levels of inbreeding and investigate the occurrence of inbreeding depression for body weight at harvest in a selected population of rainbow trout.

MATERIALS AND METHODS

The data were from a selected (for growth rate mainly) population of rainbow trout from the Norwegian Salmon Breeding Co., Ltd. The pedegree data comprise in total seven generations (gen. 0 to 6). All individuals at the base population (gen. 0) were assumed unrelated with an inbreeding coefficient of zero. In all generations full- and halfsib matings were not performed. Inbreeding coefficients of all individuals in gen 0 and 1 were therefore zero (Table 1). In later generations matings that would yield inbreeding coefficients greater than 12.5% were restricted.

The coefficients of inbreeding were calculated using the pedegree data from all generations and using the algorithm of VanRaden and Hoeschele (1990). The rate of inbreeding was calculated as: $\Delta F = \frac{1}{5}\sum_{t=2}^{6}\Delta F_t$, where, $\Delta F_t = (F_t - F_{t-1})/(1 - F_{t-1})$ and F_t is the average inbreeding coefficient of individuals born in generation t (Falconer 1989).

The study of the effect of inbreeding on body weights recorded after 16-18 months in floating net cages in the sea was restricted to data from generation 2 to 6 comprising a total of 51,369 offspring of 321 dams and 857 sires. Within generation the effect of inbreeding level on body weight was estimated using a linear model with Cage x Sex as a fixed effect and the inbreeding coefficient as first and second-degree polynomials. An over all generation estimate was obtained using a similar model but with Gen. x Cage x Sex as the fixed effect.

RESULTS AND DISCUSSION

Inbreeding. Descriptive statistics for inbreeding coefficients across generations are shown in Table 1. Inbreeding levels in the earlier generations were low because of the mating policy practiced.

Table 1. Mean level of inbreeding (%) in each generation

Generation	Mean	SD	Minimum	Maximum
0	0.0	—	—	—
1	0.0	—	—	—
2	2.92	2.99	0	15.63
3	2.85	4.51	0	25.00
4	8.50	3.93	0	18.75
5	7.97	5.32	0	30.37
6	6.58	4.66	0	26.34

Average inbreeding levels were all below 10%. However, in a breeding program, the rate of inbreeding (ΔF) is more important than the actual inbreeding level (F) because it measures how many more generations a population can be kept before reaching the critical inbreeding level. There are no estimates on tolerable rates of inbreeding in fish populations. The rates may vary depending on the depression in production and fitness traits due to inbreeding (Gjerde *et al.*

1996).

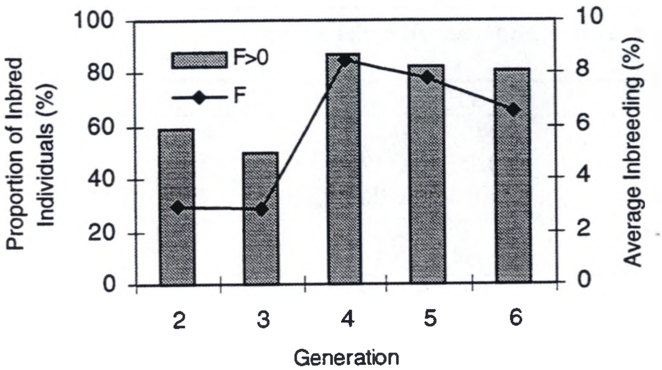

Figure 1. Proportion of individuals (%) with inbreeding coefficients greater than zero and the average inbreeding coefficients (%) per generation.

Figure 1 shows that the rate of increase in inbreeding was non-linear. The increment (ΔF) was calculated from actual inbreeding levels relative to the previous generation using the formula of Falconer (1989). The ΔFs starting from generation 2 were: +2.9%, -0.07%, +5.82%, -0.58% and -1.51%. The actual average rate of inbreeding was 1.3% per generation which is below the level of 3 to 5% typically found in commercial salmonid farms (McKay *et al.* 1992). The effective population size of $N_e = 83$ was calculated using the harmonic mean of the effective population size per generation (Falconer 1989). This yields an estimated ΔF=0.6% which is lower than actual average rate. This is due to ignoring the effect of selection in the formula. Both actual and estimated inbreeding rates were within the tolarable range. In a study to assess the critical effective population size at which natural selection for fitness and inbreeding depression balance, effective population sizes from 31 to 250 per generation could prevent a decline in fitness traits depending on the heritability of the traits (Meuwissen and Woolliams 1994). These effective population sizes correspond to ΔF = 2 to 0.2%.

Effect of inbreeding. For each generation and overall generations, the regression coefficients associated with the second-degree polynomial were significant but contributed only marginally to the model sums of squares. Thus, only the regression coefficients associated with the first-degree polynomial were considered. The effects of inbreeding on growth were all significant except in generation 4 (Table 2). Distribution of F in this generation was less variable. About 75% of the individuals were within the class of $6.25\% \leq F < 12.5\%$. As expected, inbreeding had a depressing effect on body weight of 0.2% per 1% unit increase in F over all generations, but less than the reported values of 0.45 to 0.61% per 1% unit increase in F for growth of rainbow trout after 18 months in the sea (Gjerde *et al.* 1983). The latter estimates were from a study where inbreeding was achieved at a faster rate through successive full-sib matings whereas, in the present study, the increase in F was attained at a much slower rate.

Table 2. Regression coefficients (b) with standard errors (S.E.) of body weight on inbreeding percentage. Mean and standard deviations (S.D.) are given for body weight (kg) for each generation and over all generations

Generation	b ± S.E. (kg/%*F*)	Mean (S.D.), kg.	Inb. Depr.[a]
2	-.0464 ± 0.34 *	4.03 (0.95)	-1.20
3	-.0126 ± 0.17 *	3.97 (1.14)	-0.30
4	+.0013 ± 0.26 ns	4.10 (1.22)	+0.03
5	-.0098 ± 0.17 *	4.56 (1.47)	-0.20
6	+.0054 ± 0.25 **	5.56 (2.09)	+0.10
Over all	-.0084 ± 0.09 *	4.42 (1.52)	-0.20

* P<.001; ** P<.05; ns not significant; [a] Inbreeding Depression = (b/Mean Body Weight)x100

The results suggest there is no cause for concern over the current inbreeding trend and its effect on body weight at harvest for this farmed population of rainbow trout. The actual rate of inbreeding was within the acceptable range for avoiding loss of fitness (Meuwissen and Woolliams 1994). The applied selection and mating policies were effective in delaying the rate of accumulation of inbreeding and avoiding its detrimental effect. However, the long-term rate of inbreeding is not only determined by planned mating system but also by effective population size for populations under artificial selection (Wray and Thompson 1990).

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