Korsvoll, S., Ødegård, J., Kjøglum, S., Bangera, R. (2026) Documentation of genetic gain for growth in Atlantic Salmon, *Proceedings 13th World Congress on Genetics Applied to Livestock Production* 24243: https://doi.org/10.31274/wcgalp.24243 ©2026 *Korsvoll, et al.* CC BY-NC-ND

Documentation of genetic gain for growth in Atlantic Salmon

S.A. Korsvoll, J. Ødegård, S. Kjøglum, and R. Bangera*

AquaGen AS, Trondheim, Norway; **Corresponding author: rama.bangera@aquagen.no*

Introduction

Genetic improvement of economically important traits has been a major driver of productivity gains in livestock and aquaculture systems (Gjedrem et al., 2012). In Atlantic salmon (*Salmo salar*), growth rate is a primary breeding objective because of its strong influence on production efficiency, feed utilization, and biological risk throughout the production cycle. AquaGen's Atlantic salmon breeding program has applied systematic selection for growth over more than 13 generations, resulting in substantial and consistent improvements in performance under commercial farming conditions. Modern salmon breeding programs increasingly rely on genomic estimated breeding values (GEBVs) to predict genetic merit and response to selection (Meuwissen et al., 2001; Hayes et al., 2009). However, predicted genetic gain is model-dependent and influenced by assumptions regarding genetic parameters and genotype-by-environment interactions (Mulder and Bijma, 2005). Empirical documentation of realized genetic gain therefore remains essential to validate predicted responses and to quantify the effect of genetic improvement under practical production conditions. Direct common-garden comparisons of consecutive generations are not feasible in salmon breeding because long-term cryopreservation of eggs is not possible. However, cryopreservation of milt enables the use of males from earlier generations to produce offspring that are genetically intermediate between consecutive generations. This approach provides a practical and transparent framework for empirically quantifying realized genetic gain under identical environmental conditions.

Materials & Methods

The study was conducted within the 2024 nucleus year-class (AS24) of the AquaGen Norway Atlantic salmon breeding program, produced using AS21 as parental year-class. To empirically document genetic gain, a documentation group referred to as *halflings* was established. Halflings were generated by fertilizing eggs from current nucleus females (AS21, i.e., 2021 year-class) with cryopreserved milt from selected males originating from the AS17, AS18, and AS19 year-classes. These males represent the grandparent generation relative to AS24 and were selected to provide a representative sample of genetic material from earlier selection cycles.

Under identical environmental conditions, the phenotypic difference between offspring produced using grandparent and parent-generation males (both mated with parent-generation females) represents approximately half of the realized genetic change achieved over one generation (Lynch and Walsh, 1998). Realized genetic improvement in body weight was estimated as twice the difference between the mean body weight of the AS24 nucleus and the halflings:

$$\widehat{\boldsymbol{\Delta}}_{\boldsymbol{G}} = \mathbf{2} \cdot (\boldsymbol{W}_{\mathbf{NUC}} - \boldsymbol{W}_{\mathbf{hlf}})$$

where W_{NUC} is the mean body weight of the AS24 nucleus and W_{hlf} is the mean body weight of the halflings. Under the assumption of identical environmental effects, the expected average body weight of the previous generation can thus be expressed as:

$$\widehat{\boldsymbol{W}}_{\mathbf{PrevGen}} = \boldsymbol{W}_{\mathbf{NUC}} - \widehat{\boldsymbol{\Delta}}_{\boldsymbol{G}}$$

The relative genetic improvement (RI), expressed as a percentage of body weight per generation, was estimated as:

$$\mathbf{RI} \approx \frac{\widehat{\boldsymbol{\Delta}}_{\boldsymbol{G}}}{\widehat{\boldsymbol{W}}_{\mathbf{PrevGen}}} \times \mathbf{100\%} = \frac{\widehat{\boldsymbol{\Delta}}_{\boldsymbol{G}}}{\boldsymbol{W}_{\mathbf{NUC}} - \widehat{\boldsymbol{\Delta}}_{\boldsymbol{G}}} \times \mathbf{100\%}$$

These estimators are valid under the assumption that halflings are approximately at the genetic midpoint between two consecutive generations.

Fish were reared communally under identical management conditions at AquaGen's freshwater and seawater test facilities at Tingvoll and Hemne. Body weight was recorded at freshwater vaccination, three months after seawater transfer, and at harvest. Sex ratios within nucleus groups were balanced, allowing comparisons based on simple means.

Results & Discussion

For freshwater vaccine weight, a total of 969 halflings designated for use at Hemne and 915 halflings designated for use at Tingvoll were recorded, compared with 7,289 and 9,953 nucleus fish from AS24, respectively. For three-month seawater weight at Tingvoll, 234 halflings were compared with 2,442 AS24 nucleus fish. Harvest and gutted weight at Tingvoll were based on 138 halflings and 1,657 AS24 nucleus fish, with the same individuals used for both measurements. For harvest seawater weight at Hemne, 765 halflings were compared with 5,237 AS24 nucleus fish.

Vaccine weight and early seawater growth are summarized in Figure 1. At the freshwater vaccination stage, halflings showed consistently lower body weight than AS24 nucleus fish at both Tingvoll and Hemne. The observed differences correspond to an estimated realized genetic gain of ~10-13% per generation, demonstrating that substantial genetic improvement is already expressed at the freshwater and early seawater stages. At three months post seawater transfer at Tingvoll, genetic differences between groups were more pronounced, with an estimated 15% higher body weight of AS24 compared with the previous generation nucleus (Figure 1b). This indicates that genetic improvement expressed in freshwater is maintained and further amplified during early seawater growth.

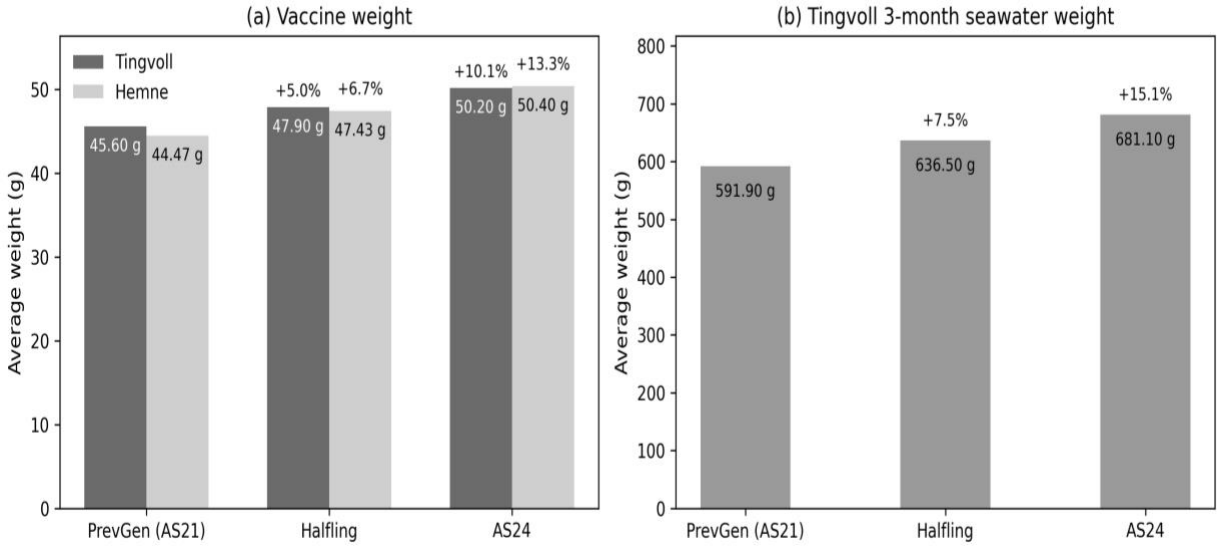

Figure 1. Vaccine weight (a) and early seawater growth at three months post sea transfer at Tingvoll (b) for the previous generation (AS21), halflings, and the current nucleus generation (AS24). Values are shown as mean body weight (g), with percent increase relative to AS21 within site.

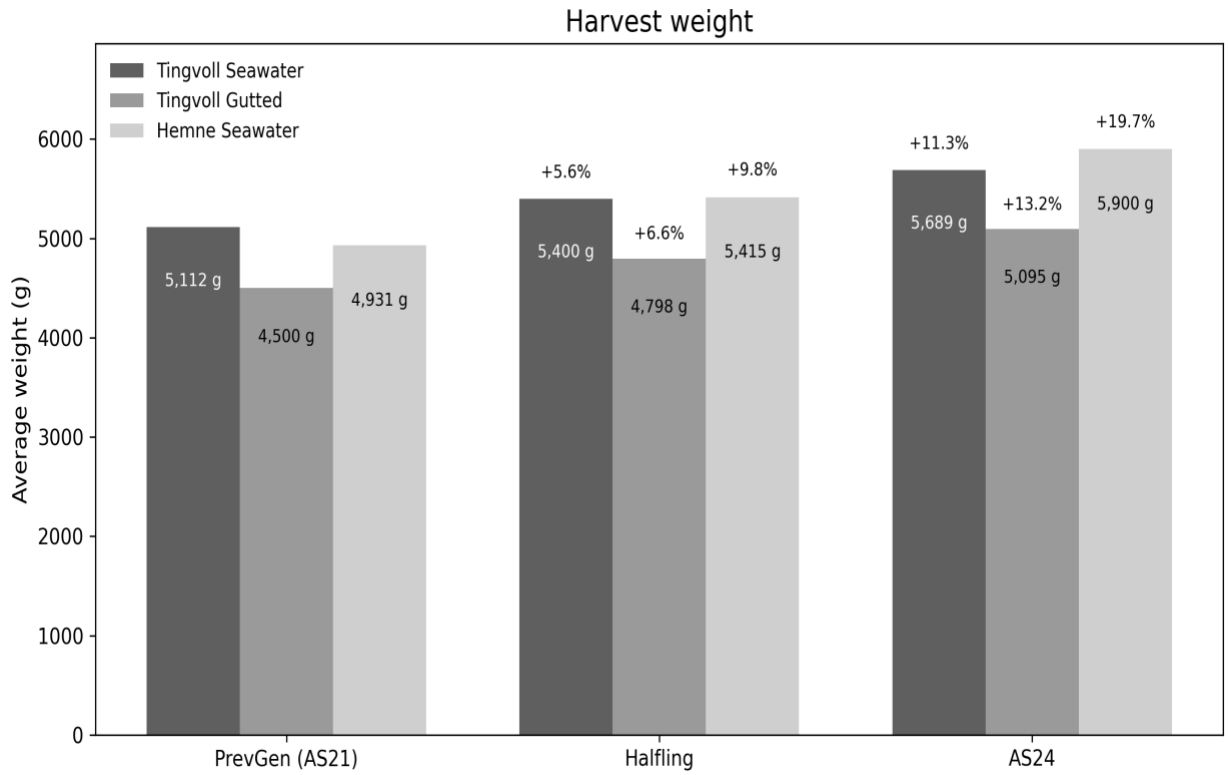

Figure 2. Harvest weight for the previous generation (AS21), halflings, and the current nucleus generation (AS24), shown as seawater weight at Tingvoll, gutted weight at Tingvoll, and seawater harvest weight at Hemne. Values are shown as mean body weight (g), with percent increase relative to AS21 within trait and site.

Harvest-related traits are presented in Figure 2. At Tingvoll, both seawater weight and gutted weight showed consistent realized genetic gains of approximately 11 to 13% per generation, indicating that early growth advantages persist through to slaughter. The largest response was observed at the Hemne harvest test, where AS24 fish were estimated to average nearly 20% heavier than the previous generation, corresponding to an approximate 1 kg improvement in harvest weight over a single generation.

Together, these results provide robust empirical confirmation of sustained genetic progress for growth in AquaGen's Atlantic salmon breeding program. Genetic gains were consistently expressed across freshwater, early seawater, and harvest stages, with particularly strong responses under seawater conditions. This pattern is consistent with genotype-by-environment interactions commonly reported for growth traits in aquaculture species, where genetic differences tend to be more strongly expressed under favorable production conditions (Mulder and Bijma, 2005; Sae-Lim et al., 2016). The close agreement between empirically documented gains and expectations based on genomic selection further supports the effectiveness and robustness of the current breeding strategy.

Conclusions

Empirical documentation using halflings (offspring of parent-generation females and grandparent-generation males) demonstrates a realized genetic gain of approximately 10 to 20% per generation for growth in AquaGen's Atlantic salmon breeding program. Genetic improvement was

consistently expressed from freshwater vaccination through early seawater growth and harvest, confirming sustained response to selection across production stages. These results validate the effectiveness of long-term systematic selection for growth and support the continued use of halfling-based approaches for empirical monitoring of realized genetic progress.

References

Gjedrem T., Robinson N., and Rye M. (2012) Aquaculture 350–353:117–129.

Hayes B.J., Bowman P.J., Chamberlain A.J., and Goddard M.E. (2009) J. Dairy Sci. 92:433–443.

Lynch M., and Walsh B. (1998) Genetics and Analysis of Quantitative Traits. Sinauer Associates, Sunderland, MA.

Meuwissen T.H.E., Hayes B.J., and Goddard M.E. (2001) Genetics 157:1819–1829. doi.org/10.1093/genetics/157.4.1819

Mulder H.A., and Bijma P. (2005) J. Anim. Sci. 83:49–61.

Sae-Lim P., Kause A., Mulder H.A., Olesen I., and Rye M. (2016) J. Anim. Sci. 94:330–343.