



Benchmark  
Genetics

**GENETICS FOR  
EFFICIENCY,  
HEALTH AND  
WELFARE**

# BENCHMARK GENETICS

## WHO WE ARE

Benchmark Genetics is a world-leader in breeding and genetics for aquaculture. Our strategy is innovation-led, making use of modern breeding technologies such as QTL and Genomic Selection.

By combining our long-established breeding programs and the latest genomic tools, we help aquaculture producers increase quality, yield, health, and welfare of their animals.

Our in-house breeding programs comprise of Atlantic salmon, vannamei shrimp and tilapia. We also support a significant number of selected breeding programs across the world for commercial species such as sea bass, sea bream, rainbow trout, and coho salmon.

Our breeding programmes and genetic support deliver strains that improve cost of production by increasing the value of the end product and reducing the losses from disease challenge. Our offering drives consistency in supply and supports the long-term growth and sustainability of our customers business.

# BENCHMARK GENETICS STRUCTURE



SalmoBreed

Salmobreed is globally recognised strain of Atlantic salmon systematically developed in Norway for over 40 years. The material is recognized for rapid growth, late sexual maturity, resistance to disease and parasites as well as outstanding flesh quality. The new land-based site in Salten, Norway is providing salmon ova all year round, produced at the highest levels of biosecurity. The SalmoBreed breeding program is certified by the European Forum of Farm Animal Breeders as proof of responsible and sustainable breeding.



StofnFiskur

Stofnfiskur is an international strain of Atlantic salmon developed in Iceland since 1991 from imported Norwegian stock. The Stofnfiskur breeding programmes operates from two land-based broodstock facilities in Iceland and is in position to supply the global industry with salmon ova all year round, produced at the highest levels of biosecurity. The product quality is obtained through continuous research, selective breeding and excellent production conditions — where pathogen free water is pumped from deep drilled wells and rinsed through lava sands.



Benchmark Genetics Chile

Benchmark Genetics Chile runs a family based breeding program for Atlantic salmon, and has recently implemented an advanced CryoLab for sperm cryopreservation of the strain's best performing males. The Chilean operation supplies tailored, locally produced ova all year round, with a supplement of imported highly biosecure and genetically advanced ova from StofnFiskur in Iceland.



Akvaforsk Genetics

Akvaforsk Genetics is the leading provider of genetic improvement services to aquaculture industries worldwide. Akvaforsk has extensive experience in design, implementation and technical operations from more than 25 applied selective breeding programs for fish and crustacean species across Europe, Asia and Latin America.

# BREEDING APPROACHES IN BENCHMARK GENETICS



## Pedigree Breeding

The three Benchmark nucleus breeding programmes in Norway, Iceland and Chile are based on long-term pedigree selection of Atlantic salmon strains originating in Norway. All individual animals in each nucleus are tagged and their family history (ie pedigree) is known. Since Atlantic salmon have a long lifecycle taking 3 to 4 years to mature, each nucleus has separate year classes of broodstock at different ages. Several hundred nucleus families are made up each year by crossing the best broodstock males and females. Several thousand eggs from each family are hatched and retained in the breeding programme as candidates for the next generation. Sub-groups from each family are tested for different aspects of commercial performance such as growth and harvest performance in the production environment and resistance to pathogens. The family relationships allow information collected on relatives to be used to determine which broodstock candidates should be used for the next generation. In addition to nucleus families, a small number of high performing families are retained to establish multiplier groups to provide large numbers of eggs for commercial production when the resulting females become mature.

The pedigree structure and data are stored in dedicated databases run by Akvaforsk Genetics. The pedigree structure allows data recorded on individuals to be analysed by geneticists using specialised software to give accurate predictions of the best animals to be used for breeding the next generation of nucleus and multiplier broodstock.

## Individual Selection

When performance can be measured on the live individual (eg body weight growth) then selection based on individual performance is effective. Traits such as growth, length, condition factor, presence/absence of

deformities are measured on the candidate broodstock and are used in a series of selections as the fish grow to identify the fastest growing broodstock with the best physical characteristics.

## Family Selection

When performance cannot be measured on the live individual (eg harvest traits) or is best measured as the percentage of the family affected (eg disease resistance, early maturity) selection of individuals from the best families, calculated using the pedigree structure, can be used. Selecting individuals from the best families using family incidence or averages is called Family Selection and is important for many traits in salmon breeding. Family selection is the basis for improvement in harvest traits such as fillet yield and fillet colour and for disease resistance but is inefficient since each individual in the family has the same breeding value. Prediction of individual breeding values using new technology allows individual, within family selection resulting in increased genetic progress.

In the nucleus and multiplier populations, the breeding goal is to improve several traits at one time. The best animals for breeding will be those that have good predicted performance for these traits. Statistical models are used to combine the individual and family information for each trait for each animal in a selection index which can be used to rank the individuals available for breeding, and choose the best for nucleus and multiplication

## Genomic Selection

Over recent years it has become possible to genotype individual salmon for large numbers of DNA markers spread across the genome (or genetic sequence). The most commonly used markers known as SNP's (Single Nucleotide Polymorphisms) can be genotyped cost effectively at many thousands of





positions for each individual. Statistical analysis can be used to determine if the genotype of each marker is associated with traits measured on pedigree animals. Analysing the genotypes at many thousands of markers for test animals with known performance can be used to predict the performance of candidates from their genotypes without performance testing. In this way, testing and genotyping of pedigree animals for disease resistance in small scale trials can be used to predict the performance in related candidate broodstock without exposure of nucleus animals to pathogens. This process is known as Genomic Selection and is now used to select individual broodstock for many traits in disease resistance and harvest performance. For many traits GS increases the accuracy and effectiveness of selection by providing accurate information that can be used to identify the best individuals from families – replacing Family Selection with Individual Selection.

#### Quantitative Trait Loci (QTL) Selection

In most cases traits are controlled by many genes spread across the genome, and Genomic Selection is a very effective method to identify the best animals for breeding. Some traits are controlled by a small number of genes and variation in one or two genes accounts for a large proportion of the trait variation. Genotyping can be used to identify the position of these major genes known as Quantitative Trait Loci or QTL's. In Atlantic salmon, one of the best-known QTL's controls resistance to the IPN virus. This QTL accounts for more than 80 % of the variation in resistance to this pathogen. Genetic markers for the IPN QTL have been used to identify and breed from resistant animals in the nucleus and multiplier populations, resulting in a significant reduction in the number of IPN outbreaks.

Genomic selection and QTL selection are now included in the selection index to more effectively identify the best individuals within and between families for a number of disease resistance and performance traits.

#### Effective Transmission of Improved Genetics

Conventionally, Atlantic salmon male and female broodstock needed to be sexually mature at the same time so that crosses could be made using fresh milt and eggs. Improvements in cryopreservation and technology for handling of salmon milt now allows indefinite storage, and much higher usage rates meaning that milt from high performance males can be retained for use when required. Using modern techniques, it is now possible to use milt from one male to fertilise eggs from over 50 females. Males used for commercial crosses now have much greater genetic merit than those used in the past because a smaller number of higher ranking males are required. Additionally, QTL and Genomic Selection can be applied to multiplier broodstock males giving greater options for customers to choose products with desired characteristics.

Benchmark Genetics has invested in milt cryopreservation laboratories in each of its programmes in Norway, Iceland and Chile to give customers access to milt from males with the highest ranking and increased choice of traits.

#### Control of Maturation

In some production systems such as closed containment Recirculating Aquaculture Systems (RAS), the environment can induce high levels of early maturation. Benchmark Genetics uses reproductive technology to make ALL-FEMALE, TRIPLOID and ALL-FEMALE TRIPLOID products. These are well-documented production strategies to reduce or prevent sexual maturation.

# TRAITS INCLUDED IN BENCHMARK GENETICS BREEDING PROGRAMMES.

**Balanced genetic improvement** requires progress to be made in several traits at the same time. Conventionally these traits are weighted in a within a selection index according to the economic value of each trait. Some traits are considered more important from a health and welfare perspective, and may receive higher weighting as a result. Some customers will consider particular traits more desirable, and may wish the selection index to be altered accordingly. Benchmark Genetics selects the nucleus in a balanced way using a selection index and produces Multiplier populations with zrequirements. Males with desired performance are selected using the selection index, and genomic breeding values / QTL status to be used to produce milt for commercial crosses.

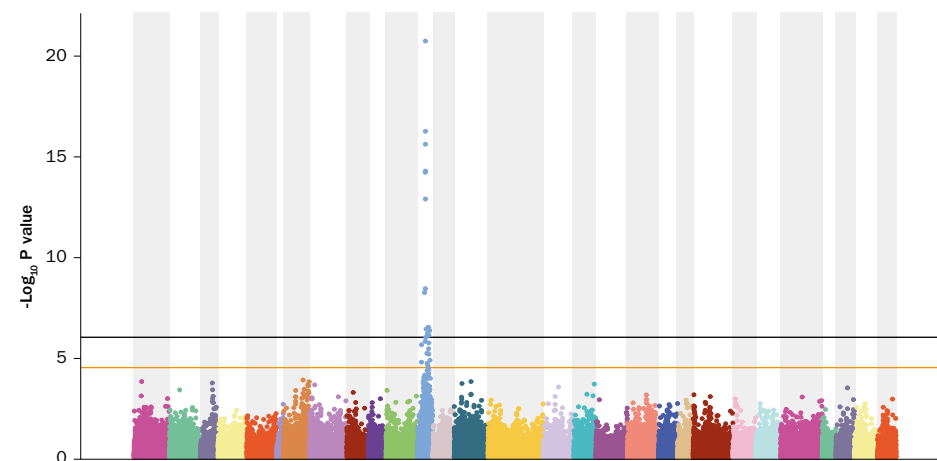
**Grow-out and Harvest Traits.** Physical performance traits like growth (fresh and sea water), production yield, fat content, pigmentation and late maturation all have a high influence on cost of production. Growth is a trait that is relatively easy to record directly from the breeding candidates and has high weighting in the nucleus and multiplication lines for commercial ova production. Additionally, the broodstock are selected several times during the production cycle with regards to traits such as growth and body condition before any final selection. Production yield, fat content and pigmentation are recorded annually on the

full-sibs (brothers and sisters) of the breeding candidates, during the test harvest.

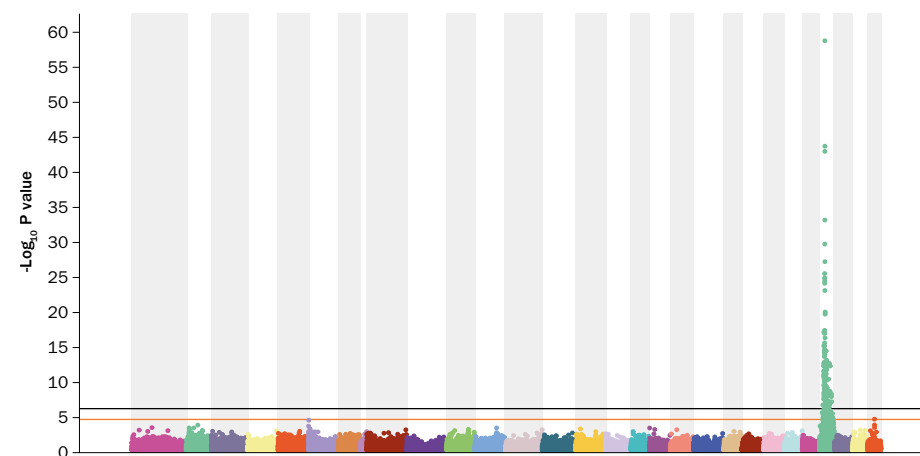
BENCHMARK GENETICS can offer GS for seawater growth, production yield, fat content and pigmentation. In addition, a QTL for pigmentation is available. GS has been implemented to improve these traits since 2017, but the traits have been under selection since the 1970's (Figure 1).

**Infectious pancreatic necrosis (IPN)** is a severe and highly contagious viral disease of salmonids that usually affects the fish during early life stages and in the first phase in the sea. The condition is caused by the infectious pancreatic necrosis virus (IPNV) and can lead to high levels of mortality. The virus is mainly spread through horizontal transmission (i.e. via infected water and from one individual to the next), although a vertical path of spread has also been suggested (i.e. from parents to the offspring). The outbreaks are usually sudden and can often cause a high number of mortalities and significant economic losses. Following infection, any animals that survive the outbreak can develop a lifelong illness.

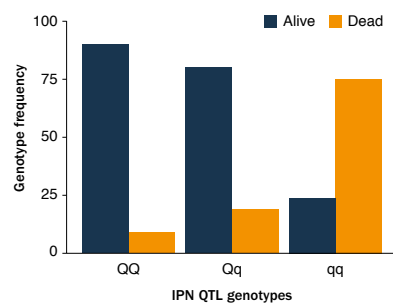
Benchmark Genetics offers IPN robust fish using QTL selection, which started in 2007 (Figure 2). Resistance to IPN is highly heritable, and can, to a large degree, be explained by genetic variations identified in a single gene. Across salmon populations in Benchmark Genetics, approximately 80-90%



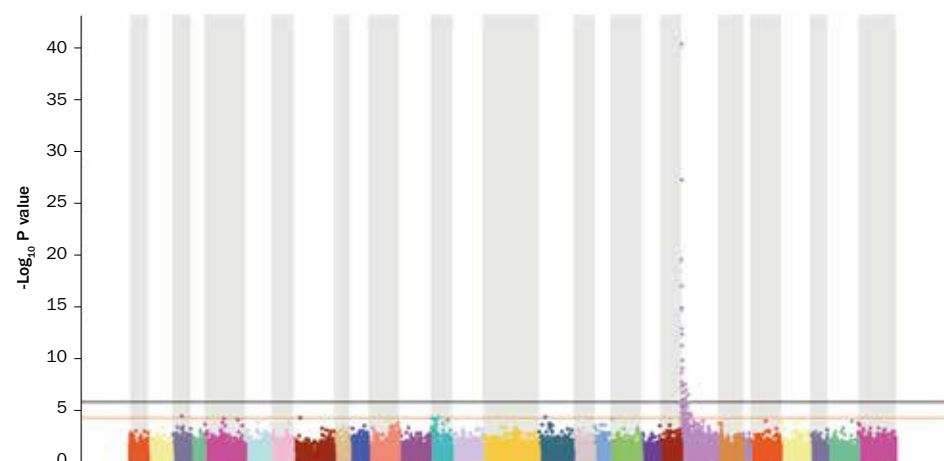
**Figure 1:** Manhattan plot, showing the genome-wide association for the level of fillet pigmentation in the SalmoBreed population. The figure shows the association of thousands of genetic markers tested against the concentration of astaxanthin in the fillet. Each chromosome is designated with a different colour. The information from a significant QTL (the light blue chromosome), has been implemented in the breeding programme, resulting in fish with improved levels of pigmentation.



**Figure 2:** Manhattan plot, showing the genome-wide association of IPN resistance in the SalmoBreed population. The figure shows the association of thousands of genetic markers tested against IPN resistance. Each chromosome is designated with a different colour. The information from a highly significant QTL (the green chromosome), has been implemented in the breeding programmes, resulting in fish with high resistance against this disease.



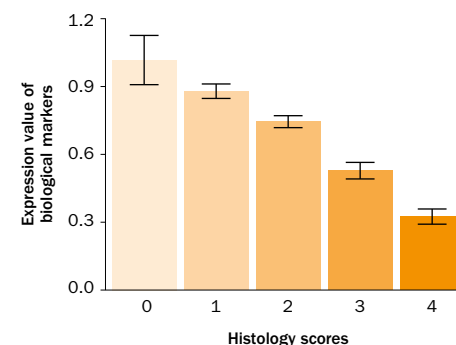
**Figure 3:** This figure shows the relationship between resistant (Q) and susceptible (q) variants of the IPN QTL and the mortality level in fish from the SalmoBreed population. By using a parent that carries the QQ genotype in ova production, there is high survival of the offspring.



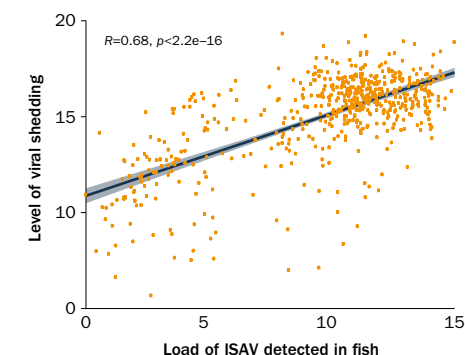
**Figure 4:** Manhattan plot, showing the genome-wide association of PD (SAV3) resistance in the SalmoBreed population. The figure shows the association of thousands of genetic markers tested against PD resistance. Each chromosome is designated with a different colour. The information from a significant QTL (the pink chromosome), has been implemented in the breeding programmes, resulting in breeding for fish with high resistance against this disease.

of the animals that carry the resistant form of the gene survive the challenge tests (Figure 3). Benchmark Genetics has IPN QTL as a standard trait in all its products, and has ensured that all ova carry the resistant QTL combination. Prior to and parallel with the implementation of IPN QTL, the company has been selecting for IPN resistance based on the family level since 2004. The introduction of the IPN QTL has resulted in a significant reduction in numbers of IPN outbreaks.

**Pancreas disease (PD)** is a highly contagious, notifiable, viral disease caused by Salmonid alphavirus (SAV). There are six known subtypes of this pathogen, with SAV2 and SAV3 being the most common forms in Norway. The primary mode of disease transmission is horizontal, through contact with infected fish. The first signs of infection are usually a sudden loss of appetite, followed by changes to the swimming behaviour. High levels of mortality, reduction in growth and fillet quality can be



**Figure 5:** Association between heart damage and biomarker expression in SAV3 challenged SalmoBreed fish. The figure shows the relationship between the profiles of biological markers and the level of damage to the heart with 0 indicating no signs of injury and 4 a suggestion of highly damaged tissue.



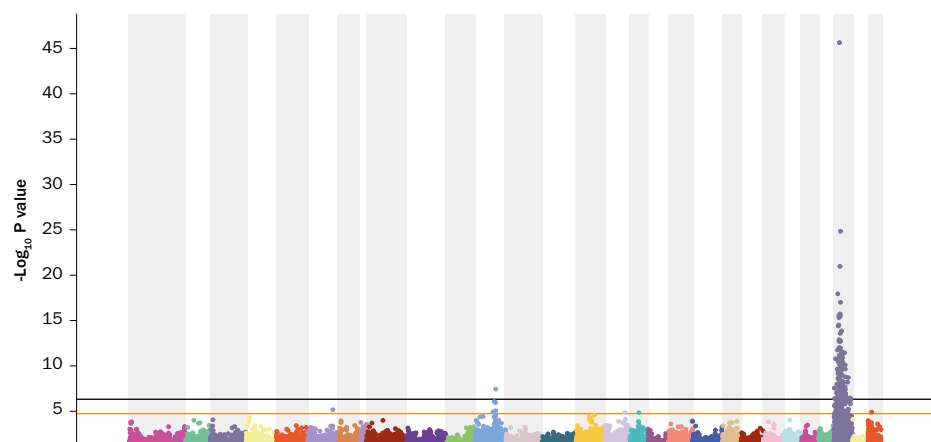
**Figure 6:** Scatterplot showing that the fish with lower levels of ISAV pathogen also tend to shed less virus in the environment and as a result, are less likely to infect other animals.

expected consequently. While there are no treatments for PD, several vaccines offer some levels of immunity against this disease.

BENCHMARK GENETICS offers PD robust fish using GS, which started in 2015. From 2008 selection for family resistance to PD was used, with a QTL for PD resistance used from 2011 (Figure 4). From 2018 Benchmark Genetics incorporated selection for superior growth after SAV infection in addition to resistance against SAV2 (QTL) and SAV3 (QTL and GS) (Figure 5).

**Infectious salmon anemia (ISA)** is a severe, notifiable, infectious viral disease caused by the infectious salmon anemia virus (ISAV). The condition causes severe anemia, poor health and high mortality. Two major epidemics, one starting in the Faroe Islands in 2003 and the other in Chile in 2008, devastated the salmon farming industry in these regions and reduced the production to only a fraction of their potentials. No successful treatment is currently available, and vaccination has not been successful in offering complete protection against this disease. The disease can cause severe losses to infected farms as all fish have to be culled, and zone restrictions will be enforced to prevent the spread of the virus.





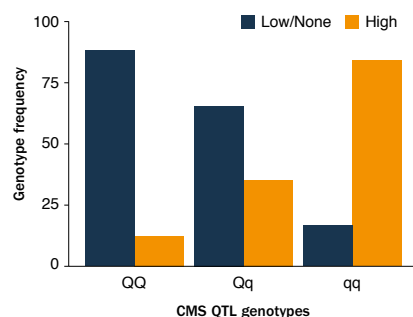
**Figure 7:** Manhattan plot, showing the genome-wide association of CMS resistance in the SalmoBreed and StofnFiskur populations. The figure shows the association of thousands of genetic markers tested against CMS resistance. Each chromosome is designated with a different colour. The information from a significant QTL (the faded purple chromosome), has been implemented in the breeding program, resulting in breeding for fish with high resistance against this disease.

Benchmark Genetics offers ISA robust fish using GS, which was initiated in 2016. Prior to the implementation of GS, the company has been selecting for ISA resistance based on family levels since 2001. From 2018, Benchmark Genetics added additional measures while selecting for ISA robust fish to ensure that the more tolerant animals have higher resistance by carrying low to undetectable levels of the virus while retaining higher growth and lower rates of pathogen shedding (Figure 6).

**Cardiomyopathy syndrome (CMS)** is a severe heart disease of Atlantic salmon caused by the Piscine Myocarditis Virus (PMCV). As the fish usually become affected during later stages of production, mainly in the second year after transfer to sea, the economic losses due to CMS outbreak can be significant. Over the past few years, the frequency of CMS outbreaks has increased throughout Norway, Scotland and the Faroe Islands with no effective vaccine or treatment yet available.

Benchmark Genetics offers CMS robust fish using QTL, which was initiated in 2018. A major QTL, affecting the level of the virus and damage to the heart, has been detected in the SalmoBreed and StofnFiskur populations (Figure 7). In challenge tests, high frequency of the fish carrying the favourable version of the QTL showed low to undetectable levels





**Figure 8:** This figure shows the relationship between resistant (Q) and susceptible (q) variants of the CMS QTL and the level of virus detected in fish from the StofnFiskur population. Sires that carry the homozygote, resistant QQ genotype will be used to provide CMS QTL ova to the customers, where the offspring will consist of either QQ or Qq genotypes.

of the virus, with little signs of heart damage. In contrast, fish with the unfavorable copy of the QTL had substantially higher loads of the virus and severe cardiac damages (Figure 8).

**Sea Lice** is a major critical threat to the global salmon industry caused by a copepod parasite that mostly lives off the skin mucus and blood of the fish. Different species of sea lice occur in Northern and Southern hemispheres with *Lepeophtheirus salmonis* (Lep.) predominating in Norway, Scotland, Faroes and Canada and *Caligus rogercresseyi* (Caligus) in Chile. Infection with sea lice can result in large wounds on the skin and lead to anaemia, secondary infections or even might be fatal to the salmon. Salmon are regularly monitored for sea lice, and require to be treated if numbers exceed critical values. A range of treatments are available such as pharmaceutical, anti-sea lice functional feed, water flush, lasers or cleaner fish but these methods have either a limited effect or cause high levels of stress to the animal. As a result, the direct and indirect costs of treatments can be significantly high.

Benchmark have nucleus programmes that operate across Northern and Southern Hemispheres. The breeding programmes in Norway and Iceland have focussed on breeding for improved resistance to Lep. and Chile have targeted Caligus. With the recent establishment of a StofnFiskur nucleus in Chile that is directly linked to the nucleus in Iceland, Benchmark Genetics now has the ability to breed for general sea lice resistance using data and samples for both species of sea lice obtained in Iceland/Norway and Chile. This unique approach allows identification of salmon that have strong resistance to both species of sea louse.

BENCHMARK GENETICS offers sea lice robust fish using GS, a program that started in 2015. Before the implementation of GS, family selection was used to improve sea lice resistance. The rate of genetic gain in sea lice resistance using GS is more than three times greater than using family selection. Benchmark Genetics continues to work on novel approaches for identifying and selecting the most robust animals.

**Amoebic gill disease (AGD)** is caused by a harmful parasite amoeba, *Neoparamoeba perurans*, an amoeba typically found in cultured fish. As the amoebas colonise the gill tissue, multifocal lesions appear on the gills as plaques or white mucoid spots, reducing the fish oxygen uptake. Although, if treated, the degree of mortality can be relatively low, the infection may lead to other fatal gill diseases, permanently reduced gill function and cause significant economic losses. Warm sea water temperatures and increased salinity increase the number of AGD outbreaks. The infected fish can be treated using either freshwater or hydrogen peroxide. However, the treatment usually needs to be repeated, and the associated cost and stress of the procedure can be high.

Benchmark Genetics offers AGD robust fish using GS, which started in 2017. Prior to the implementation of GS for this trait, the company has been working towards AGD resistance through a number of R&D projects since 2013. From 2017, Benchmark Genetics included more detailed measurements for assessing and phenotypic scoring of the AGD infected fish while accounting for higher growth performance following infection.

**Salmon Rickettsial Syndrome (SRS)** is caused by an intra-cellular bacteria *Piscirickettsia salmonis* which results in lethargy, anorexia and anaemia with consequent reductions in growth and performance of affected farms. Treatment with antibiotic is used to reduce the effects. A vaccine is available, but this is not completely effective. SRS treatment is estimated to cost the Chilean Industry over \$100M per year.

Benchmark Genetics have shown that resistance to SRS is controlled by many genes and use GS to identify broodstock that show improved SRS resistance for breeding. Ova with improved resistance to SRS have been available to StofnFiskur customers in Chile since 2018.

**Bacterial Kidney Disease (BKD)** is caused by *Renibacterium salmoninarum* which is an intra-cellular bacterium that causes lethargy, ascites, anaemia and bulging eyes resulting in reduced growth and performance in affected groups. Affected fish can be treated with antibiotics, and vaccination is partially effective. Biosecurity and screening of broodstock is used to prevent vertical transmission, but horizontal transmission from infected wild fish is difficult to prevent, especially in cold-water production areas of Chile where BKD represents greater problems.

Benchmark Genetics has begun trials to measure susceptibility to BKD in Chile to identify families that have better resistance, and use GS to identify individuals with high resistance to this disease for use in the nucleus and commercial ova production. Commercial ova with improved BKD resistance will be available from early 2021.



#### Disclaimer

Every attempt has been made to ensure the accuracy and relevance of the information presented in this document. Benchmark Genetics Ltd. however, accepts no liability for the consequences of using this information for the breeding of Atlantic salmon or for any other purpose.

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