
Benchmark®
Genetics
Genetics for the
production of
**Atlantic salmon in
land-based farms**

Why land-based farming?

Sustainability, sea-lice and disease challenges, limitations of growth by regulators and high production costs are fuelling the farmers and investors to look at projects on land.

Land-based production provides a high level of environmental control to the producer, where salmon grows within an optimal environment throughout the production cycle. Land-based recirculating aquaculture systems (RAS) is a technology that helps grow sustainably raised seafood. Land-based systems are categorised by the degree of water recirculation or water recycled within the system. More recently, the development of hybrid land-based systems offers the combination of flow-through and RAS technologies, recycling up to 70 % of the water volume. Producing close to the market positively affecting the carbon footprint is another argument for investing in land-based RAS-systems worldwide.

Benchmark Genetics is working with the majority of the land-based technology providers and producers to enhance our understanding of the latest technology and devise the optimised method for salmon culture on land. Growing salmon on land removes interactions with the natural environment, reduces the risk of disease, escapees and impacts on wild stocks, and can lower the requirement of precious water sources compared with traditional farming practices.

Land-based production with RAS-technology has evolved into two different directions:

- Production of large smolt, from 200g up to 1kg on land, reducing the time for grow-out in the sea from 18 to less than 12 months;
- Full-cycle production on land, including the grow-out phase.

This brochure focusses on ova production and genetics adapted for full-cycle land-based production systems.

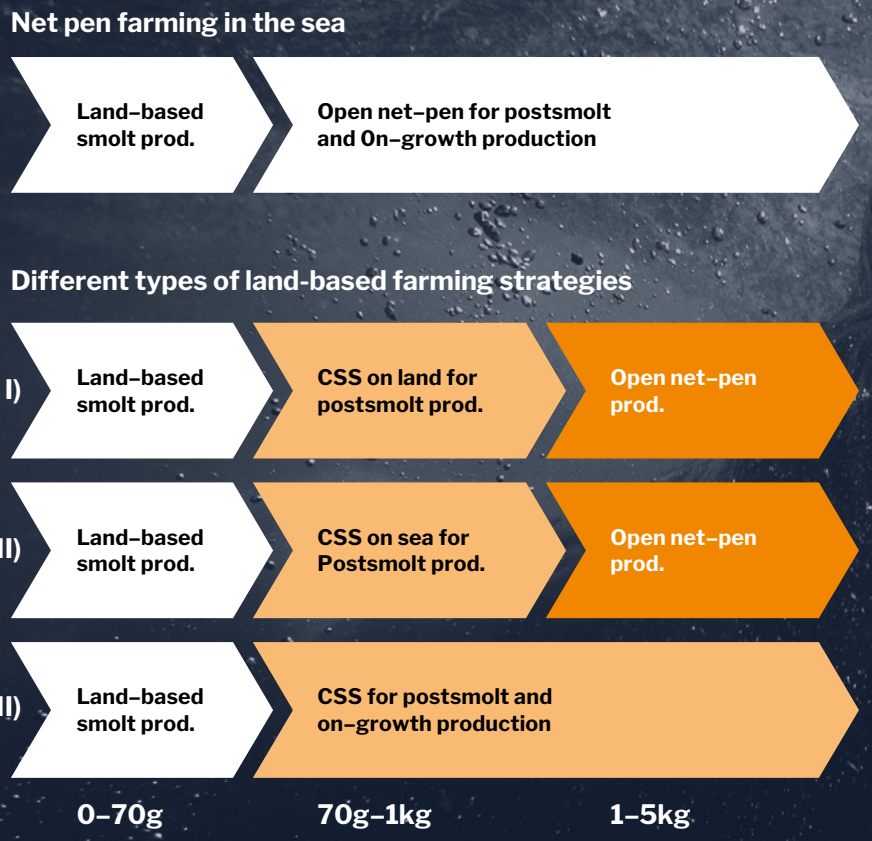


Fig. 1: Traditional systems v.s land-based systems

Source: Nofima and CtrlAQUA

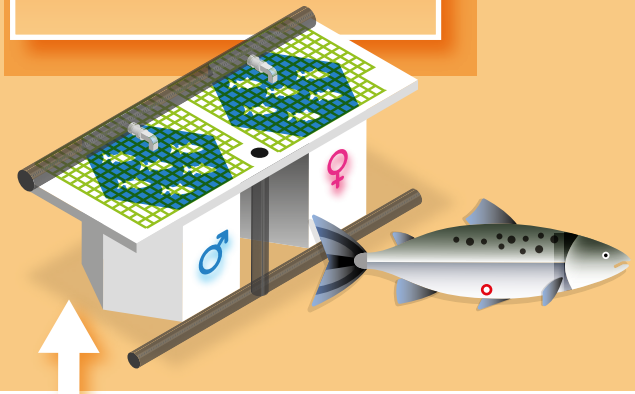
Land-based broodstock farming

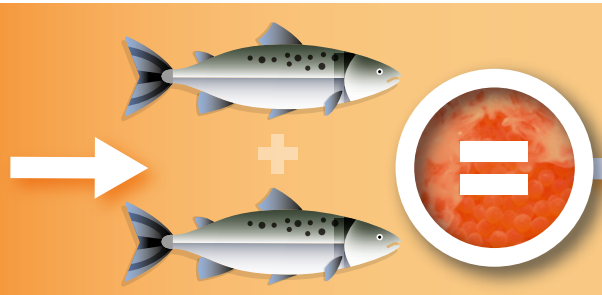
We operate in-house breeding programs for three strains in Norway, Iceland, and Chile, managed by a highly skilled team of geneticists.

Production at land-based facilities ensures the industry's highest levels of biosecurity.

1 OUR NUCLEUS
The best of the best

After many generations of selection, these are the best performing and most robust fish. They are all individually tagged, using a PIT tag (harmless electronic chip in their bodies).

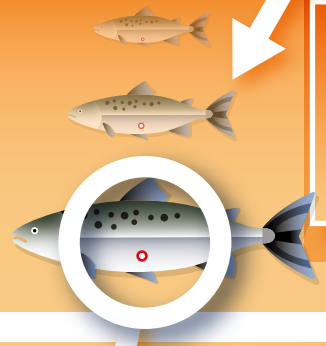




2 We then cross them, keeping a record of which father and mother were selected for the crossing.

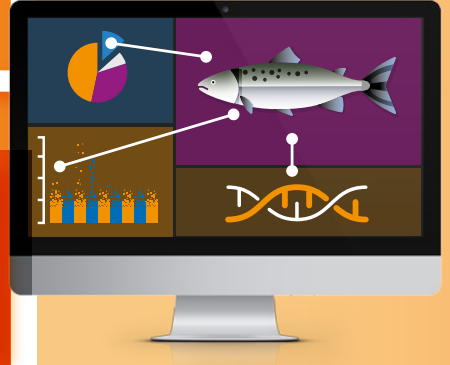
The resulting offspring of each crossing is called a Family.

3 Each of the resulting families is carefully reared in separated and marked individual tanks in identical controlled feeding, sanitary and environmental conditions.



4 We select and separate a small representative number (15 to 20) of individuals from each family and tag them using a PIT tag.

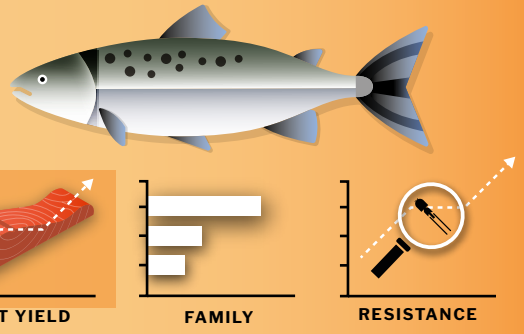
This provides individual identification, as well as information of which family they come from.



5 These individuals from each family are then:

PHENOTYPED:
We measure, weight, and analyse them, keeping record of the observable characteristics or traits of the fish.

GENOTYPED:
We observe their DNA, searching for specific markers to identify genes linked to a specific trait.



6 We test siblings of candidates to see how good they are at the traits we are checking on. It could be fast growth, fillet yield or quality, or resistance to parasites (lice) and diseases, etc.

The test allows us to score and rank our families, from best to worst, for each specific trait we are testing for.

The performance or resistance result of each tested individual lets us assume their family members performance will be same.

7 Finally, we do individual selection based on the breeding candidates' genotypes. The elite, which will then reproduce the next nucleus generation, with **GENOMIC PRECISION.**

We strive to be the foundation of our customer's success

6 steps for delivering top-quality products and services to our customers

1 **Strict biosecurity protocols** are one of our most significant advantages. We understand the importance of healthy broodstock and maintaining a clean production environment to provide biosecure, robust, year-round supply of eggs.

2 **Our Atlantic Salmon Ova Portfolio**, a meticulously curated selection of salmon ova engineered to deliver superior genetic performance and resilience. It is based on refined selection techniques aimed at maximising growth potential and robustness.

3 **Robust R&D capacities** allow us to innovate and improve our products continuously. With cryopreservation laboratories in-house connected with each of our egg production facilities, we have access to seamen of the best males from the breeding nucleus to match customer requirements.

4 **Outstanding customer service** is a key differentiating factor. We are committed to delivering excellent service, and our team is always available and knowledgeable to address our customers' concerns or questions.

5 **Worldwide delivery** is a vital part of a growing global industry. Our ability to send ova worldwide from our facilities in Iceland and Chile allows us to meet customer needs in a global market.

6 **Strong focus on environmental sustainability,** with nearly 100% of our power consumption in Norway and Iceland based on renewable energy sources.

Production strategies for broodstock

Conventionally, broodstock has been produced in the sea and only transferred to land the very last period before spawning for temperature and light manipulation to induce maturation.

Such a production strategy is associated with risks for the producer as the broodstock spends one year more in the sea than the commercial salmon. Risks of losses caused by diseases, the introduction of pathogens, attachment of sea lice, and risks of escape are all associated with production in the sea. Benchmark is continuously seeking ways of producing salmon more sustainably, taking care of both the value of genetics as well as fish welfare. For this reason, a large part of production of broodstock has been moved on land for a more extended period and even the entire life cycle. The so-called semi-closed strategy means that the broodstock are transferred on land after just one year in the sea, reducing the biological risks significantly.

Such an approach also allows maturation and spawning time to be controlled by using advanced light and temperature regimes developed by the company, resulting in continuous production of ova, all year round. A third option is a Closed strategy, keeping the broodfish on land for the entire cycle — from egg to spawning. A significant part of Benchmark's global production follows this scheme. Just as for the Semi-closed strategy, the closed approach allows introducing light and temperature regimes, giving complete control of the maturation of the fish. In addition to being able to deliver eggs all year round, this strategy also secures the highest levels of biosecurity, setting a whole new standard for the salmon industry.

Production strategies Benchmark Genetics

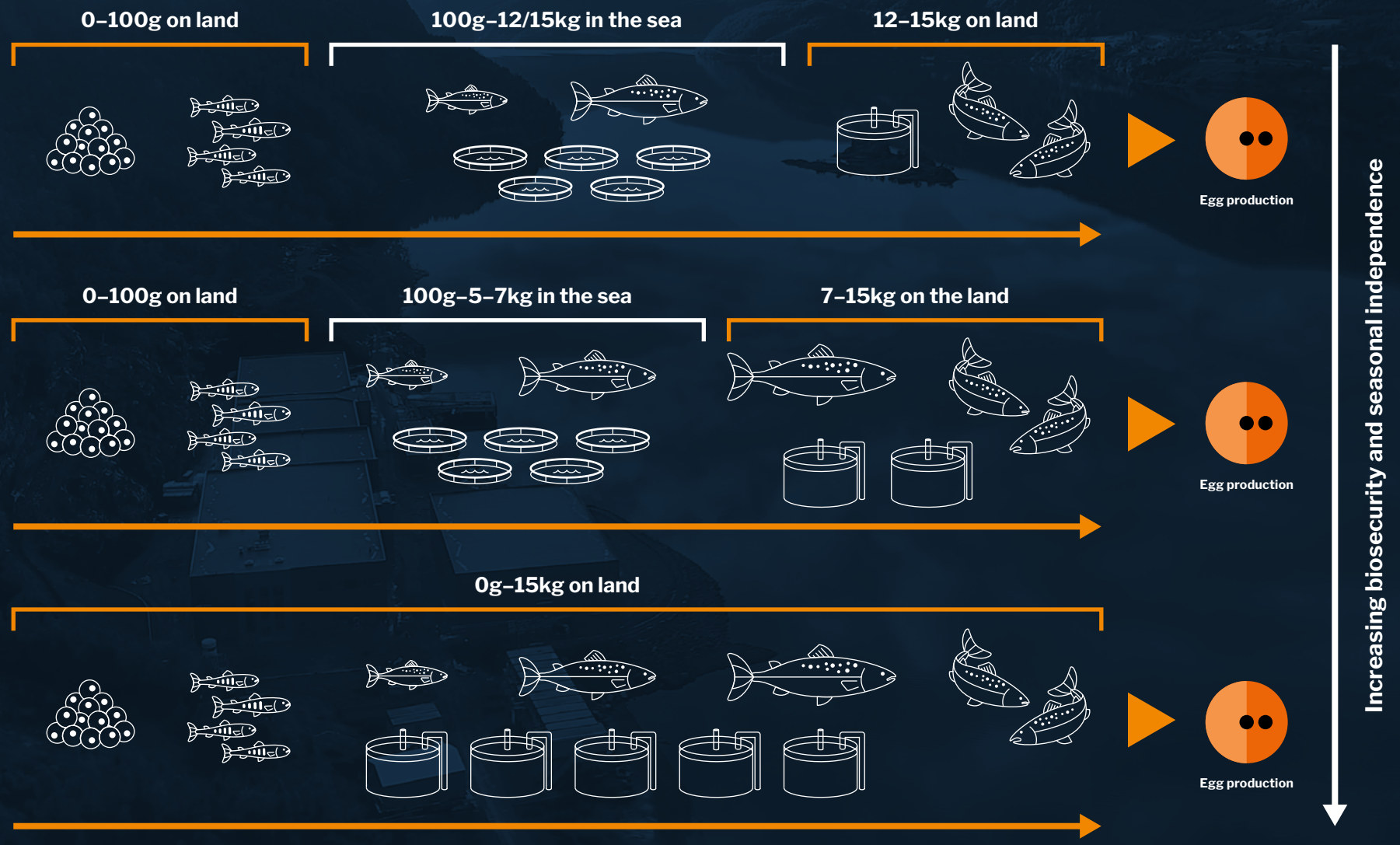


Fig. 2: Production strategies

Sharing the experience across the world

Benchmark Genetics has the most extensive experience in the land-based broodstock farming industry, starting in Iceland back in 1991.

At our two broodstock facilities, Vogarvik and Kalmanstjörn, clean and pathogen-free fresh and seawater are pumped from deep-drilled boreholes and naturally filtered through porous lava stone, providing the best starting point for farming broodstock. Experiments with light and temperature regimes in Benchmark Genetics has resulted in a set of standard operation procedures (SOP) for closed broodstock production that is unique to the industry and has an international patent.

Sharing the SOP's developed in Iceland across the entities in the division has put Benchmark Genetics at the forefront of broodstock production worldwide. The top modern facility in Salten opened in 2019, combining the semi-closed and closed production strategies to optimize the capacity of the ova production. The same is the case for our new operations in Ensenada and Curacalco in Chile, both to operate on closed land-based production cycles.

Check out our updated list of certifications at bmkgenetics.com/certificates

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Number of geneticists at Benchmark

A global team of experts in aquaculture genetics

1 Iceland

Line of business:
Atlantic salmon ova

Sites:

- 2 land-based broodstock sites, Vogarvik and Kollafjörður
- Freshwater family production
- Incubation center Vogarvik

Capacity: 200m ova/year

Offices: Hafnarfjörður

2 Norway

Line of business:
Atlantic salmon ova and technical genetics improvement services

Sites:

- Land-based broodstock and incubation site Benchmark Genetics Salten
- Freshwater family production Lønningdal
- 50% J.V Salmar Genetics
- Partnerships Bolaks, Salten Stamfisk, Kvarøy and Salmar

Capacity: 300m ova/year incl. partners

Offices:

- Bergen, Sunndalsøra and Ås

3 Chile

Line of business:
Atlantic salmon ova and technical genetics improvement services

Sites:

- Land-based broodstock and incubation site Ensenada
- Freshwater family production Curacalco

Capacity: 50m ova/year

Offices:

- Puerto Varas

Biosecurity

At land-based RAS facilities, it is extremely important to be in control of any biological material entering the site. In particular, it is crucial to avoid pathogens to establish reservoirs in the systems.

Getting rid of the pathogen will require extensive and costly operations of cleaning and disinfecting, and at worst case fish may have to be culled.

Benchmark Genetics' production sites have been designed to hold the highest standards of biosecurity, including closed hygienic compartments, high levels of UV water treatment and bore-hole water (Iceland and Chile).

Besides, a comprehensive screening program is performed to eliminate broodfish carrying unwanted pathogens. Benchmark Genetics Iceland and Chile are free of ISA, IPN, PD/SAV, CMS/PCMV, IHN, VHS and BKD.

In 2015 Benchmark Genetics biosecurity system was taken to another level with compartmentalization according to the guidelines of the OIE (World Organization for Animal Health).

In 2016 Benchmark Genetics Iceland (formerly StofnFiskur) was granted WOHA disease-free compartment status by MAST. Benchmark Genetics Chile was granted WOAH disease-free compartment status by Sernapesca in 2023.

Benchmark Genetics is currently the only company permitted to export Atlantic salmon ova to the global market. We are offering individual screening for all relevant Atlantic Salmon pathogens, including:

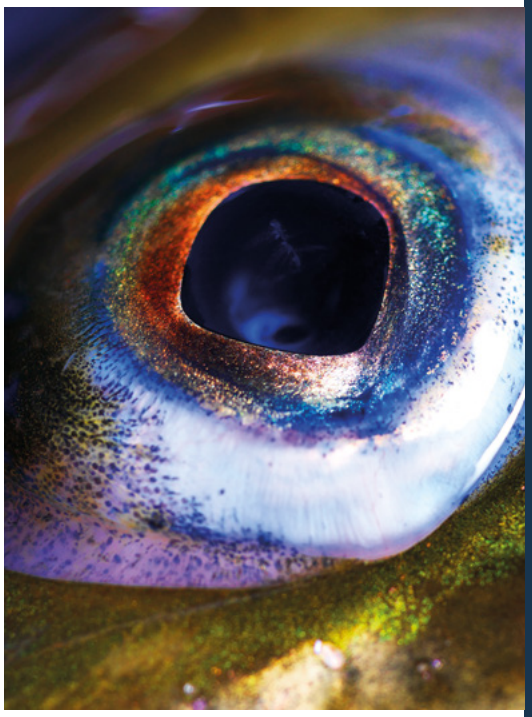
- ISAV
- SAV/PD
- IPNV
- PMCV/CMS
- PRV/HSMI
- VHSV
- IHNV
- OMV
- BKD
- Yersiniosis
- EHNV
- G. salaris

Genetic traits for closed land-based production cycles

Advantages in producing on land are highly controlled production systems, improved growth, no sea-lice issues and high levels of biosecurity.

Fewer traits — higher genetic gain

Farming salmon in open cages in the sea is far more biological challenging than farming on land. The genetics product offering has up to recently been tailored to improve resistance for many diseases occurring in the sea. As most of these diseases are not prevalent in closed land-based systems, the number of traits required for the genetics products are fewer. This means that we can tailor the genetic pool by putting higher pressure on the traits in focus and thereby obtaining significantly higher genetic gains per generation, to the benefit of land-based farming operations.



Type of trait	Demand from farming in sea-cages	Demand from closed land-based systems
Production efficiency traits	Freshwater growth	Freshwater growth
	Seawater growth	(Seawater growth)*
	Late maturation	(Late maturation)**
Disease resistance traits	IPN	IPN
	PD	
	ISA	
	CMS	
	SRS	
	Sea-lice	
	CGD	
Physical quality traits	Body shape	Body shape
	Slaughter Yield	Slaughter Yield
	Fat	Fat
	Pigmentation	Pigmentation

* Relevant for land-based system using seawater in the grow-out process
** Can be solved by All-Female/All-Female-Triploid products

Table 1: Selection pressure on traits — comparison between cage and land-based farming

1. Growth

Fast growth is the single most important trait for producers using land-based systems. Since 1991 Benchmark Genetics has had a substantial focus on improving the growth rate, both in freshwater and in the sea.

Since 1991, we have been using family selection and adding on Genomic Selection (GS) for seawater growth in 2017.

To gain more insights to growth in full-cycle land-based farming, Benchmark Genetics have since 2012 been running trials, both in-house and with The Conservation Fund Freshwater Institute (TCFFI). Results from these trails and how they are being implemented in the commercial production of ova are shown in the sections below.

1.1 Environmental factors and growth

Environmental factors have a significant impact on growth performance, and adjustments in water quality, temperature, light, nutrition and standard operation procedures (SOP) can give immense results, as we recently experienced in our broodstock facility, Kalmanstjörn in Iceland. Back in 2016, we made changes related to equipment, management training, SOP's and nutrition, resulting in a doubling of the growth rate, shortening the production time significantly and improving the fish welfare. Our broodstock can achieve smolt to 4kg in less than 12 months in our flow-through system.

As growth is strongly correlated with temperature, we are using Thermal Growth Coefficient (TGC) when measuring growth. It should also be noted that research and experience from commercial production have shown that farming at temperatures above 12°C induces early maturation, particularly in males. Losses due to maturation can reduce the total production efficiency even if the TGC is higher for the non-mature population. However, there are solutions for overcoming the maturation challenge that is explained in section 2. It is generally accepted that the optimum temperature for seawater growth in Atlantic Salmon is 11.9°C, and this is considered to be optimum for growth in RAS-systems until further analysis can be completed.

A trial at TCFFI was designed using light regimes inducing artificial winter, resulting in higher growth than the parallel groups undergoing 12:12 light:dark regimes and ambient photoperiods. By gaining more experience and knowledge of the impacts of environmental factors such as temperature and photoperiods, there is potential to improve the TGC significantly in the future. With the current production systems, protocols and genetics, producers in land-based systems will typically use between 24 and 26 months from the reception of ova to reaching harvest weight of about 4.5kg. A test group of All-female diploids and triploids at TCFFI was reported to have reached an average weight of 6.5kg in 27 months (source: TCFFI, 2019). Improved technology, production protocols and further adaptation of the genetics is likely to reduce the time from egg to harvest to 20 months.

1.2 Selection for growth based on systems

In Benchmark Genetics, the correlation between growth in different farming systems; RAS, Land-based flow-through and sea cages, by parallel comparison trials using a large number of families has been measured. Growth in RAS-systems is clearly below the growth in the other two technologies, indicating that there is potential for improving growth in RAS production by using breeding and genetics strategies. We also found that there is a relatively high genetic correlation, 0.7, between growth in land-based flow-through systems in Iceland and the RAS systems used by our customers, meaning that we have an excellent base for selection for growth in our Icelandic facilities. Trials also show that the families that perform best in RAS are also the same that grow fastest in flow-through systems.

Genetic gain for land-based salmon farming

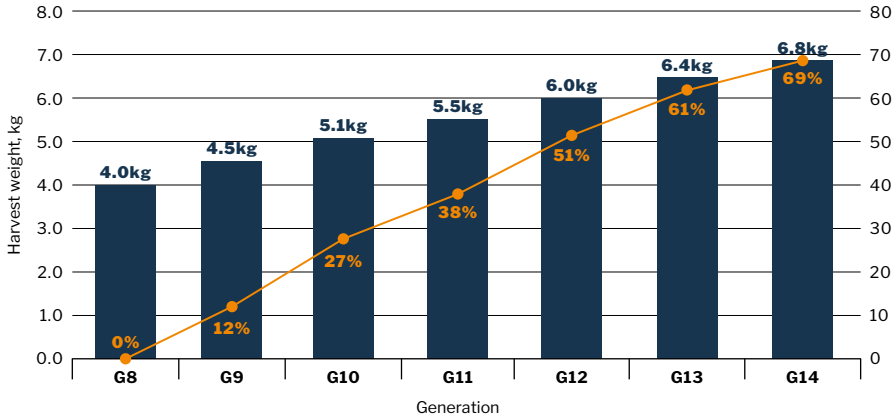


Fig. 3: Benchmark Genetic trend analysis, last 6 generations, 2024

- 2.8 kg increase in mean harvest weight G14 vs G8
- Harvest weight increased 10-12 % per generation
- Gain ~ 0.5 kg per generation

2. Early maturation

Early sexual maturation of males, also known as "precocious maturation", is a major concern when producing on land. When the fish goes into sexual maturation, it stops growing and converts muscle and fat into testes and ovaries.

In the event that salmon mature, the red pigmentation is extracted from the fillet to the gonads and the skin, resulting in salmon with pale fillet and brown skin which is not commercially acceptable. There are many theories behind why some fish are triggered to mature at an early stage. However, research and experience have shown that the maturation ratio tends to increase with water temperatures above 12°C. Sudden changes in temperature also seems to trigger the sexual maturation and should be avoided at all times. TCFFI estimates that an average of 15% of fish in RAS systems mature ahead of schedule. 20–30% is not uncommon, and some companies have even experienced levels as high as 50%, which is devastating for the profitability of their operations (source: TCFFI/Undercurrent News).

Benchmark Genetics has been selecting for late sexual maturation in the breeding programmes since the early 1970's; starting with phenotypic selection, moving into family selection in 1991 and further introducing Genomic Selection (GS) in 2017. In addition to GS, populations are monitored for the so-called "salmon puberty gene", published in Nature in 2015 (https://www.nature.com/articles/nature16062).

At Benchmark Genetics in Iceland, we have also been introducing specific treatments of broodstock and eggs, resulting in a significant reduction in sexual maturation; All-Female and triploid. These products are now gaining increased popularity with land-based customers, as they are experiencing improved production output and profitability by greatly reducing the rates of early maturation.

2.1 All-Female Ova

The All-Female method is a complex breeding strategy where female broodstock are sex-reversed in a process called masculinization. These males produce sperm cells that all carry X-chromosomes giving offspring populations that only consist of females, resulting in the "All-Female" product. As females have much lower incidence of early maturation, this significantly reduces the early maturity challenge that many land-based farms are experiencing with mixed-sex populations. The All-Female product has become very popular with full-cycle land-based customers, who experience a higher number of individuals fully grown to the ideal harvest weight and a more homogeneous weight distribution.

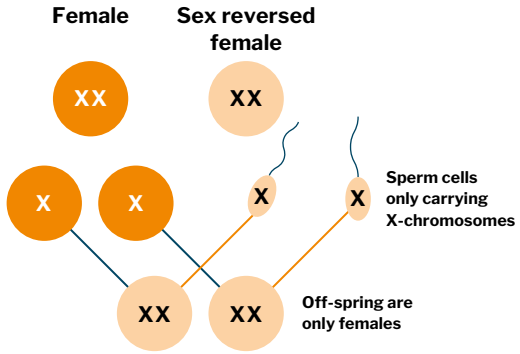


Fig. 4: All-Female process

2.2 All-Female and Triploid Ova

Some producers using combinations of high temperature and full-cycle freshwater are still experiencing increased maturation in all female. It is possible to eliminate the problem by letting the All-Female eggs go through a process called Triploidization. Triploid salmon carry three sets of chromosomes instead of two, are sterile and never mature. Triploids occur naturally at low levels in all plants and animals and are commonly used in crop production (e.g. tomatoes) and aquaculture (e.g. oysters).

In salmon, triploidy can be induced by exposing eggs to pressure shortly after fertilisation. Although the number of chromosomes is increased through this reproductive technique, no genetic modification is involved, and triploid crops and animals are not GMO. Triploid salmon are slightly more sensitive to temperature during incubation, and low oxygen levels during growth. Nutritional requirements are different and a triploid specific diet is required to achieve the highest genetic potential.

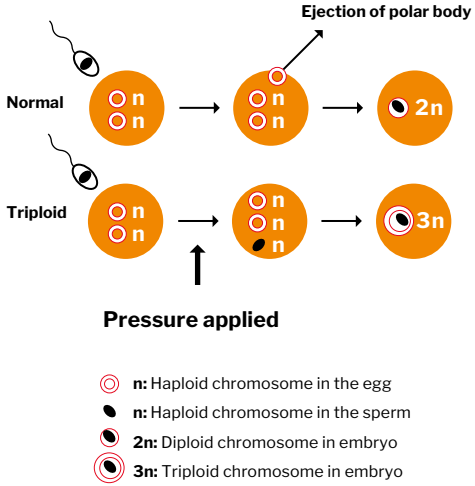


Fig. 5: All-Female Triploid process

3. Disease resistance

Modern genetic technologies are being applied to develop salmon that are more resistant to various diseases that are common in farming environments.

Using Quantitative Trait Loci (QTL) and Genomic Selection (GS) allows the use of genomic information to select the best performing breeders to improve resilience for specific pathogens and parasites in the offspring.

3.1 Infectious Pancreatic Necrosis

Farming on land means reduced risks of disease outbreaks. However, the disease 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 grow-out stage.

The condition, caused by the infectious pancreatic necrosis virus (IPNV), may lead to significant 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 on the year-class 2007 and was initially commercialized in 2010. Resistance to IPN is highly heritable, and can, to a large degree, be explained by genetic variation in a single gene. Across salmon populations in Benchmark Genetics, approximately 80–90% of the animals that carry the resistant form of the gene resist exposure to IPNV when tested in controlled trials. The introduction of the IPN QTL has resulted in a significant reduction in numbers of IPN cases in Norway and other salmon producing countries.

3.2 Other disease and parasite challenges

In Benchmark Genetics, we are continuously following the developments of emerging diseases and evaluating the need to include more traits into our breeding programmes. As examples, Yersiniosis, Pox and skin blisters are health issues we are closely monitoring for product developments associated with RAS-systems.

Diseases such as Vibriosis and Furunculosis have been detected in land-based farming systems, and vaccination should be considered if the farming operation is located in an environment where these pathogens are prevalent in the water sources.

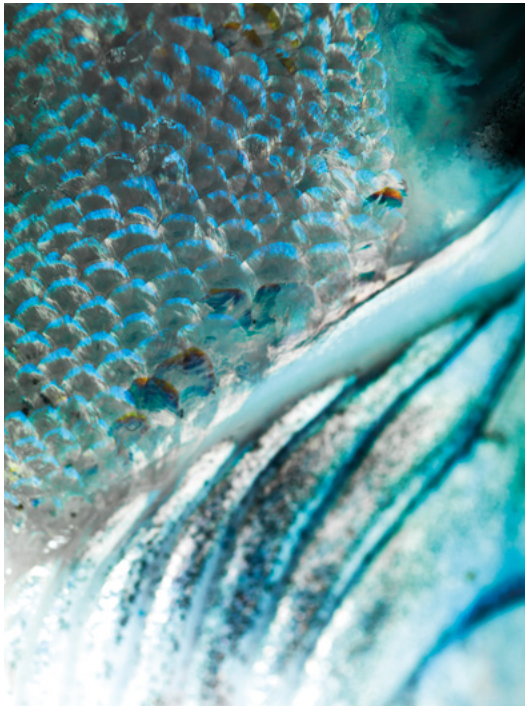
4. Quality

With fewer disease resistance traits needed, land-based farming allows an increased focus on improvements of the performance on harvest and quality traits such as pigmentation.

Physical quality traits, having been included in the breeding programme using phenotypic selection since the very start, are since 2017 also based on the latest genetic technology, Genomic Selection (GS). Pigmentation is controlled by a large number of genes, each contributing with a small effect. This is where the strength of the GS method lies, as it allows the use of information from thousands of genetic markers, covering the entire length of the salmon's genome. By genotyping these markers, the accuracy of the breeding values calculated for each animal is increased allowing the best animals for breeding to be precisely identified.

Using GS for quality traits allows the best broodstock for these traits to be used in the nucleus and production of commercial eggs for RAS-systems.

Selection of the best broodstock for RAS-production has been improved in two ways: increased selection pressure on the important traits for RAS-production by reducing the pressure on disease resistance and introduction of GS to increase the accuracy with which desirable broodstock are identified.



Product range for land-based farming

SalmoRAS®

Product	Selection pressure — traits	Optional key properties
SalmoRAS	Fast growth	All-Female, Triploid, IPN

The product range for full-cycle production in land-based farms offers the best combinations of characteristics to suit growth and fish welfare in recirculation systems (RAS). Combining different traits and treatments, we have aimed to make it easy to choose the product specifically suited for each customer.

Premium selection of salmon ova for the specific requirements of the land-based production environment. This product is selected for high growth and reduced early maturation (All-Female) or even complete elimination of early maturation (All-Female Triploid).

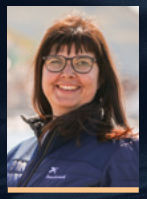
Cryopreservation — choosing the best males at any time

Conventionally, males and females with the best characteristics had to sexually mature at the same time to produce the desired products. Advances in cryopreservation of Atlantic salmon milt now allows the sperm from desirable males to be stored for use when required.

In three cryolabs around the world (Norway, Iceland and Chile) we can freeze and store milt from the best-performing males to be used at any time of the year, according to order planning. Milt from the same male can be used for several orders to the same customer, resulting in high consistency of the delivered eggs.

Contacts

Our people are the key to our success



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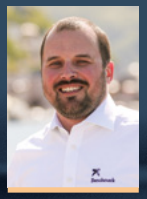

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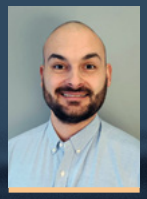

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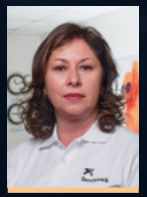

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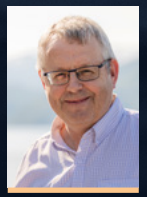

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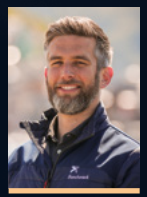

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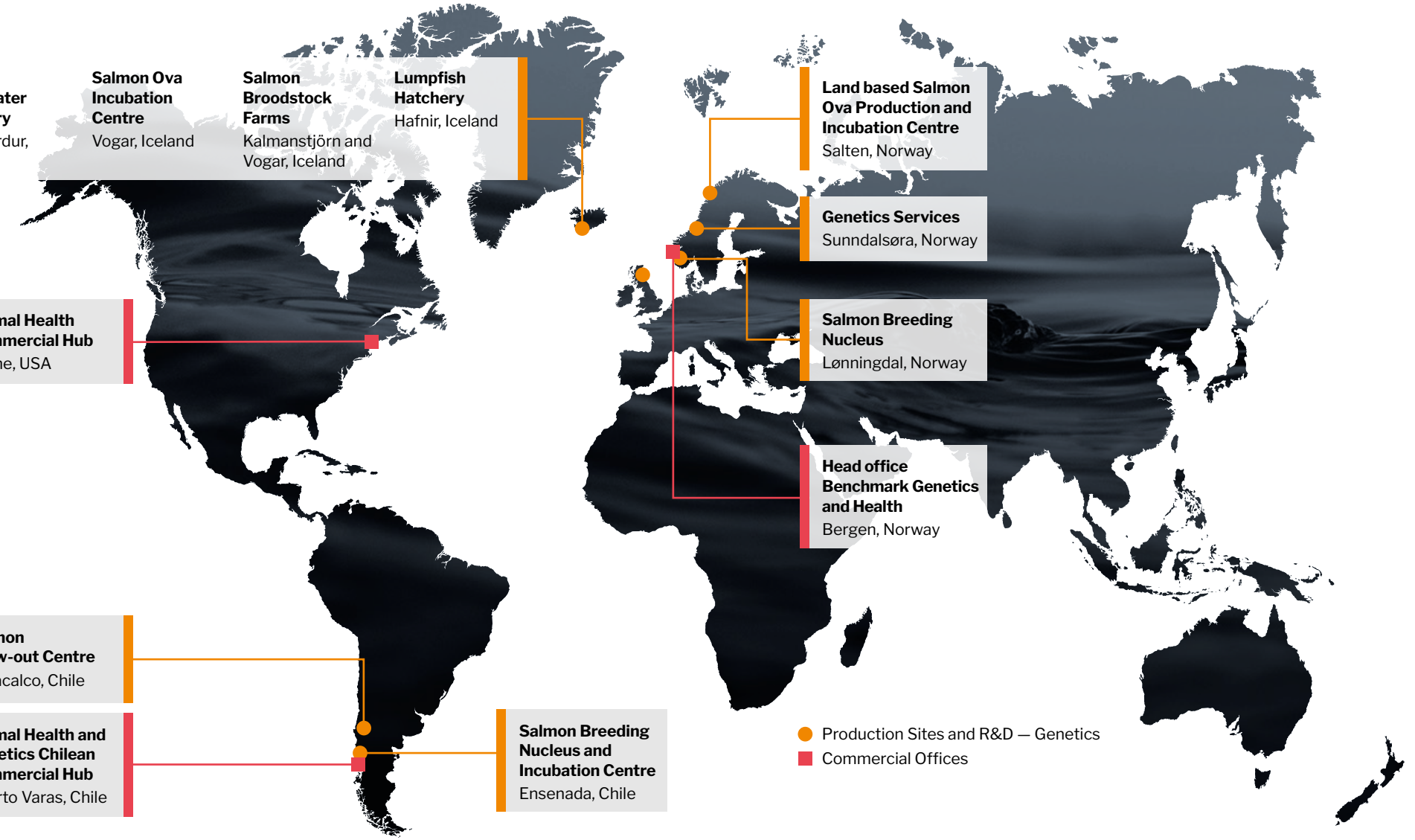
Solving salmon challenges on a global scale through genetics and health solutions

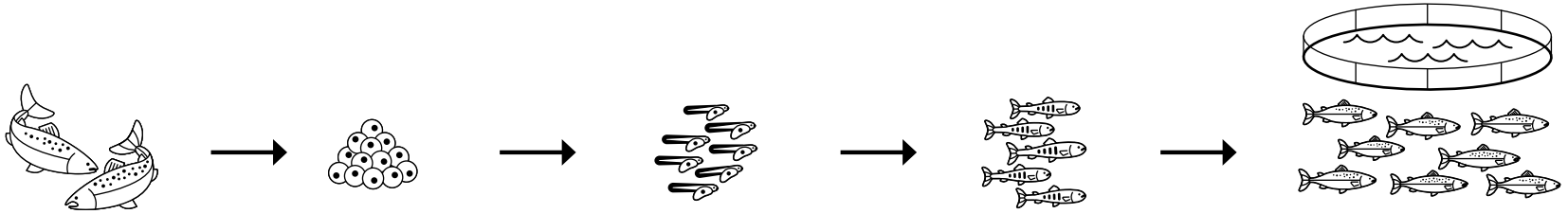
High biosecurity salmon egg facilities

Global technical support teams are here for you to support your production



Product portfolio

Supporting you throughout the production cycle



BUSINESS AREA	BROODSTOCK	HATCHERY	NURSERY	GROW-OUT	PRODUCTS
GENETICS Improved genetics provide a crucial starting point for production efficiencies and health resilience	**Eggs, breeding (parent stock) animals for salmon**	**Hatchery stage fish**			SalmoPrime® SalmoRobust® SalmoBoost® SalmoRAS® SalmoTailored®
	Genetic improvement services for external programmes				
ANIMAL HEALTH Solutions for some of the most persistent disease and fish welfare challenges				**Sea lice medicines** **Purification system**	Salmosan® Vet Ectosan® Vet CleanTreat® by Benchmark® CleanTreat® Integrated by MMC FIRST PROCESS

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