BC Salmon Aquaculture: Innovation & Technology

BC SALMON FARMERS ASSOCIATION

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Message from John Paul Fraser

I am honoured to present the BC Salmon Farmers Association's inaugural Innovation and Technology Report. As a population, we're at a critical point in the climate action conversation; by looking forward our industry is anticipating and shaping its own future, striving to be the lowest carbon food industry in Canada. This report is a source of pride for the nearly 7,000 British Columbians working and living in remote coastal communities and the Lower Mainland; in fact, it's a record of just how far we've come and where we're going.

Our report explores future-forward thinking that can help British Columbia's salmon farming sector remain a leader in the global and growing aquaculture industry. By presenting both past and current technologies, the report dives into the evolution that the BC Salmon farming industry has undergone in technological sophistication since its establishment in the 1970s. Throughout its history, industry has conceived, tested, and implemented state-of-the-art technology and innovation focused on protecting the marine environment and its resources (e.g. monitoring the benthos beneath farms; reducing reliance on wild forage fish species), wild stocks of Pacific salmon, marine mammals, and freshwater resources. As society has raised its climate action awareness, the industry has responded by expanding its suite of eco-focused technologies and management practices. Today's BC salmon farmers care deeply about the environment, wild salmon, and operating in a way that protects and respects our ocean eco-system.

If you're curious about what we do; join us for a farm tour visit or on social media @BCSalmonFarmers, but first have a read below.

Sincerely,

John Paul Fraser
Executive Director

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03 New Technologies and Practices Being Tested or Implemented

Modern ocean-based farmed salmon containment systems are much more than simply floating 'pens' used to restrain the geographic movement of salmon during their later growth and development. Rather, today's containment options are integrated, technologically-sophisticated production systems strategically designed, operated and maintained to ensure economic, environmental, and social sustainability. A review of containment system options must therefore consider not only the integrity of the basic containment structure, but also the integral technologies and innovations that ensure sustainability.

01

Past Technology and Practices

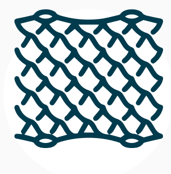
Past Technology and Practices

1 Coastal Net Pens

The development of net pen technology in BC began in the 1960s—primarily for wild salmon enhancement projects. From that time, up to at least the early 1980s, the framework of net pens was primarily constructed from wood—chosen for its buoyancy, flexibility and ability to withstand waves. These wooden frames were supported by hollow or styrofoam floats. Most pens were attached to the seabed via rigid poles at each corner of the pen. The general shape of the net was achieved by hanging weights at each of its corners.

Mooring Systems

During this early developmental phase, one-ton pieces of concrete were often used to anchor the net pen to the seabed—with cables and stifflegs serving as anchor lines.



Nets

Nylon knotted netting—similar to that traditionally used in the fishing industry—was widely utilized in the early stages of net pen aquaculture. Knotted nets had good resistance to wear and were relatively easy to repair. However, the protruding knots often created abrasions on the skin of the fish—particularly when fish density was increased during fish handling and pen maintenance (e.g. during net changing).

To overcome this problem, the industry began to transition to a stretch knotless nylon during the 1970s. However, other materials—such as a semi-rigid, woven mesh made of a 9:1 copper-nickel alloy—were also used due to their anti-fouling capacities.

Feeding Systems

Early feeding practices consisted of hand-feeding—where feed was thrown onto the surface of the water. The amount fed was dependent upon observations by the individual throwing the feed—who based feeding decisions on surface feeding behavior (active eating, or a ‘feeding frenzy’); feeding was continued until the feeding frenzy ceased—which was considered to reflect satiation. As pens became larger, accurate visual observations of fish behavior became more difficult. Moreover, over time, it was realized that the observed feeding frenzy did not accurately reflect the amount of feed being consumed.

2 Fish Health

Soon after the inception of salmon aquaculture in BC, farmers began to encounter infection and disease from the naturally occurring pathogens in the water. Due to the lack of vaccines, mixing antibiotics into salmon feed became a common practice for the treatment of bacterial diseases. As vaccines were registered for use in Canada, BC salmon farmers began to implement vaccination programs as one of a range of alternatives to antibiotic usage.

3 Benthic Quality

During the early years of salmon farming in BC, benthos-related siting considerations were poorly defined by regulatory agencies. For example, a 1983 Department of Fisheries and Oceans Canada (DFO) overview paper on net pen rearing contains the following statements:

- Siting should be aware of potential pollutants from mills or domestic sewer outfalls—and identify other uses such as log booming, marinas, and marine traffic.
- Minimal chance of sedimentation is preferred. “No formal check is recommended. Simply be aware of noticeable changes”
- Minimum ocean depth should be ~3m below bottom of pen at lower end of tidal flux range.
- Maximum ocean depth should be ~10m at the higher end of tidal flux range.
- Chemical analysis: normal ranges for concentrations of Zn, Cd, Hg, Cu, Fe, Nitrate/Nitrite, Phosphate.
- Flora and fauna: qualitative survey of benthos and intertidal zone.

4 Genetics and Breeding

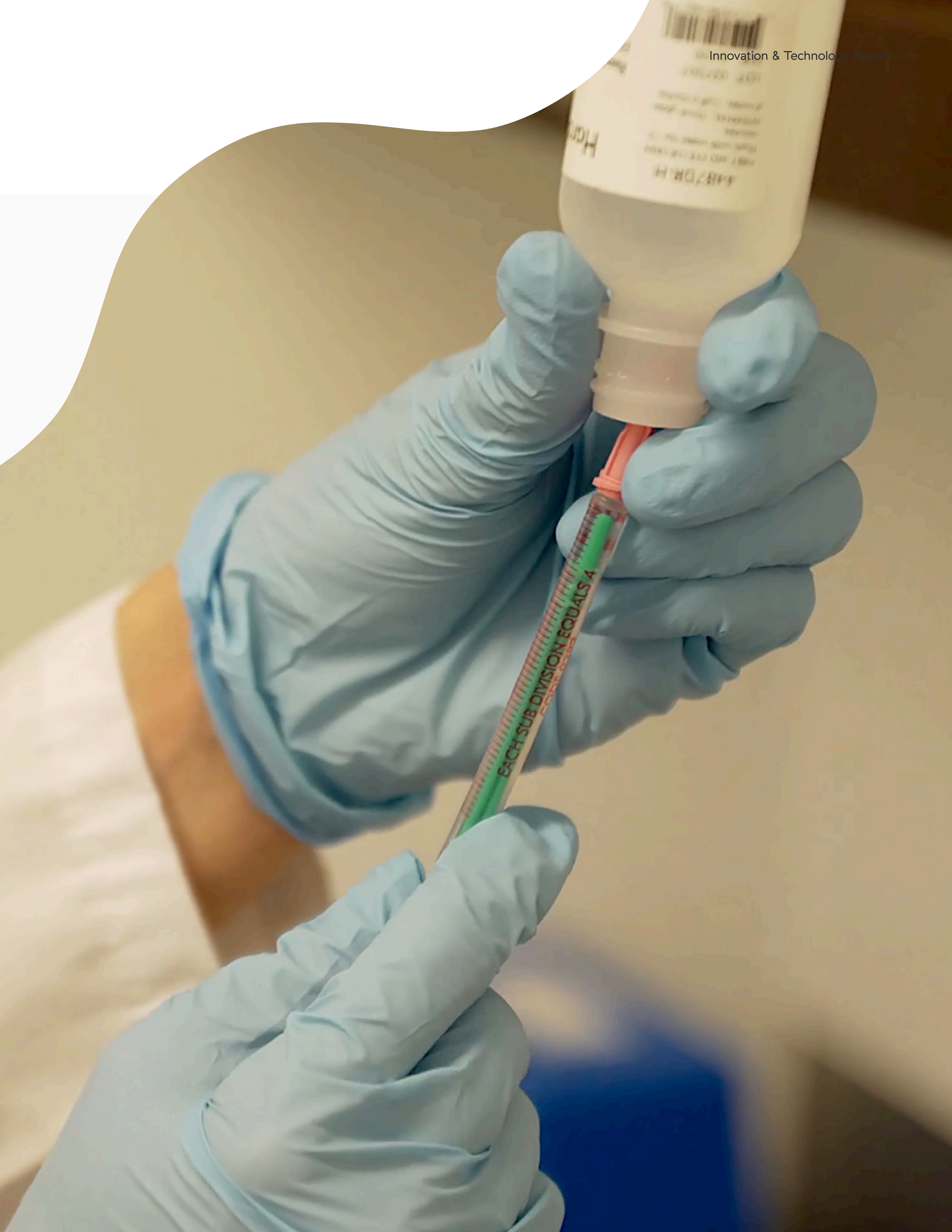
The first Atlantic salmon breeding programs were established in the 1960s. Initially, breeding candidates were selected on the basis of their growth performance. From the 1990s onwards—as breeding programs became more advanced and needs of producers changed—the breeding goals broadened to include traits such as disease resistance, age at sexual maturation, and quality-related traits.

5 Processing Wastewater

Like all fish, seafood and land animal processing, the processing of farmed salmon creates wastewater. Prior to discharge into the marine environment, this wastewater was historically passed through a screen to remove particulate matter.

02

Current Industry Standard Technology and Practices


EACH SUB DIVISION EQUALS

Current Industry Standard Technology and Pratices

1 Coastal Net Pens

Net pen systems have evolved significantly from their wood-based predecessors. The most common coastal net pen systems currently used by BC salmon farms are: steel square net systems and high-density polyethylene (HDPE) circle net systems. These systems are engineered, built, and anchored to the specifications of the operational environment.

Mooring Systems

Current net pens are anchored to the seabed via sophisticated mooring systems designed and modelled by engineering firms to ensure fitment for the conditions of the infrastructure and the site e.g. engineered to dampen the forces generated by site-specific wave motion. Modern mooring systems can be a combination of wire and/or synthetic ropes, tackle (shackles, thimbles, masterlinks, etc.), concrete blocks, shovel anchors and buoys—all interconnected in a manner that ensures the integrity of the system, even in the harshest conditions. The components of these anchoring arrays are constantly being improved to allow for longer life, easier deployment, and a greater safety margin—thereby reducing the potential for the escape of farmed fish.

Nets

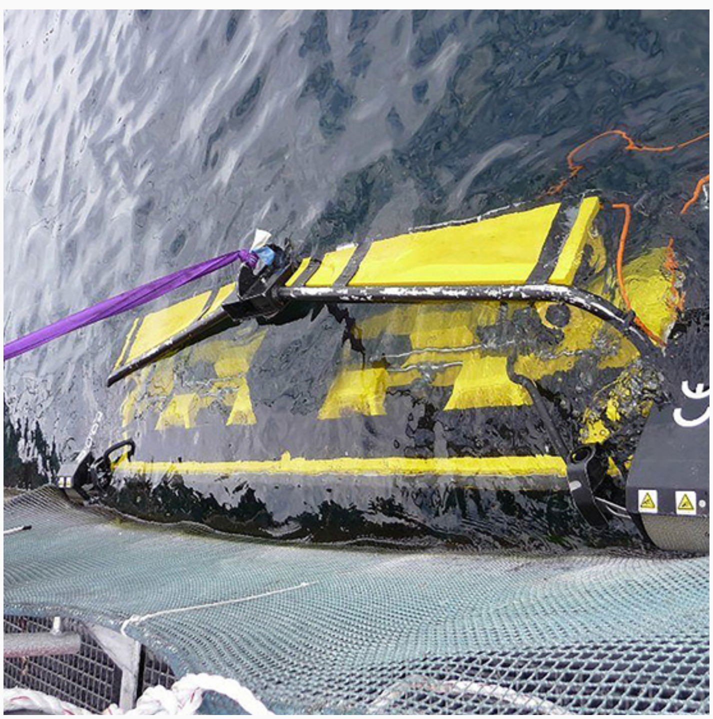
Currently, the most common synthetic polymers used for the manufacture of nets and ropes are nylon or polyamide (PA); polyester (PES); polypropylene (PP); and high-performance polyethylene (Dyneema™ or Spectra™). Polyester and polypropylene fibres can be braided together to create netting with the combined characteristics of the two polymers. All of these polymers are non-water-soluble and therefore provide excellent and long-lasting durability, strength, and reliability in the marine environment.

While both knotted and knotless netting is available for use in net pens systems, knotless netting has now almost completely replaced knotted varieties. The advantages of knotless nets include: lighter weight (>50% lighter than knotted); lower production costs; lower potential to cause abrasion; easier to handle; and greater strength.

The use of these synthetic polymer nettings has contributed significantly to decrease in fish escapes during recent years. Moreover, ongoing research and development (R&D) of new polymeric fibres continues to provide new innovative materials for nets and ropes.

i. **Non-Fibre Nets**
Non-fibre nets are composed of smooth monofilament polyethylene terephthalate (PET). PET nets have a very hard surface that resists marine fouling—thereby making *in situ* cleaning easier. Due to the very low water drag resistance, non-fibre nets also ensure maximum water flow to the fish. This higher water flow facilitates higher production, lower mortality, and higher fish quality. While traditional nets last 3-6 years, non-fibre nets have a potential lifespan of up to 20 years. PET nets have also proven to be very resistant to predator attacks. Moreover—even if damage does occur—the net's semi-rigid structure has proven to have self-closing properties that prevent fish escape.

ii. **UV Resistant Nets**
Ultraviolet radiation can cause polymer degradation of net material—with a consequent long-term loss of strength. UV stabilization materials are therefore incorporated into modern netting during the fibre production process. In addition to the incorporation of UV stabilizers, nets are treated with products that can further protect the net from UV light. By protecting nets against degradation, these UV stabilizers further reduce the likelihood of fish escapes due to net failures. Some UV net coatings also increase the net's resistance to attachment by fouling organisms—thereby reducing the likelihood of net damage due to biofouling and/or frequent net cleaning.



Remotely operated net cleaner

Akva net cleaner

iii. **Bird Nets**
Cormorants, seagulls and other birds of prey represent a threat to farmed fish. To prevent bird predation, the open top of the pen may be covered with a bird net.

iv. **Marine Mammal Nets**
Pinnipeds—such as sea lions and seals—can damage the net in their attempts to access the farmed salmon, thereby creating an opportunity for the fish to escape from the pen. To prevent this damage, predator nets are installed to cover the whole underwater part of the pen net. Perimeter fencing can also be implemented to prevent the pinnipeds from 'hauling out' onto the piping or decks. Salmon farms may also implement pinniped deterrence (PD) systems—such as electric fences—around the perimeter of the site. The current of these electric fences has been recognized by veterinarians as safe and humane to all animal species. Early deterrence of pinnipeds is important to prevent the animals from becoming habitualized to boarding the farm system, which could potentially harm the animals.

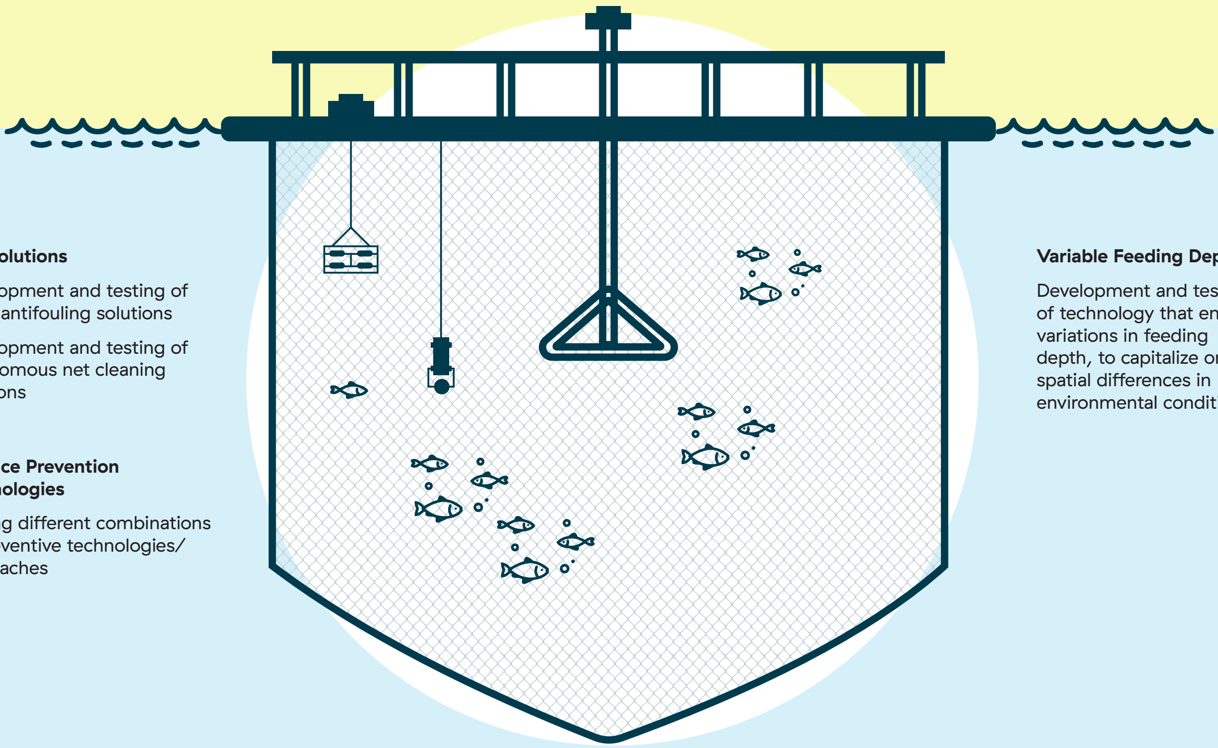
Net Cleaning

Diverse macro-algae, bivalves (e.g. mussels and oysters), sea urchins, sponges, and others sessile organisms settle onto nets and farm structures. This 'biofouling" can limit water exchange in the pen, thereby reducing water quality and depleting dissolved oxygen. These conditions can cause a reduction in feed consumption and increase stress due to poor water quality.

Like marine vessels, nets were traditionally treated with antifouling coatings to inhibit the build-up of marine organisms. Antifouling coatings can also extend the working life of the net by reducing both the UV degradation of net polymers and the excessive wear caused by frequent net cleaning.

Most antifouling paints used as net treatments have traditionally contained cuprous oxide as the active ingredient—with zinc-based biocides also being used. However, in recognition that copper and zinc can become significant and persistent pollutants in the marine environment, the vast majority of BC salmon farms have eliminated the use of copper-based anti-foulant coatings. Nets are now primarily cleaned on land or *in situ*, e.g. using a net cleaning vessel equipped with remotely operated net cleaners. Cleaning is achieved by using high pressure seawater; these cleaners can be operated with a mobile pilot console or a pilot chair with integrated control system. These control systems include advanced camera solutions and sensors that offer a graphic visual presentation showing the cleaner's position in 3D and providing full control of its movement within the pen.

Innovation on Net Pens



Net Solutions

Development and testing of novel antifouling solutions

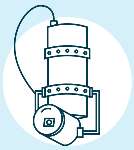
Development and testing of autonomous net cleaning solutions

Sea Lice Prevention Technologies

Trialing different combinations of preventive technologies/ approaches

Variable Feeding Depth

Development and testing of technology that enables variations in feeding depth, to capitalize on spatial differences in environmental conditions



Camera Development

Development of novel camera solutions to improve feeding control and allow implementation of machine vision

Machine Learning

Developing machine learning models to allow identification of individual fish and realtime welfare monitoring, real-time biomass estimation, automatic sea lice counting and autonomous feeding control

Remotely Operated Vehicle Surveillance

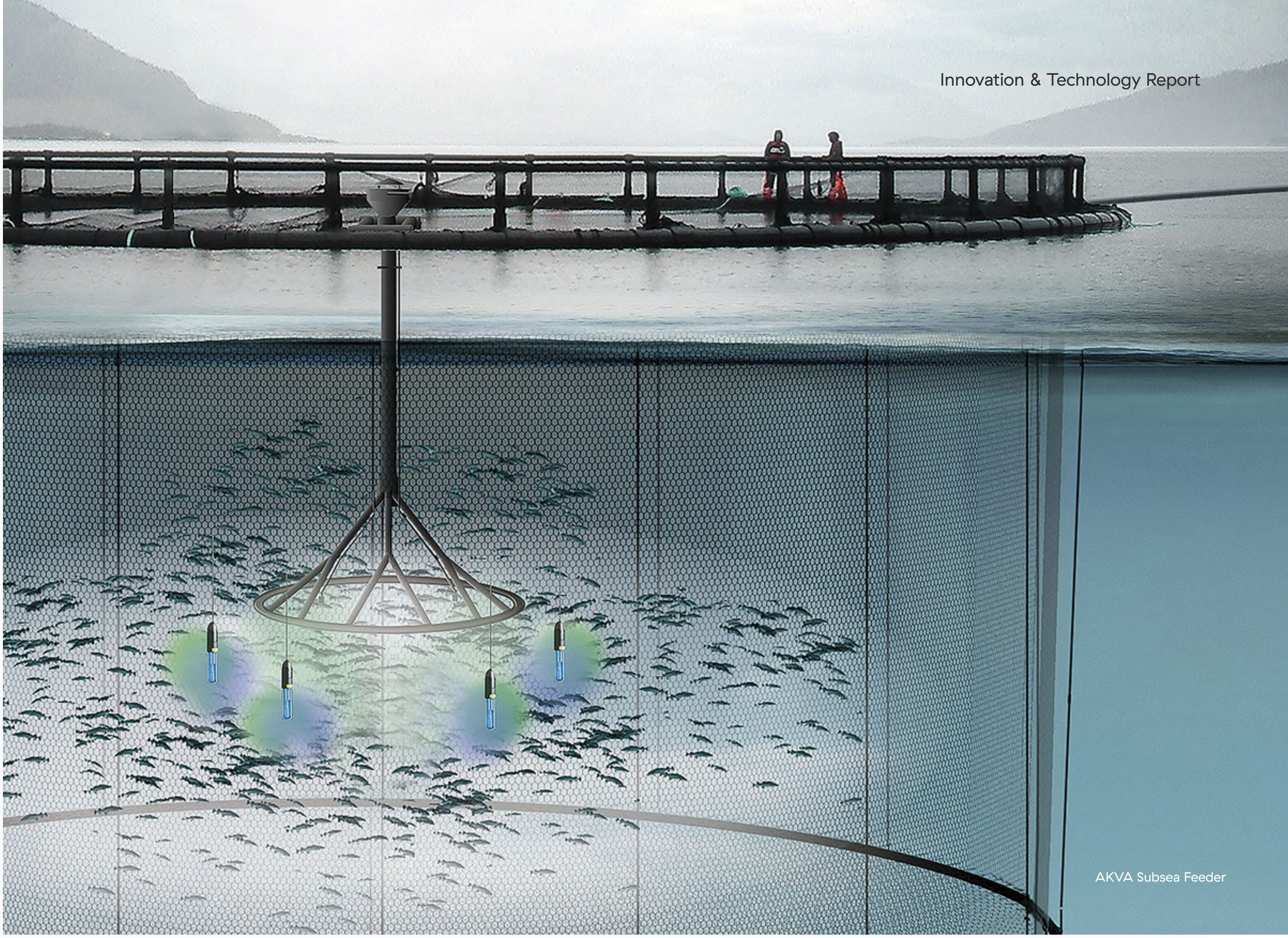
Monitoring of nets, moorings and other site infrastructure

Key development for offshore/exposed operations

Feeding Systems

Salmon farms now primarily use automated feed delivery systems that evenly distribute a set amount of feed throughout the pen at designated times. To ensure that satiation is achieved—and avoid feed wastage due to overfeeding—feeding behaviour and unconsumed feed is closely monitored primarily via underwater video cameras. Increasingly, these feeding systems are supported by state-of-the art technologies such as:

- Environmental sensors—for real-time measurement of parameters that directly impact feed behaviour e.g. dissolved oxygen, temperature, pH, and turbidity.
- Hydroacoustic technology—to provide real-time monitoring of fish biomass, average size, size distribution and growth trends for optimized feeding.
- Lighting systems—to promote more effective feed utilization, higher growth rates, and reduced incidence of precocious maturation.
- Feed spreaders—to regulate and improve feed distribution.
- Air coolers—to regulate feed temperature during delivery, thereby preventing protein denaturation and lipid release.
- Feed blowers—to transport feed to the net pen via air pressure, thereby optimizing feed spread and preventing feed pellet breakdown.
- Production control software—to facilitate integration and analysis of camera and sensor data for optimization of both amount and rate of feeding.
- Autonomous feeding systems—pellets are detected by pellet detection software which then uses learned behaviour to control the feeding.
- Vendor Managed Inventory (VMI) systems—digitally monitor farm site's inventory through a cloud based and RFID tracking system to ensure 'Just in Time' inventory as well as more accurate raw material sourcing.
- 360 degree monitoring—utilizes centrally controlled underwater camera-based systems that allows the user to position cameras precisely where the salmon are eating.
- Remote central feed stations—allow operator to manage the feeding of multiple cages at multiple locations—all from a single laptop, tablet, or mobile device.
- Real time environmental sensors/alarms—provide feed operator with *in situ* environmental parameters that enable monitoring all changes in water quality—and thereby equip operator with real time decision making ability.



AKVA Subsea Feeder

HD Camera System

2 Feed and Feed Conversion Efficiency

Feed makes the largest contribution to the industry's environmental foot-print. To remain at the forefront of environmental responsibility, the industry prioritizes the sourcing of sustainable feed ingredients, and strives to utilize feed as efficiently as possible.

It is well recognized that the industry has moved on from its initial dependence on fishmeal and fish oil through the inclusion of other types of protein and lipid raw materials. To reduce the industry's dependency on wild fisheries, aquafeed companies are increasingly replacing wild-caught protein and oil sources with alternative plant and animal sources. New sustainable raw ingredients being incorporated into feed include: certified soy and palm oil products, soy protein concentrate, maize gluten, guar meal, and by-products from cereal processing & oil seeds. These alternative and novel raw materials have enabled fish feed companies to develop some salmon feed formulations that are completely fishmeal-free while delivering equal performance in terms of fish growth, health, and performance.

For feed formulations that do require marine oil and/or protein, aquafeed companies are increasing their usage of seafood trimmings and locally sourced by-products. The use of trimmings and by-products from wild fisheries upcycles 'waste' materials into healthy food. Up to 30% of the marine oil and proteins utilized in some feed formulations is now derived from seafood trimmings and by-products. In BC, no local pacific herring—from either the fishery or bi-products—is used in the formulations of farmed salmon diets.

BC farmed salmon now require only 1.15 — 1.2 kg of feed to gain 1 kg of body weight. The current feed conversion ratio (FCR) of farmed salmon of 1.2:1 has decreased over three-fold from 1990. Moreover, with the greater replacement of marine ingredients with alternatives, only ~0.75kg of wild fish are now needed to produce 1kg of farmed salmon. Salmon farming has thus become a net producer of high quality marine protein.

3 Sea Lice Prevention and Treatment

Prevention

i. **Area-based Integrated Pest Management**
Where possible, BC salmon farmers implement an area-based Integrated Pest Management (IPM) strategy to manage sea lice. IPM is a globally recognized decision-making process to manage pests in an effective, economical and environmentally-sound way. IPM involves the coordinated application and rotation of all available management practices, with monitoring, communication and cooperation between operators within an appropriately defined area. The goal is to effectively manage sea lice numbers in a way that prevents the development of resistant lice populations.

ii. **Year-Class Separation**
Ensuring that year-classes of farmed salmon are reared on separate farm sites is a Best Farm Management Practice on BC salmon farms. Year-class separation reduces the potential of sea lice transfer by preventing the mixing of farmed fish of different ages.

iii. **Proactive Monitoring**
Sea lice numbers are routinely monitored at all BC farm sites to enable optimal use of management tools.

iv. **Anti–Sea Lice Skirts**
Sea lice larvae are generally found in the first few meters of water below the surface. Some BC salmon farming companies therefore suspend sheets of material (e.g. tarpaulin) from the top of the net pen; these sheets create a shield that prevents lice within the upper part of the water column from entering the pen. To ensure that these skirts do not negatively impact water oxygen levels in the upper part of the pen, dissolved oxygen levels are monitored (and supplemented if necessary) when using skirts.

v. **Smolt Quality**
As a result of years of selective breeding, the smolts placed in BC net pens grow faster, convert feed into flesh more efficiently, and are more resistant to environmental challenges than the fish originally raised on BC salmon farms. They therefore require less time in net pens to reach market weight—thereby reducing their exposure to sea lice.

vi. **Chimney (Snorkel) Nets**
Some BC salmon farms equip net pens with a net 'roof' that is positioned at a depth of ~10m. This 'roof' ensures that the salmon spend most of their time deeper in the water column—away from sea lice, which are primarily found in the first few metres of water. Since salmon must access the water's surface to take air into their swim bladders, the design of the net roof includes a chimney (snorkel) that extends from the roof to the surface; this chimney (snorkel) is impermeable to sea lice—and thereby enables the salmon to avoid contact with sea lice when travelling to the surface.

vii. **Aeration Diffusers**
Aeration diffusers (bubble curtains) can be placed around the circumference of square salmon pens at a depth of 15–20 m; this device releases a line of air bubbles that rise from the bottom to the surface of the pen. The air bubbles create a barrier that deters sea lice from entering the salmon pen.

Bubble Curtain

Treatment

Fisheries and Oceans Canada has set a regulatory threshold of three motile salmon lice (Lepeophtheirus salmonis) per fish. Once this threshold has been reached, BC farms initiate semi-monthly assessments and appropriate health management procedures. These procedures could include:

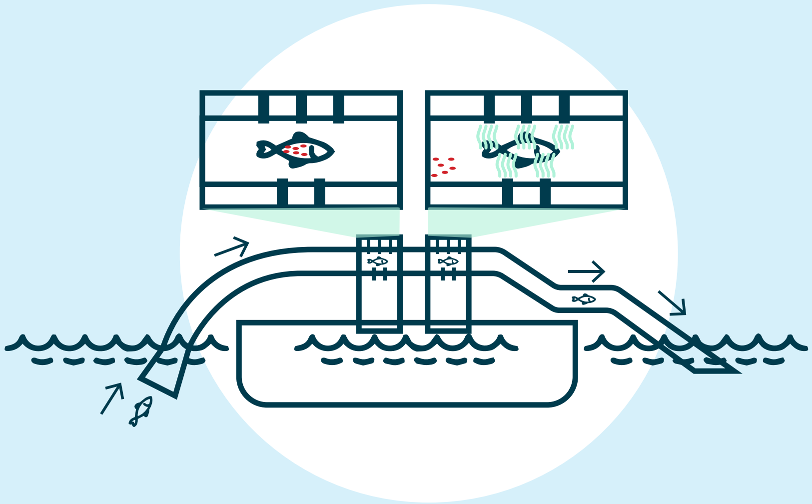
Non-Mechanical Treatments:

i. **Slice Treatment**
Slice (emamectin benzoate) is an in-feed treatment that has been used effectively by BC salmon farmers since 2009. Slice kills all parasitic stages of sea lice and provides post-treatment protection for up to 10 weeks.

ii. **Hydrogen Peroxide Treatment**
BC salmon farms use hydrogen peroxide (H_2O_2) treatments according to permits issued by the BC Ministry of Environment and Climate Change. During hydrogen peroxide treatment, salmon are temporarily exposed to dilute H_2O_2 —either in a well boat or a specifically designed tarpaulin. The H_2O_2 temporarily paralyzes sea lice, causing them to detach from the salmon; the detached lice are then collected and removed from the production environment. After the treatment, seawater is used to dilute the H_2O_2, which breaks down into water and oxygen. As a result of its zero toxicity and zero persistence in the environment, the Aquaculture Stewardship Council recognizes hydrogen peroxide as an environmentally sustainable sea lice treatment.

Hydrolicer

Sea lice can be dislodged by jets of water (like a shower). The hydrolicer system is fitted to a barge near to salmon pens, and fish are briefly passed through jets of water. Detached lice are collected and then salmon are returned back into the pen.



Mechanical Treatments:

i. **Freshwater Treatments**
Sea lice cannot survive when water salinity is very low. By exposing the salmon to freshwater treatments, the lice detach from the salmon and are then collected and removed from the production environment. State-of-the-art wellboats now have the ability to do freshwater treatments on board by producing freshwater through reverse osmosis systems. The dewater systems—that remove fish from water for treatment—allow the water to be recycled for multiple uses.

ii. **Hydrolicer**
Hydrolicers are custom built barges which are capable of effectively treating an entire farm for sea lice in two or three days using only pressurized ocean water. The barge works by bringing fish onboard through four gentle intake tubes where the fish are then moved through two chambers of opposing water pressure — the first loosens and the second removes the lice and eggs. The ocean water is then triple filtered to remove any lice, eggs or other biological materials removed during the treatment. The filtered water is then released back into the ocean and the collected lice, eggs and other materials are stored for disposal on land.

4 Fish Health

Disease Prevention

i. **On-Farm Record Keeping**
Research has shown that the state of animal health & welfare within a production facility can be indirectly assessed through the ongoing monitoring of performance, health, and management/husbandry data. All land-based and net-pen facilities therefore maintain accurate and up-to-date records of growth and health related parameters. These measurements are then used to calculate reliable indicators of optimal growth, including:

- Feed conversion ratios
- Specific growth rate
- Specific feeding rate—the daily feeding rate expressed as a percent body weight, per day
- Rmax—the maximum ration of feed that provides optimal growth

Other parameters measured and recorded include:

- Mortality number and classification
- Stocking densities
- Water quality parameters
- Feed (composition, quantity, age)
- Therapeutants administered
- Stock identifiers (e.g. age, origins)
- Stock movements

ii. **Health Management Plans**
Finfish farms maintain sets of surveillance, monitoring, reporting and disinfection policies to ensure proper bio-security. Licensed veterinarians and fish health technicians sample fish for pathogens and disease on a regular basis.

iii. **Vaccines**
Vaccines have been developed against many of the common bacterial and viral pathogens that impact farmed salmon. These have resulted in a significant decrease in antibiotic use. BC farmed Atlantic salmon are currently vaccinated against furunculosis, vibriosis, winter ulcers, enteric red mouth disease, bacterial kidney disease (BKD), and infectious hematopoietic necrosis—while Chinook salmon only require vaccination against vibriosis and BKD.

iv. **Cleaning/Disinfection of Enclosures, Boats, and Equipment**
In land-based facilities, tanks are cleaned prior to fish being entered and after fish have been removed from a particular tank—and all equipment is disinfected on a regular basis, before and after use. During the fallow between crops, nets are removed for cleaning and disinfection and site infrastructure is cleaned. In a net pen facility, boats and equipment are cleaned and disinfected on a regular basis; and where between-site usage is necessary, boats and equipment are cleaned and disinfected between sites. Every effort is made to reduce the use of equipment at multiple sites to help maintain each site's biosecurity.

v. **Entry Practices and Restrictions**
All facilities have policies applicable to both employees and facility visitors pertaining to procedures to be followed upon entry, as well as protocols regarding visiting multiple facilities over a short period of time.

vi. **Water Source Management**
Design of land-based facilities includes the installation of filtration and disinfection systems that remove any pathogens within the incoming water before it enters the facility.

vii. **Fish Removals and Introductions**
Prior to moving fish into a facility, stringent pathogen testing is conducted to ensure that only healthy, strong fish are being transferred from hatcheries to farm sites. Federal regulations exist to prevent the movement and entry of diseased fish into a facility. To reduce exposure of disease-free introductions to pre-existing pathogens, all fish are removed from a site prior to restocking.

viii. **Fallowing**
As part of industry Best Practices, when salmon are harvested from a farm, the farm is left vacant (fallowed) for a short period of time before restocking. Farms practice regular fallowing of sites to further reduce the risk of disease or parasite transmission.

ix. **Site Specific Year-Class Segregation of Fish**
Year-classes of fish are kept on separate sites to reduce the likelihood of pathogen transfer.

Disease Mitigation

i. **Detection**
A sample of healthy fish in both land-based and net-pen facilities are euthanized on a regular basis to test for the presence of pathogens. Veterinarians and fish health staff also sample and examine facility mortalities for signs of disease. Additionally, moribund fish (those displaying abnormal signs e.g. swimming/floating near the surface, lethargic etc.) are removed from the stock, humanely sacrificed, and examined for signs of disease and sampled.

ii. **Treatment**
If disease-causing bacteria are determined to be present in a stock, a veterinarian-prescribed treatment may be administered and fish health monitoring is increased. Only treatment products authorized for sale by Health Canada are prescribed. The majority of antibiotic treatments in BC farmed salmon are for two bacterial diseases: mouthrot and salmonid rickettsial septicaemia.

5 Benthic Quality

Siting

Sites are situated in areas where the natural movement of water helps to move oxygenated water through the area to support fish health; the oxygenated water also enhances the breakdown of waste material—thereby reducing the likelihood of localized build up of benthic waste. Prior to establishing a new site or expanding an existing one, the benthos beneath the proposed site is surveyed to establish baseline information. Benthic monitoring technologies and procedures utilized depend on the nature of the sea floor beneath the farm. For soft bottom sites, the following information is recorded:

- The rate of deposition of biochemical oxygen demanding (BOD) matter from the facility during maximum daily quantity of feed usage is calculated using an aquaculture waste deposition model; the 1, 5, and 10 grams carbon per meter squared per day (g C/m2/day) depositional contours are then mapped.
- A bathymetric survey covering the entire lease is conducted using echosounders, transducers, and associated equipment
- Horizontal position fixing measurements are carried out using a differential Global Positioning System (dGPS).
- Samples of the benthic substrate are collected at a minimum of two sampling stations (30 m and 125 m away from the cage edge) along two transects that align with the area of greatest predicted impact and with the dominant and sub-dominant current directions. The following information concerning the seabed is recorded with samples collected:
  - Latitude/longitude using dGPS
  - Depth
  - Date and time of sampling
  - Sediment texture and colour
  - Photo of sediment sample
  - Presence of gas bubbles

- Estimation of surface coverage of bacterial mats
- Estimation of surface coverage marine worms
- Presence of fish feces and feed
- Presence of flocculent organic material
- Free sulfide
- Redox
- Sediment grain size; and
- Total volatile solids

At hard bottom sites (where samples specified above cannot be obtained), underwater cameras are used to video the gravel, boulder or bedrock seabed at 100–124m from the net pen edge. The video is then reviewed for the presence of Beggiatoa bacteria and opportunistic polychaete complexes (OPCs); their presence is an indicator of elevated sulphide levels.

Operational Monitoring

DFO requires salmon farmers to conduct benthic matter monitoring at all farms that grow more than 2.5 tonnes of fish annually. Benthic monitoring samples or video is taken at the facility at least once during the production cycle at sea or every 24 months for farms with finfish continuously on site (within 30 days of peak feeding or peak biomass). With minor exceptions, site assessment monitoring procedures are repeated during operational monitoring. Any site exceeding the established threshold for free sulphides (soft bottom sites) or Beggiatoa/OPCs (hard bottom sites) cannot be restocked with fish until further monitoring shows that sufficient recovery has occurred.

Fallowing

The fallowing process (as described above) encourages the restoration of the benthos (seabed) by allowing any waste matter on the seabed to be naturally dispersed. A responsible and sustainable production schedule that allows for appropriate fallow times is essential to ensure no long term impacts on benthic quality.

6 Genetics and Breeding

As a result of the publication of the complete Atlantic salmon genome in 2016, salmon breeding companies are now able to address these challenges with high resolution genotyping tools. These tools are allowing greater accuracy in the selection of breeding stock with superior growth, quality, and disease resistance.

Marker Assisted Selection

Individual genetic markers linked to a number of important production and disease resistance traits have been identified. In cases where this linkage is strong, selection of breeding stock on the basis of a single marker (known as quantitative trait locus; QTL) can significantly accelerate the rate of genetic gain. For example, selection for a QTL associated with the resistance to infectious pancreatic necrosis (IPN) can reduce the incidence of IPN outbreaks to near zero. While IPN is not found in BC, the dramatic increase in IPN resistance demonstrates the potential of marker assisted selection to impact BC breeding programs seeking to enhance resistance to viruses found in BC waters.

Genomic Selection

Genomic selection expands the efficacy of marker assisted selection by tracing multiple QTLs associated with a production trait i.e. it is based on genome-wide genetic marker data; this data allows the identification of genetic signatures that correlate with performance for a given trait. Breeding stock is then selected based upon whether or not they carry this genetic signature. Genomic selection programs are accelerating the rate of improvement in breeding programs focused on disease resistance and sea louse resistance. It is also a strong tool in programs selecting for carcass traits such as flesh color and fat content. Research indicates that genomic selection can increase the accuracy of breeding candidate selection by 38% over traditional selection methods.

Traceability

Genomic technologies allow a high-resolution genomic fingerprint to be determined for each strain of farmed salmon. These fingerprints support the traceability of farmed fish captured in the wild—thereby allowing companies to monitor and verify potential escape events.

7 Processing Wastewater

BC farmed salmon processing facilities recognize that processing wastewater may contain elevated levels of several parameters that could impact the marine environment. BC facilities have therefore developed and implemented Best Management Practices (BMPs) that focus on pollution prevention rather than remediation. These BMPs focus on improving the recovery of products and by-products, reducing water use where possible, minimizing the contact time between seafood solids and water, and designing conveyance and pumping systems that minimize the breakdown of seafood solids into finer particles and dissolved solids.

In addition to BMPs, BC farmed salmon processing facilities also implement Best Achievable Technologies (BATs) to extensively treat wastewater prior to discharge. BATs reduce wastewater parameters including biological oxygen demand (BOD), total suspended solids (TSS), oil and grease, and fish pathogens. To decrease these parameters prior to discharge, wastewater undergoes:

- Preliminary treatment. Wastewater is passed through a screen to remove all particulates greater than 0.5mm.
- Primary treatment. Technologies—such as Dissolved Air Flotation—are used to reduce BOD, TSS, and oil and grease.

- UV disinfection. To significantly reduce the possibility that processing wastewater could contain pathogens (e.g. bacteria, viruses) which could cause disease in wild stocks, the wastewater is subjected to UV or chlorine disinfection prior to discharge.

8 Land-Based Closed Containment

Salmon farmers are proven experts in environmentally, socially and economically sustainable land-based freshwater farming systems. Billions of young fish have been hatched and raised to the smolt stage on land. In addition to land-based smolt facilities, the salmon farming industry also successfully operates land-based facilities for a variety of broodstock programs.

However, while some small-scale commercial production facilities do exist, land-based facilities for the post-smolt grow-out phase are not yet the best choice. For land-based post-smolt systems to become viable, the industry must overcome challenges including:

- **The real costs of energy, water and land usage**
- **Production challenges e.g. early sexual maturation**
  Within land-based production systems, the incidence of early maturation of Atlantic salmon greatly exceeds that of net pen production systems. On average, 50% of Atlantic salmon reared in land-based post-smolt grow-out systems undergo early maturation. These salmon tend to be smaller in size and often exhibit an inferior flesh quality. Early maturity also compromises the health status of the salmon, making them more susceptible to disease. The economic impact of these factors are reflected in: loss of flesh weight due to gonadal development; direct loss of value due to inferior flesh quality; losses due to mortality and disease.
  The techniques to control early maturation in net pen production systems are ineffective in land-based systems. Research exploring the role of pheromones in early maturation is currently ongoing in a West Virginia land-based facility.
- **Quality-related issues**
  In addition to inferior flesh quality due to early maturation, the flesh of salmon reared in land-based systems exhibits earthy, musty off-flavors that negatively impact consumer acceptance. These off-flavors are caused by geosmin and 2-methylisoborneol—metabolites released by microbes that grow within the land-based systems. To remove these off-flavors, geosmin and 2-methylisoborneol must be purged from the flesh of the fish prior to harvest by moving the fish to tanks equipped with a continual flow-through water system—where they must be deprived of food for ~10-15 days. While this depuration process does reduce the off-flavors, the food deprivation negatively impacts the body weight and composition of the fish (lower body weight; lower lipid content; higher moisture content). In other words, the practices implemented to reduce the economic impact of the off-flavors impose an alternative set of economic impacts.


HH
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03

New Technologies and Practices Being Tested or Implemented


Tile View
Daily Aggregates
Pen 102
13.0
Pen 104
13.0
Pen 106
12.8
Pen 103
Pen 105
Pen 107
Pen 109

New Technologies and Practices Being Tested or Implemented

1 Coastal Net Pens

While the coastal net pen is currently the best production system, its traditionally low production costs are being challenged by losses due to water-borne insults such as changing water chemistry (dissolved oxygen and temperature), increased risk of loss due to harmful algal blooms, increased costs for sea lice mitigation measures, and other costs related to managing the rearing environment.

The industry is therefore further developing and optimizing net pen production systems. A number of groundbreaking tools are being tested that will provide new and profound insights into salmon biology, production efficiency, and cost reduction.

Net Strength and Durability

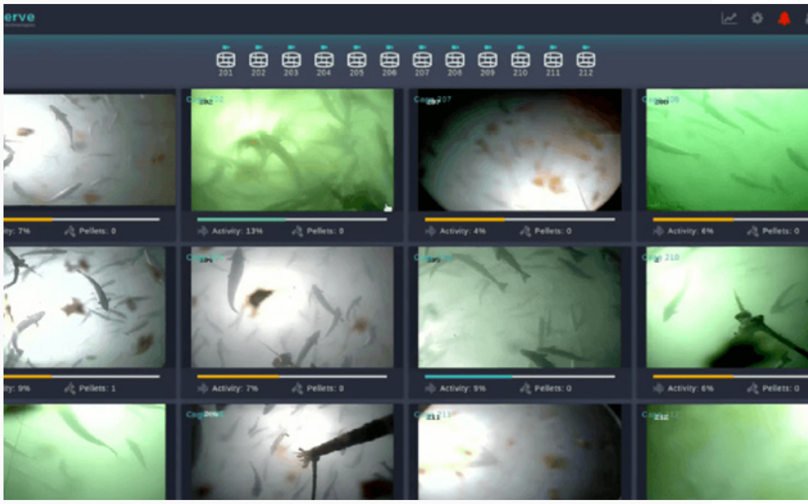
The durability and strength of net pen systems—as well as predator and bird nets—will continue to evolve through the use of netting comprised of innovative combinations of materials e.g. high density polyethylene around a stainless steel core.

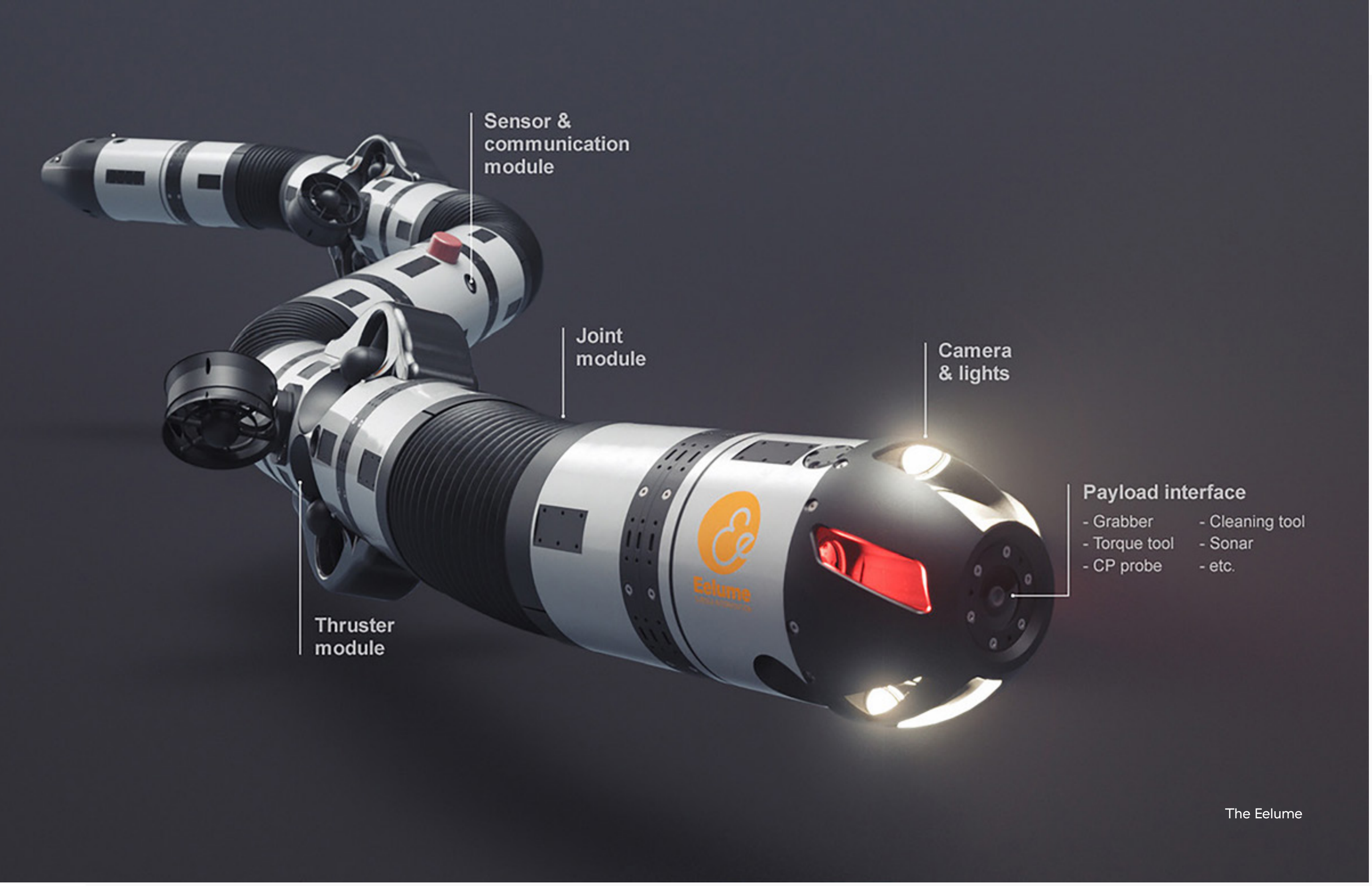
Other new technologies that have been trialed—and have been shown to have both economic and environmental benefits—include:

- Semi rigid nettings with stiffeners
- Copper steel chain link
- Anti predator coatings
- Copper Polymer infused HDPE

Net monitoring

Industry is now testing a machine that has the capacity to target, find and track any anomaly in a net pen. When implemented in underwater drone technology, machine-learning applications can be used to survey the net for the presence of holes and tears, with each net deviation digitally “tagged” to allow swift repair. Similar capabilities can be used for inspections of shackles and moorings, where 3D imaging ability enables the measurement of the condition of net pen components e.g. chain thickness. These features could potentially make diver inspections redundant, providing a safer working environment. They can also provide a safety measure to prevent large escape incidents by facilitating swift repairs.





Net Cleaning Solutions

Industry is working on technoloiges to radically improve net maintenance procedures. For example, the development of novel new compounds is creating the potential to manufacture nets with inherent antifouling capabilities (e.g. copper polymer infused HDPE). These novel net coatings could extend the interval between cleanings to 6 months—even during the challenging summer period, when high biological activity causes rapid fouling of the nets.

Industry is also working to test solutions for automated, continuous and gentle net cleaning using net-cleaning robots. Some new robots run on thrusters—rather than wheels—to minimize the risk of damaging the net while in operation. Other robots are designed to remain within the pen to clean the nets on a daily basis—using brushes rather than pressurized water to lessen the risk of damage to the net. These robots also inspect the net during the cleaning process—and map any faults that may be developing. In addition, the use of thruster technology in some ROV net cleaners allows for the use of these systems in any orientation on the net surface (inside and outside of both containment and predator nets).

IMR Vehicles

Inspection, Maintenance & Repair (IMR) vehicles—e.g. the Eelume—represent a new class of subsea technology with direct applications in salmon aquaculture. Eelume IMR vehicles are self- propelled robotic arms whose slender and flexible 'eel-like' body can transit over long distances and carry out IMR in confined spaces not accessible by conventional underwater vehicles. Sensors and tools can be mounted anywhere along the flexible body. For example, a dual-arm configuration can be achieved by mounting tooling in each end and forming the vehicle body into a U-shape. One end of the arm can grab hold to fixate the vehicle, while the other end can carry out inspection and intervention tasks. One end of the arm can also provide a perspective camera view of a tool operation carried out at the other end. These vehicles are engineered to remain permanently under water, where they can be mobilized 24/7 regardless of weather conditions. continuous IMR capability near the subsea installations (without the need for surface vessels) will facilitate greener, safer and less costly subsea operations.

Feeding Systems

Industry is currently developing and testing cameras that will radically change underwater monitoring. The new cameras will provide digital images that will allow a machine to be trained to recognize almost everything in the image. This is done by building machine-learning models that respond to a certain range of criteria within an image e.g. the presence or absence of a feed pellet or fish feeding behavior. The detection of one or many feed pellets—together with fish behavior and other related parameters—can then be translated into a range of actions. As an extension of basic machine-learning models, artificial intelligence (AI) and Deep Learning can be used to decipher exceedingly complex relationships not easily modeled or manually controlled e.g. salmon behavior in a net pen. AI software can then work out an optimal course of action (e.g. how to optimally feed 200,000 salmon) with minimal human interference—learning from its past experiences every time.

The development and implementation of innovative camera solutions, coupled with machine- learning capabilities, will provide new and transformative insights e.g. it will allow measurement of growth-related parameters of more than 10,000 fish everyday. With a precise tool for real-time biomass surveillance, the industry will be able to directly compare ‘feed fed’ with ‘weight gained’. This will be used to optimize feeding rates to achieve higher growth rates and better feed conversion—thereby reducing even further the impact of net pens on benthic quality. In terms of feed utilization, the new technologies will facilitate the acquisition of new knowledge on periodical feed conversion rates.

Industry is also developing subsea feeder systems that feed fish at a depth of approximately 7m. Due to the reduced presence of sea lice at this depth, fish fed by this system exhibit lower sea lice counts—together with improved growth rates and efficiencies.

Other feeder-related innovations include the development of water borne feeder systems that minimize the ecological footprint by reducing noise pollution, micro-plastics, and pellet damage.

2 Feeds and Feed Conversion Efficiency

Feed companies will continue to research various sources of raw materials—such as seafood processing streams, vegetable oils, single-cell proteins, and micro-algaes. This approach—together with improved utilization of fish oils and proteins (e.g. efficient use of by- products)—will allow aquafeed companies to further decrease dependencies on wild fish resources. These new ingredients will have a smaller environmental footprint than most of the currently used ingredients due to less land use, lower emissions, and higher resource efficiency during production.

Feed research is also investigating the potential of producing the omega-3 fats EPA and DHA from phototrophic algae by "trapping" carbon emissions from oil refineries, thereby utilizing carbon dioxide as a resource. Oil produced from this source could significantly reduce aquaculture's arable land requirement.

A feed has also been developed that contains no fishmeal or fish oil. It relies upon omega-3 from Canola plants to meet the omega-3 requirements.

Farmed salmon breeding programs are developing strains of salmon capable of even better feed utilization and growth performance in the future.

3 Sea Lice Innovations

Prevention

In the near future, coastal net pens will be equipped with sophisticated systems that effectively reduce the likelihood of sea lice infestations, thereby further contributing to the wellbeing of both farmed and wild salmon populations.

i. **Anti-Sea Lice/Escape Proof Shields and Skirts**
Industry continues to develop new anti-sea lice shields. These shields consist of a permeable fabric that fully encases the pen to a depth of 6m. The shields provide a barrier against sea lice (most commonly found in the first few meters below the water's surface)—yet their permeability allows water and oxygen to move freely into fish pens. Recent tests have shown that these shields are capable of keeping sea lice levels below threshold—thereby allowing the fish to exhibit strong growth and biological performance. Prototypes of a fish production system designed to prevent both fish escapes and sea lice infestations are already being tested. These prototypes have a steel lice skirt, making them more resistant to deformation and mechanical impacts from the surrounding environment than conventional lice skirts. The prototypes are equipped with water current generators inside the net that pull deeper water into the net and increase the water exchange rate. Water drawn from a deeper origin also provides more oxygen to the salmon than water passively transported through the net. Additionally, the deep-water supply ensures less variation in water temperature in the net pen—while the use of a water current generator creates a current that the fish must swim against, thereby encouraging physical exercise that contributes to good fish health.

ii. **HD Cameras and Machine Learning**
Industry is developing and testing cameras that will radically change underwater monitoring. The new cameras will provide high-quality images that allow a machine to be trained to recognize and count sea lice. The switch to automatic sea lice counting will eliminate the need for laborious manual sea lice counting. Machine-based sea lice counting based on high resolution imagery (rather than manual inspection) will allow sampling of 10,000 fish or more per day. This high sampling rate will inevitably boost confidence in the estimated figures for the prevalence of sea lice; documentation of prevalence trends will enable treatment to be applied at precisely the correct time. Continuous information about sea lice numbers will also provide a continuous assessment of the efficiency of sea lice management and treatment. In addition, real-time surveillance will reveal information about the circumstances during which sea lice infestation occurs--and lead to new innovations in management and treatment. More precise data on sea lice numbers will also facilitate robust forecasting of the sea lice population size—and thereby guide decisions and actions for optimal fish welfare and performance. Knowing the sea lice situation weeks in advance, through forecasting and predictive tools, should result in fewer treatments over a full production cycle. Fewer treatments will lead to improved fish welfare, increased growth and significant cost savings. The industry is also developing software applications capable of identifying individual fish via

dot pattern analysis. This will allow sea lice management at the individual fish level. A sensor chamber in the application will recognize each individual fish and record its sea lice numbers. Individuals with above threshold sea lice numbers can then be removed for individual treatment. Since lice can be unevenly distributed among fish, this will allow customized sea lice treatment. By only treating infested fish, the amount of treatment deployed will be reduced.

iii. **Sea Lice & Big Data**
Industry is testing new platforms to track, compare, and improve treatment strategies against sea lice. These platforms are based upon treatment efficacy data across the entire industry; this database allows the platform to determine the best treatment to use under a given set of conditions (e.g. environmental, fish health etc.). The platforms will also allow the treatment efficacy at a specific farm to be compared with the industry average.

iv. **Sea Lice Resistance Breeding Program**
Scientists have identified that resistance to sea lice infestation in farmed salmon is significantly influenced by genetics; fish with a higher resistance are genetically different from less resistant fish. The discovery of genetic indicators of resistance has allowed the establishment of selective breeding programs to create salmon strains highly resistant to sea lice infestation. Research suggests that it may take as few as 10 generations of selective breeding to produce fish that naturally resist infection and, therefore, seldom require treatment.

v. **Sea Lice Vaccines**
The global salmon farming industry has invested heavily in the development of sea lice vaccines. In 2018, Chilean researchers announced the development of a recombinant vaccine against the Chilean sea louse; in laboratory tests, the vaccine was effective in reducing infestation volumes by 97%. Reverse or recombinant vaccination is a relatively new technology in which the antigens of potential vaccines can be found significantly faster than by traditional methods. This new technology may accelerate the development of vaccines effective against sea lice species present in BC.

vi. **Next Gen Sea Lice Traps**
Next generation sea lice traps are becoming increasingly effective in attracting and containing sea lice before they enter the net-pen. These traps take advantage of the sea lice's instincts by amplifying attractors, lights, and odorants—thereby making the trap more attractive than the salmon.

Treatment

i. **Ultrasonic Technologies**
Ultrasound technologies are being actively investigated as a means to prevent sea lice infestations in net pens. Tests results show that 60% of attached sea lice can be removed by using ultrasound technology in combination with fish and water quality monitoring. By varying the ultrasonic sound wave frequency used, sea lice will be unable to develop resistance to the ultrasonic control method. Moreover, due to the low power and frequencies used, ultrasound does not negatively affect the farmed salmon, wild fish, or marine mammals.

ii. **Underwater Resonators**
Underwater resonators are another new technology being developed to prevent sea lice infestations. The resonators are capable of producing 40,000 vibrations/sec; these vibrations create millions of small water bubbles that then 'nano-cavitate' to create billions of microscopic water jets. The water jets kill early life stages of sea lice, making it impossible for the lice to reproduce and grow. Testing indicates that this technology is also effective against algae—and therefore may have applications in protecting salmon against algal blooms.

iii. **Cleaner Fish**
Globally, there are several species of fish, including ballan wrasse and lumpfish, that naturally eat sea lice. When these fish are introduced to salmon pens, they eat sea lice off the salmon. In BC, laboratory testing of two local species of Pacific perch – kelp perch and pile perch – suggest they may have significant potential as cleaner fish.

iv. **Wellboat Technology**
With improved sea lice filters, new wellboats are being outfitted to capture 100% of sea lice treated in the holds of the vessel. These sea lice are then collected and removed from the production environment.

v. **CleanTreat Technology**
CleanTreat is a new purification system that has the potential to cleanse the treatment water after delousing in well boats, ensuring that all medicated particles are removed from the water before it is released into the environment. This technology also prevents treatment-resistant lice from re-entering the environment—thereby preventing the spread of resistance.

4 Fish Health

Vaccine Development

Vaccine research is currently underway for two bacterial diseases endemic to BC: Mouthrot and Salmonid rickettsial septicaemia. Sea lice vaccine R&D is also underway.

Detection

The industry is developing and testing cameras that will radically change underwater monitoring.The new cameras will provide high-quality images that will allow a machine to be trained to track any anomaly in a net pen. Integration of these cameras into machine-learning application will allow the external characteristics of individual salmon to be traced and measured; as a result, each individual salmon will be distinguishable based on subtle differences in their morphometrics and skin pigment pattern. This may eventually allow for an individual fish health and welfare approach to management. These systems will provide insights into when and why morphological changes occur—and will eventually facilitate the implementation of an ongoing assessment of fish health and welfare based on parameters such as outer condition, prevalence of biological anomalies, and fish behavior.

These innovative camera/machine-learning solutions will support sampling rates of 10,000 fish or more per day. This will allow parameters reflecting fish growth & development and fish behavior to be measured in detail over time. This detailed data will serve as an early-warning system, by identifying abnormal growth patterns indicative of early-stage infections.

Mortality Collection and Removal

Remotely operated mortality collectors (ROMoCs) are being developed to meet the future needs of large-scale offshore salmon farms. The ROMoC system relies on sophisticated control algorithms that allow the ROMoC vehicle to cover the complete pen surface area in 24 hours. Rapid removal of mortalities will help reduce the risk of disease transmission, thereby supporting the maintenance of a healthy salmon farm environment.

5 Benthic Quality

eDNA Metabarcoding

The BC industry will continue to implement all innovations that allow improved monitoring and protection of benthic habitat and organisms. The industry is currently validating environmental DNA (eDNA) metabarcoding as a powerful new tool to complement existing monitoring technologies. The eDNA test uses DNA isolated from water or sediment samples to determine the composition and diversity of the benthic species community living in the proximity to salmon farms. In addition to being rapid and cost-effective, eDNA-based benthic monitoring is more sensitive, more accurate, and more reliable than existing monitoring methods.

Feed Monitoring

The development and implementation of innovative camera solutions, coupled with machine-learning capabilities, will provide new and transformative insights e.g. it will allow measurement of growth-related parameters of more than 10,000 fish everyday. With a precise tool for real-time biomass surveillance, the industry will be able to directly compare 'feed fed' with 'weight gained'. This will be used to optimize feeding rates—thereby further reducing the impact of net pens on benthic quality.

Open Ocean Farming

The industry is currently developing net pen technologies that will allow salmon farming to take place in more exposed coastal areas. Higher velocity water currents in exposed areas will facilitate a further reduction in the already minimal impact on benthic quality beneath salmon farms.

6 Genetics and Breeding

The application of future genetic technologies in salmon breeding programs will be subject to public and regulatory acceptance.

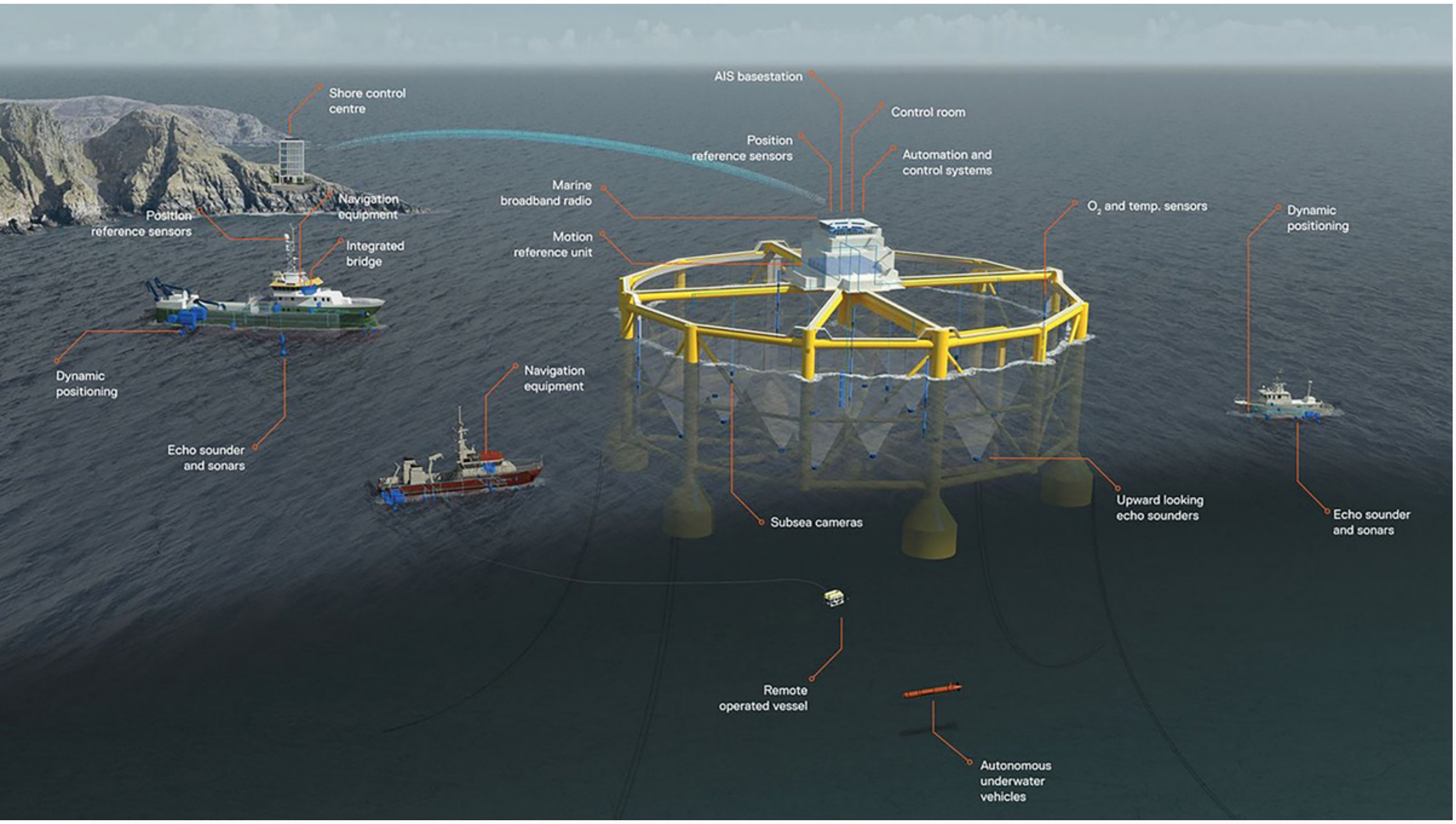
Genome editing

Genome editing technologies involve the use of "gene scissors" to precisely cut the genome at a specific location—leading to small-scale targeted changes in the DNA sequence. For example, genome editing has been used to 'knock out' a gene essential for germ cell development in salmon—thereby rendering the experimental salmon sterile. While still in the experimental stages, the validation and approval of this approach could allow net pens to be stocked with sterile fish—thereby mitigating the potential problems created by escaped farmed Pacific salmon mating with wild salmon.

Genomic editing also holds significant potential as a means of improving disease resistance e.g. editing of a gene in pigs resulted in complete resistance to the porcine reproductive and respiratory syndrome virus. The recent discovery of QTLs affecting sea lice resistance may lead to the development of genomic editing strategies to enhance sea lice resistance.

7 Processing Wastewater

BC farmed salmon processors continue to identify and implement new technologies that will ensure that discharged wastewater will not negatively impact the marine environment. For example, the implementation of fluidized bed reactors will allow the removal of 80-90% of the organics within wastewater.



Shore control centre
AIS basestation
Control room
Position reference sensors
Automation and control systems
Marine broadband radio
Navigation equipment
Position reference sensors
Integrated bridge
Motion reference unit
O$_2$ and temp. sensors
Dynamic positioning
Dynamic positioning
Navigation equipment
Echo sounder and sonars
Subsea cameras
Upward looking echo sounders
Echo sounder and sonars
Remote operated vessel
Autonomous underwater vehicles

Ocean Farm 1

8 Open Ocean Farming

Innovative new production system concepts are allowing the industry to move even further beyond the coast—and into the open ocean. *Ocean Farm I*—a massive semi-submersible production system—has already undergone a one-year trial in the open ocean three miles off the coast of Norway. This $300 million project is the world's first deep sea aquaculture endeavour. The system includes a 61m high x 91m diameter pen made from a series of mesh-wire frames and nets that are designed to disperse wastes better than conventional farms in sheltered coastal waters; as a result of this innovative design, the system is able to support 1.5 million salmon. The salmon are fed via sixteen movable, submerged valves that disperse food at set times—and allow fish to live at depths of up to 55m; this depth is well below the water depths inhabited by sea lice—and therefore reduces the need for sea lice prevention and treatment measures. Oxygen sensors and HD cameras monitor a wide range of growth, feeding, and health parameters and behaviors. Initial results from the one-year trial indicate that the fish reared in this system exhibit strong growth and low mortality rates.

An even larger open ocean prototype is currently in development: *Smart Fish Farm* will be 160m in diameter—and hold 3 million fish.

Submersible production systems for open ocean farming are also currently in the developmental stage. The capacity to operate the production system underwater during storms will allow farming to take place under even more extreme conditions.

Subsea production systems are also being developed. These permanently submerged systems may be designed to form large offshore farm clusters. The design of submersible and subsea production systems may give industry the flexibility to move systems to new locations during the production cycle to secure optimal farming conditions.

9 Floating Semi-Closed Containment Technologies

The industry is currently developing floating, semi-closed production systems (S-CC systems). These S-CC systems will make use of a large but controllable water intake, solid tank walls, and optimized internal water hydraulics—and will have the potential to extract particles from the discharge water. Moreover, their water intake can be filtered and then treated with UV light to prevent lice, algae, bacteria, and viruses from entering the production environment. These systems will also offer a high degree of flexibility in terms of geographical placement. Early testing has shown that these systems can support excellent fish health, growth and post-smolt quality. Research projects related to water quality, microbiology, fish health and water hydraulics in these systems are currently ongoing.

10 Floating Closed Containment Technologies

State–of–the–art floating closed containment (CC) systems have been designed to reduce losses in sea production, protect the environment against undesired impacts, increase productivity, and at the same time reduce production costs. The walls of these systems are impenetrable to both sea lice and pathogens—and escape–proof for the farmed salmon. Like S–CC systems, their water intake can be filtered and then treated with UV light to prevent lice, algae, bacteria, and viruses from entering the production environment. The system also has the capacity to grind and spread waste sludge so that there is no build–up beneath the farm site. Alternatively, the system can collect and filter solid waste discharge—so that it can be transported to land for further processing.

Ocean–based S–CC and CC farms will therefore prevent sea lice infestations, virus transfer from the wild, and escapes. They will also avoid the massive energy requirements of land–based CC facilities.

11 Land–based closed containment systems

Closed Containment Grow–Out Systems

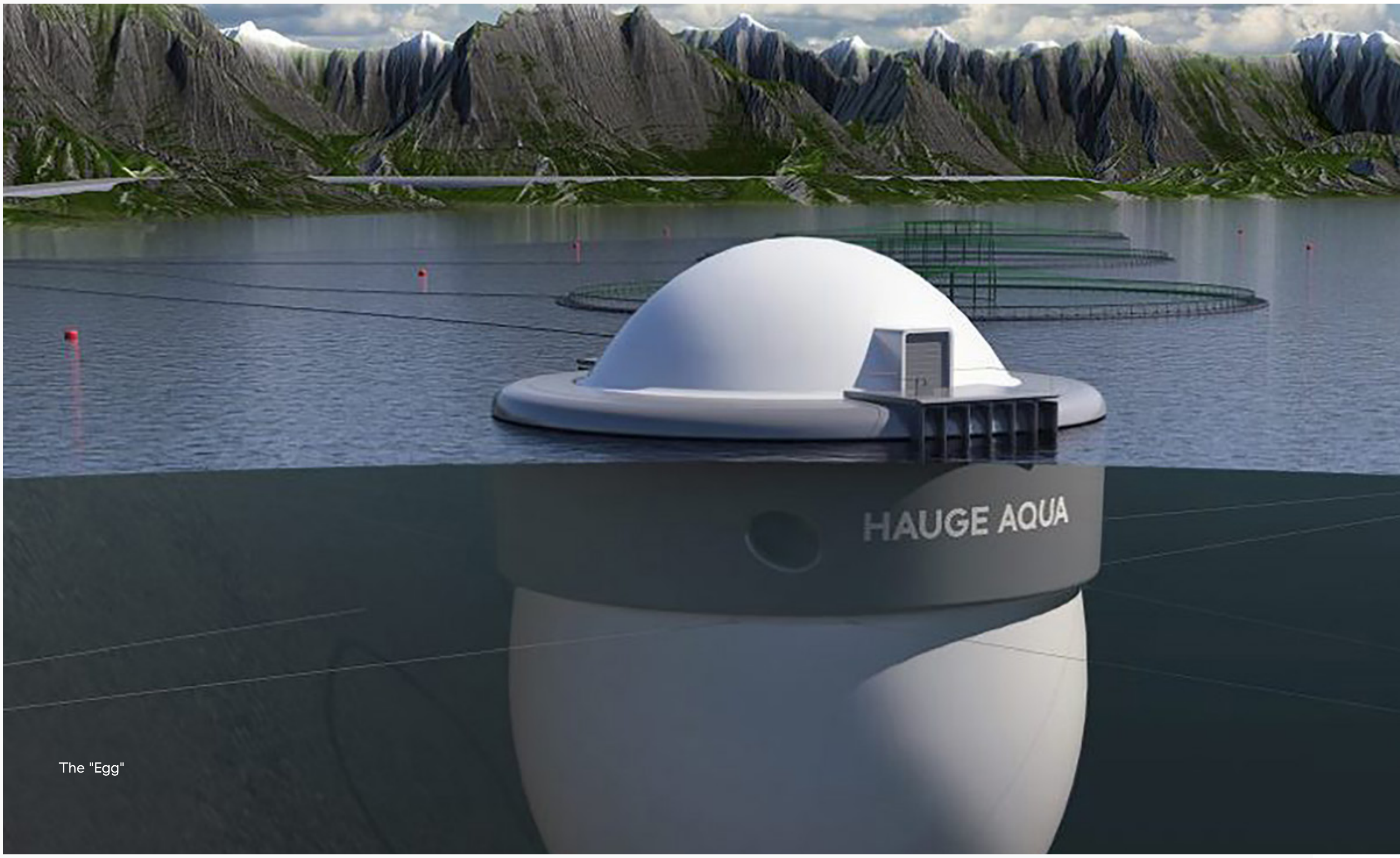
While industry will continue to invest significantly in the development of land–based CC grow–out facilities, capital investments, higher operating costs, larger environmental footprint, and inferior quality flesh will challenge the viability of these systems for the foreseeable future.

Post–Smolt Programs

Post–smolt programs focus on rearing smolts (juveniles) to a larger, more robust size within land– based recirculating aquaculture systems (RAS) before transferring them to ocean–based production systems. The growth and survival rates of larger smolts surpass those of traditional sizes when grown in the new open ocean, floating S–CC, and floating CC grow–out systems.

Post–smolt programs therefore allow the industry to reap the clear benefits of ocean–based grow– out—yet significantly lower the length of time that the salmon spend in the ocean, thus effectively reducing production and environmental challenges related to water chemistry, sea lice infestation, and potential interactions with wild salmon stocks.

Post–smolt programs therefore represent a hybrid production strategy that integrates the environmental, social, and economic benefits of land–based smolt production with those of ocean– based grow–out production.



The "Egg"

BC SALMON FARMERS ASSOCIATION

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