No 1 2025
www.LandbasedAQ.com

LandbasedAQ

Stuck in transition or poised for a breakthrough?

OVERVIEW – INSIGHT – EXPERTISE

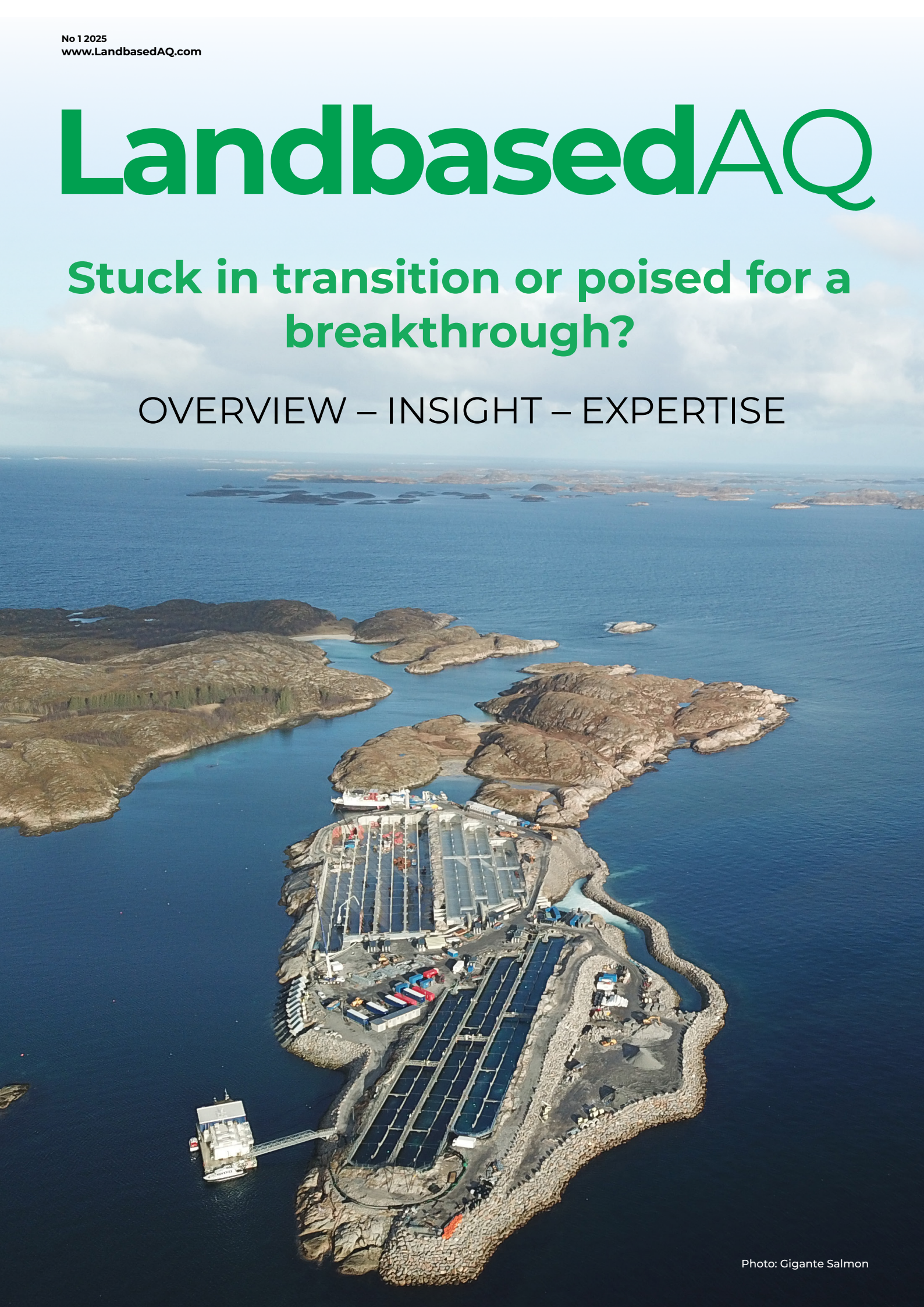


Photo: Gigante Salmon

Revolutionizing particle removal:

The power of disc filters

Each disc consists of several filter cassettes of a well-proven design that also simplifies maintenance.

Drum filters have long been the go-to solution for particle removal in Recirculating Aquaculture Systems (RAS). But as the industry pushes toward greater sustainability and efficiency, a new player is gaining ground - enter the disc filter.

In the world of land-based aquaculture, water quality isn't just important – it's everything. Since 2012, NP Innovation has focused on designing advanced filtration and CO_2 degassing systems tailored to RAS, helping fish farms around the world maintain the optimal conditions for healthy growth and long-term sustainability.

A smarter filtration strategy

When NP Innovation set out to develop disc filters for fish farming, the goal was simple: maximize filtration capacity within a compact footprint. But, during real-world side-by-side testing between the disc and drum filter, something unexpected emerged — the disc filter didn't just match performance. It outperformed.

"In aquaculture, fast removal of solids is key," says Patrik Strandberg, Sales Manager at NP Innovation.

Patrik Strandberg, Sales Manager at NP Innovation.

"If waste feed and feces aren't quickly removed, they break down into fine particles that are much harder to filter. Not only did the disc filter handle larger volumes of water in a smaller space – it also captured and eliminated large particles much faster than the traditional drum filters."

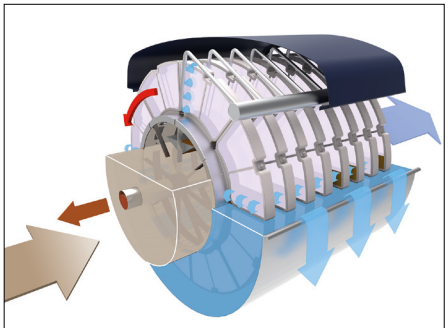
Higher flow, less space – better result

Disc filters offer three times the filtration area of traditional drum filters, all within a smaller footprint. Their rotating design allows for faster, more effective removal of large particles, which means clearer water, healthier fish and greater operational efficiency, making them a game-changer for modern RAS systems.

"As the aquaculture industry faces increasing pressure to balance productivity with sustainability, we are proud that NP Innovation continues to refine solutions to meet the demands." says Patrik Strandberg.

Both drum and disc filters have their strengths, but for fish farms aiming to scale sustainably, disc filters are proving to be the smarter long-term investment. With higher flow rates, optimized filtration space, and superior water quality preservation, disc filters are helping shape the next generation of RAS technology.

The result? A more sustainable future for aquaculture.



The NP Discfilter is a mechanical self-cleaning filter for removal of suspended solids, specially designed for aquaculture applications.

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UK: RAS FOCUS IS ON SMOLTS, NOT FOOD FISH

There are several large landbased facilities in the UK but none that produce harvestsize salmon.

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Pål Mugaas Jensen

Chief editor
LandbasedAQ

Land-based salmon farming – stuck in transition or poised for a breakthrough?

Land-based salmon farming has long been heralded as a sustainable alternative to traditional net pen farming. Using recirculating aquaculture systems (RAS), producers can grow fish with minimal environmental impact and greater biosecurity. But while the vision is clear, progress has been uneven across the globe.

Norway: Slow and steady growth

Norway is leading in real-world implementation, with a total of 444,000 tonnes MTB in commercial permits as of March 2024. Yet actual harvests remain modest. In 2024, only around 5,000 tonnes of land-based salmon were harvested, the vast majority from Salmon Evolution.

Still, signs of momentum are clear. Salmon Evolution is expanding capacity to 18,000 tonnes, while companies like Gigante Salmon and Andfjord Salmon are preparing for significant increases in production. These projects use hybrid or flow-through systems rather than full RAS, focusing on cost-efficiency and system simplicity.

Norway's pipeline is robust. New entrants such as Årdal Aqua, Arctic Seafarm and Hima Seafood are building large facilities, with the latter aiming to scale globally with RAS trout farms in North America. Even with regulatory uncertainty, investor interest and innovation remain strong.

UK: Focusing on smolts

In the UK, land-based facilities are focused almost exclusively on producing larger, healthier smolts for marine farming in Scotland. Companies like Mowi, Bakkafrost Scotland and Scottish Sea Farms use RAS to reduce time at sea and improve fish robustness.

While plans exist for market-sized salmon production—like the 5,000-tonne Aquacultured Seafood project in North Lincolnshire—none have yet materialized. Legal challenges and limited political support have kept full grow-out ambitions on hold.

USA: The American dream on hold

The U.S. once seemed poised to lead the land-based revolution, with plans for hundreds of thousands of tonnes in RAS projects. But many ventures have stalled. AquaBounty has shut down operations, Nordic Aquafarms abandoned its Maine project, and even Atlantic Sapphire has downsized expectations after years of technical and financial issues.

A few projects are moving forward. Great Northern Salmon is building a 7,500-tonne facility in Maine, and Pure Salmon aims to open its Virginia plant by 2028. But most initiatives are delayed or scaled back, often struggling with permitting and funding.

Elsewhere in the world

Globally, plans for land-based production exceed 1.4 million tonnes, though definitions vary and many projects remain speculative. Asia is moving quickly, with several operations already harvesting fish. Salmon Evolution is also pursuing a long-term expansion to South Korea.

Challenges remain

RAS is not for the faint-hearted. It demands high capital investment, skilled operations, and tight biological control. Profitability is still elusive for most, and new regulations—such as Norway's pending framework for land-based farms—could shift the landscape further.

Outlook

Land-based salmon farming is no longer a novelty. It has proven benefits: reduced disease, no sea lice, and the ability to bring production closer to market. But success requires flawless execution and long-term vision.

For now, the pioneers are forging ahead—sometimes slowly, often with setbacks—but always pushing the boundaries of what's possible. Whether the sector can scale sustainably remains to be seen, but one thing is certain: it is no longer just a dream.

Landbased

RAS focus is on smolts, not food fish

There are several large land-based facilities in the UK but none that produce harvest-size salmon

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If you're looking to the United Kingdom for an example of the kind of food fish recirculating aquaculture system (RAS) facility being developed in Norway and Iceland, you'll be disappointed.

There is only one commercial-scale grow-out salmon RAS facility planned – at New Clee, between Grimsby and Cleethorpes in North Lincolnshire, England – and that is currently stalled by a legal challenge.

In February, the campaign group Animal Equality UK forced a judicial review of the decision to grant planning permission for the 5,000-tonnes-per-year facility proposed by Aquacultured Seafood.

The NGO claimed North East Lincolnshire Council's planning committee was wrongly advised that animal welfare could not be considered as a material factor in land use decisions.

A judgement on whether permission should be rescinded is expected soon.

Despite the lack of food fish RAS in the UK, land-based facilities are increasingly important for the production of healthier, larger, and more robust salmon smolts for marine pens in Scotland. The challenges brought by warmer sea temperatures mean that fish farmers want to keep fish at sea for a shorter time, and that requires growing them to a larger size before they are stocked in marine sites.

A move towards "high energy" sites further offshore, where fish must

Fry tanks at Mowi's Inchmore RAS hatchery, which was opened in 2018. Photo: FFE

Bakkafrost Scotland's hatchery and post-smolt facility at Applecross, Wester Ross, in the Scottish Highlands. When completed, the RAS facility – which uses technology supplied by Norwegian company Nofitech - will have an annual capacity of 10 million post-smolts with an average weight of 500g.
Photo: Bakkafrost Scotland

withstand stronger currents, also requires bigger post-smolts.

Mowi, Scotland's biggest fish farmer, produces smolts at two large RAS hatcheries at Lochailort (opened 2013) and Inchmore (opened 2018). It is proud of its hatcheries, and last month opened a visitor gallery at Inchmore.

The company is also building a land-based broodstock facility at Ardessie, Wester Ross, that is designed to allow photoperiod and water temperature control using RAS technology to advance or delay the spawning of the fish.

The facility, due to be completed this year, will feature three different egg incubation RAS units with each one held at a different temperature to extend the period of egg supply. This will ensure that eggs can be stocked throughout the year to Lochailort and Inchmore.

But Mowi isn't investing in a land-based post-smolt facility. Instead, it has opted to grow its smolts on in freshwater and brackish water lochs before transferring them to sea as large post-smolts.

Another of Scotland's 'Big Four' salmon farmers, Cooke Scotland, has one RAS hatchery at Furnace in Argyll, and traditional flow-through hatcheries in Cumbria, Clackmannanshire and the Scottish Highlands. It does not produce very large post-smolts for its marine pens at its sites in Orkney and Shetland.

The other big producers, Bakkafrost Scotland and Scottish Sea Farms, favour the control offered by RAS facilities to grow bigger smolts.

Scottish Sea Farms' Barcaldine hatchery currently produces smolts of 150g or more, a big change from just three or four years ago, when the average size of smolts put to sea by all producers in Scotland was generally below 100g.

But the company most invested in RAS for large smolts – financially and strategically – is Bakkafrost Scotland, owned by the Faroese Bakkafrost Group. It is well on the way to completing a RAS hatchery and post-smolt facility at Applecross in Wester Ross that will eventually produce 10 million post-smolts per year with an average weight of 500 grams.

In November last year, the first large batch of 200g smolts produced at Applecross was transferred to sea and the site's phase 5 module began operating, increasing capacity by 50% to around 3,500 tonnes of smolts. This capacity is being utilised to make Bakkafrost self-sufficient with around 14 million smolts of 250g. Further capacity will be added when the phase 6 and 7 modules are completed.

The smolt facility is in fact two identical but separate units. The facility uses 100% renewable power and is also the first smolt facility in the UK to gain a licence for pyrolysis of sludge to produce biochar, a useful product for agriculture or forestry. Biochar can store large amounts of carbon in the soil, and improve soil structure, water retention, and nutrient availability, leading to healthier plants and soils.

Bakkafrost Scotland's Faroese parent company is a strong advocate of using RAS to grow post-smolts and is also working towards a target of stocking smolts at 500g. The Faroes operation stocked 17.7 million fish with an average weight of 410g last year and expects to stock 18.5 million post-smolts with an average weight of 430g in 2025.

RAS developers have yet to fulfil their American dream

Entrepreneurs remain positive but progress has been slow

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All is not lost: Bredna Chandler, CEO of Nordic Aquaculture's US subsidiary updates a public meeting about progress towards a yellowtail kingfish RAS on the Samoa Peninsula in northern California. The company has abandoned plans for a RAS in Maine after a court ruling that blocked access to Penobscot Bay. Photo: Andrew Goff, Lost Coast Outpost.

There was a time not too long ago when the United States was seen as the place where land-based salmon farming would really take off, propelled by a raft of projects that were mostly originated by Norwegian companies.

Atlantic Sapphire led the way in terms of ambition, promising to produce 200,000 tonnes of salmon per year by 2030 at its facility south of Miami in Florida, while further north Nordic Aquafarms had plans for 33,000-tonne RAS salmon facilities in Belfast, Maine, and on the Samoa peninsula in Humboldt County, northern California.

Meanwhile, US company AquaBounty had plans to build five 10,000-tonne RAS facilities in North America to produce its AquAdvantage salmon, which inherit a genetic modification that makes them grow more quickly.

Another US company, Whole Oceans, planned a 20,000-tonne salmon RAS in Bucksport, Maine, and Wyoming-based Aquabanq proposed a RAS salmon facility at Millinocket in the north of the same state.

Diggers and bulldozers clear sludge from the floor of a drained lagoon where Great Northern Salmon will build a RAS salmon farm with a capacity of around 7,500 tonnes HOG. Photo: GNS

In Maryland, AquaCon – with a team that includes several experienced Norwegian salmon industry players – envisaged producing a total of 50,000 tonnes annually at different sites on a peninsula east of Baltimore, and Pure Salmon – which plans a network of RAS facilities around the world - chose a site in Virginia. A fish farm was also planned in Reno, Nevada by another Norwegian company, West Coast Salmon.

Fast forward to 2025, and little progress has been made. Some projects appear stalled, and others have been scrapped. One of the casualties is AquaBounty, which ran out of money and credit after years of losses. Costs had spiralled for the new farm it was building in Pioneer, Ohio, and AquaBounty began selling off its assets to pay its bills and debts.

The company ceased production of AquAdvantage salmon at its 1,200-tonne-capacity RAS facility in Albany, Indiana, last year and later sold the farm to Superior Fresh, a small-scale RAS salmon producer based in Wisconsin, for a bargain basement price of $9.8 million.

It wasn't enough. In December last year AquaBounty announced plans to cease its other farming operations at hatcheries on Prince Edward Island (PEI) in Canda, and in February it auctioned off equipment it had bought for the Pioneer site, netting $2.2m. The following month it sold its PEI operation and intellectual property to conventional open net pen farmer Cooke Aquaculture, earning a further $1.9m. Cooke stressed that it made the purchase to acquire the PEI hatcheries and had no plans to farm or sell any genetically engineered seafood products.

AquaBounty's interim chief executive David Frank said the money raised has provided the company with the liquidity to continue to pursue strategic alternatives for its Ohio farm project, which is partially complete, but didn't elaborate.

Norwegian-owned Nordic Aquafarms is another company that has suffered a reverse in fortunes. It gave up its ambitions for Belfast after opponents won a multi-year legal battle over who owned a strip of intertidal land connecting Nordic's site to Penobscot Bay. The ruling cut Nordic's site off from its source of intake water and discharge area.

"This is a sad day for Maine's economy and outlook for aquaculture or any significant investment in the state," said Brenda Chandler, chief executive of Nordic's US operations when the company announced its decision in January this year.

"While a few may view this as a victory, we argue that this is a significant loss overall - not just for Nordic Aquafarms but for the community. The expanded tax base for the City of Belfast was significant; new jobs for the area were significant; and Maine's leadership in aquaculture-born solutions was also significant."

Nordic is still planning to build a RAS facility in California but has downsized its plans to around 10,000 tonnes and has switched species from salmon to yellow kingfish (Seriola lalandi).

In October last year, Chandler told a public meeting organised by the local chamber of commerce that the company had all but wrapped up the permitting process and was shifting its focus to clean-up of its brownfield site at the Harbor District-owned Redwood Marine Terminal II property.

She added that if everything goes according to plan, Nordic will begin construction in late 2026 or early 2027, with commissioning carrying on until 2028.

Atlantic Sapphire has survived a string of technical setbacks, but it has required millions of dollars of investment to stay afloat. It has a new chief executive – former Cermaq Chile boss Pedro Courard – who has warned that the company must spend millions more on a chiller plant and completion of phase 2 of its Bluehouse facility if it is to be viable.

Phase 2 will take annual production capacity to 25,000 tonnes. Phase 1 has a nominal capacity of 10,000 tonnes, but this has never been reached. Last year the company harvested just 4,400 gutted weight tonnes, due in part to a decision to harvest salmon at just 1.4kg because the facility had too many fish in the tanks for the biofilters to support.

The strategy is paying off, with fish now being harvested at 4kg (3.2kg head on, gutted) but it has also delayed the company reaching break-even, which won't happen this year, Courard has said. The plans for RAS in Reno, Nevada, and in Bucksport, Maine, have so far failed to materialise, while Aquabanq has swapped location and species, and has been focused on building a shrimp RAS in Hampshire County, West Virginia.

Nonetheless, it looks as if Millinocket will become the first – and perhaps only -town in Maine to get a RAS salmon farm, courtesy of Great Northern Salmon (GNS), a company founded by former Nordic Aquaculture executives and husband-and-wife team Erik Heim and Marianne Naess.

The facility will have a capacity of around 7,500 tonnes HOG and is being built on the site of a lagoon associated with a former paper mill. Work to drain the lagoon and remove sludge started in September last year and restarted in April after a pause for winter.

GNS is raising $20m for the remediation work and has secured approximately 60%, Naess told Fish Farming Expert. "We are raising the remaining now in addition to capital to finish detailed design, construction planning and estimation." The lagoon covers 27 acres, and the total site area is 45 acres.

In Virginia, work is progressing on Pure Salmon's facility on a site that straddles the border of Tazewell and Russell counties, although construction of an access road due to be built by Russell County has been delayed by engineering issues, reports Cardinal News.

Tenders for upgrades to water supply and sewerage for the site, due to be paid for by Tazewell County, are also higher than anticipated, which has delayed the work.

Despite the delays, Pure Salmon told Cardinal News in December that the project remained on track to open in mid-2028.

In Maryland, AquaCon abandoned its plan to build in the Federalsburg area after encountering some local opposition and is now looking to build a $600m RAS facility at a new site around 100 miles to the north at a former US Navy training base at Port Deposit on the Susquehanna River.

The development site is state-owned and has existing power, water and discharge infrastructure. AquaCon recently secured a water discharge licence from the Maryland Department of Environment and only needs standard building permits – and not least financing – to begin work on the RAS facility.

AquaCon plans to start construction by the end of 2025, with eggs in place by the end of 2026, and the first harvest of 5kg fish in 2028, the company says.

One other potentially major player in the US is Salmon Evolution, which is currently the world's largest land-based salmon farmer. It harvested 4,981 tonnes HOG last year and expects 6,000-6,500 tonnes this year, including some post-smolt it is selling to net pen farmers.

Salmon Evolution, which uses a hybrid flow-through recirculation system, will eventually produce around 32,000 tonnes a year at its facility in Norway and has ambitions to build a same-size plant in either the US or Canada. However, it is still in the scoping phase and has not chosen a site.

Facilities world wide (ex Norway)

It's not just in Norway that things are happening on land when it comes to salmon or rainbow trout. Quite the opposite. There is intense planning and construction activity abroad as well.

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Our list includes facilities with plans totaling more than 1.4 million tonnes. The accuracy of this figure is not perfect, as it's not always easy to determine exactly what the companies are referring to. Different sources report different numbers. Some use HOG weight, while others refer to round weight. Most often, they are talking about annual production, not the maximum biomass the facility can handle at any given time. Plans also tend to change over time.

We have deliberately excluded several companies we've read about that once had plans, but from which we haven't heard anything in years.

There may of course be obvious candidates that should have been included but were left out for one reason or another. The list should therefore not be considered fully comprehensive.

We have also not distinguished between those who have actually started operations—including some that have been producing fish for years—those under construction, and those who are still just in the planning stage.

We know, for instance, that several of the facilities planned in the U.S. are struggling both with permits and financing, while some of those in Asia are moving full steam ahead and have already started harvesting or are close to doing so. Some plans, such as Salmon Evolution's in South Korea, on the other hand, appear to be a longer-term project.

Nordic Aqua Partners is producing, building, and planning further expansion. The current capacity is 4,000 tonnes, phase 2—another 4,000 tonnes—is under construction, and if phase 3 gets financing, the facility is expected to produce 20,000 tonnes annually within a few years. Photo: Nordic Aqua Partners.

Company	Country	Production plans
Columbi Salmon	Belgium	12.000
Pure Salmon Brunei	Brunei	10.000
Cape d'Or Salmon	Canada	7.000
Namgis Kuterra	Canada	300
Sustainable Blue	Canada	1.000
Taste of BC Aquafarms	Canada	1.500
West Creek Aquaculture	Canada	90
Sustainable Blue	Canada	1.000
Bordemar	Chile	24.000
Nordic Aqua Partners	China	20.000
Norsal	China	30.000
Pure Salmon China 5 plants	China	100.000
Qingdao Guoxin	China	20.000
Danish Salmon	Denmark	2.700
Skagen Salmon	Denmark	3.800
Fifax	Finland	3.200
Local Ocean	France	8.500
Pure Salmon	France	10.000
Smart Salmon	France	8.000
Berliner Land Lachs	Germany	5.000
First Water	Iceland	51.000
GeoSalmo	Iceland	20.000
Laxey	Iceland	32.000
Matorka	Iceland	1.500
Samherji	Iceland	4.000
Omega Aqua	India	2.000
Atland Corp./Cermaq	Japan	2.500
FRD Mitsui	Japan	3.500
Proximar Seafood	Japan	5.300
Soul of Japan/Pure Salmon Mie	Japan	10.000
Pure Salmon Lesotho	Lesotho	20.000
Mt Cook Alpine Salmon	New Zealand	1.000
Jurassic Salmon	Poland	1.000
Maiken Foods	Portugal	6.000
Aqua Group	Russia	5.000
Aquaproduct	Russia	7.500
Strizh-Aqua HUB	Russia	10.000
Strizh-Aqua	Russia	10.000
F-Trout	Russia	500
AquaMaof	Russia	2.500
Pure Salmon Saudi Arabia	Saudi Arabia	30.000
Singapore RAS	Singapore	1.000
Cape Nordic	South Africa	6.000
Eco Aqua Farm	South Korea	500
Salmon Evolution - Dongwon Industries	South Korea	20.000
Norcantabric	Spain	3.000
Smøgenlax	Sweden	6.000
Nordic Salmon AB	Sweden	10.000
Re:Ocean	Sweden	10.000
Quality Salmon	Sweden	100.000
Swiss Blue Salmon	Switzerland	3.400
Swiss Lachs	Switzerland	2.300
Ocean Harvest	UAE - Dubai	2.000
Fish Farm	UAE - Dubai	3.000
Vikings Label	UAE- Dubai	50.000
Norwegian Mountain Salmon	UK	130.000
Aquacultured Seafood Ltd	UK	5.000
AquaCon Maryland	USA	20.000
Atlantic Sapphire	USA	100.000
Blue Star Food	USA	21.000
Great Northern Salmon (formerly Katahdin Salmon)	USA	10.000
Finger Lakes Fish	USA	400
Hudson Valley Fish	USA	1.200
Hima	USA	6stk x 23 000
Nordic Aquafarm, Maine	USA	33.000
Pure Salmon USA, Tazewell	USA	10.000
Riverence Holding	USA	15.000
Salmon Evolution	USA	?
Superior Fresh Indiana (bought from AquaBounty)	USA	10.000
Superior Fresh Wisconsin	USA	680
West Coast Salmon	USA	50.000
Whole Oceans	USA	50.000
SUM		1.304.970

Overview of land-based salmonid production facilities abroad. Includes both planned and existing projects. Sorted by country.

Milestone progress for Gigante Salmon

An aerial view of Gigante Salmon's flow-through fish farm, which will have 10 separate raceways divided among three pools (3, 3 and 4). The pool at the bottom of the picture is complete and operational. Photo: Gigante Salmon 2024 report

Farmer expects 550 tonnes from trial batch.

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By the time you read this article Gigante Salmon, which is building a flow-through fish farm on a small island in Norway, may have reached an important milestone by carrying out its first harvest.

The company intends to produce 20,000 gutted weight tonnes of salmon annually in 10 separate raceways divided between three pools excavated into the bedrock of Lille Indre Rosøy in Rødøy municipality, Nordland. One pool containing three raceways is already in use, a second was completed in late March, and construction of the third is well advanced.

A trial stocking of smolts was made in the first completed pool early last year, and it is these fish that were due to be harvested in Q2 2025. Gigante Salmon expects a harvest of 550 gutted weight tonnes.

A second stocking of smolts in another of the same pool's raceways was made in the third quarter of 2024. Harvesting of these fish will start in Q4 2025.

£218,000 operating loss

Gigante Salmon AS made an operating loss of NOK 2.97 million (£218,000) in

2024, a reduced loss compared to 2023, when it lost NOK 3.324m.

“Even though the project has commenced operations on a limited basis, sales revenues are not expected before Q2, when the first harvest is scheduled to take place,” directors explained in the company’s 2024 annual report.

The company made a net loss for 2024 of NOK -2.098m, compared with a net profit of NOK 0.728m in 2023.

“The difference is due to a decrease in financial income resulting from the increasing share of equity financing for the Rødøy project,” said the directors.

The group’s liquidity on December 31, 2024, was NOK 106.623m.

Construction loan financing has a total framework of NOK 324 million and was expected to be fully utilised during Q1 2025.

"We will then use buffer capital from previous capital raising to complete the facility," said directors. "The group maintains a solid financial position, and as of 31 December, our available cash was sufficient to meet our short-term liabilities. Total assets on the balance-sheet date amounted to NOK 1,216.466 million, compared with NOK 657.653 million the previous year. The equity ratio on 31 December was 59%, compared with 73% as of 31 December 2023" .

An illustration of Gigante Salmon's facility, showing the three raceways in the completed pool. The company was due to make its first harvest from one of the raceways in the current quarter, and will begin a second harvest from another raceway in Q4. Image: Gigante Salmon 2024 report

From zero to one hundred in four years

When Johan Fredrik Gjesdal, centre, took over as head of the land-based department about four years ago, there was no one at the head office at Klepp who worked with land-based farming. Today, the staff numbers 100 here at the head office, and globally a total of 250. Here he is flanked by R&D and engineering director Jan Christian Kerlefsen and AKVA group Land Based commercial director Siri Tømmerås.

The growth in the land-based department at AKVA group in Klepp in Norway has been strong in recent years. But building an organisation and scaling up can present problems if not done correctly. This is also reflected in the way the technology is approached.

Pål Mugaas Jensen (Text and photos)
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When RAS technology began to make its entry into the Norwegian aquaculture industry 20 years ago, the center of gravity for this technology was in Denmark, where AKVA group's land-based activity also originated.

A lot of water has flowed through biofilters since then, and with some resource rent tremors along the way, the center of gravity has gradually shifted north to Norway. Today's RAS providers have main centres in Eastern Norway, in Central Norway and in Western Norway. One of these centres is located at Klepp, half an hour's drive south of Stavanger.

Fully integrated into the Group

"When I took over as head of the land-based department about four years ago, we had no employees at the head office at Klepp who worked with land-based farming. Today, we are around 100 at the head office, and globally we are 250 employees," says chief operating officer Johan Fredrik Gjesdal.

The land-based department is now fully integrated into AKVA group and benefits from the competence environment both internally and in the Stavanger and Western Norway region.

“We realised relatively quickly that we were not well enough equipped for the future. The industry has undergone a professionalisation, and we have placed great emphasis on strengthening our scientific approach to ensure optimal performance and scalability. We understood that we needed to further develop our technology and improve the way we delivered projects if we were to remain competitive in this market," he says.

"Therefore, we have spent a lot of time and energy on strengthening expertise, improving processes and documenting the technology. We simply had to take a real boost as a technology company.”

Siri Tømmerås, commercial director for AKVA group Land Based, says that it has also been about the relationship with the customers.

"We did what most others did, we focused primarily on delivering the facilities, with little follow-up afterwards. Now we see that we must, to a far greater extent, be a partner that helps the fish farmers ensure quality in fish production,” she explains.
“We must be able to deliver solid service and operational support. It requires us to think like a fish farmer, and to achieve that, we need to spend more time with the customers. That's why we've also hired people with experience from production.”

Scientific documentation

An important element that is highlighted is the need for scientific understanding of why a component or process works the way it does, and how it is affected by different variables, says Jan Christian Kerlefsen, director of R&D and engineering at Land Based.

“We call it ‘science behind’. We have systematically reviewed everything we deliver to ensure optimal performance and correct sizing. We have gone from an experience-based to a scientific approach, which makes us far better able to scale up or down to the production sizes we are going to deliver to.

"I came here three years ago from a job at ABB Robotics, where I primarily worked with industrial robots for the automotive industry – a very modern industry. What I have brought with me to this job in particular is the scientific approach to research and development.

“Much of what we are going to test and document must be done at the customers' premises. That's why we've spent a lot of time with customers like Tytlandsvik Aqua."

They have also delivered to and worked closely with companies such as Mowi, Ænes Inkubator and Bindalssmolt, as well as customers outside Norway, such as Cooke in Canada and Sealand in Chile. They are also involved at Årdal Aqua.

The plant was originally built with Billund technology, and after that company went bankrupt, AKVA group has continued the project to ensure completion and stable operation.

Built up a laboratory

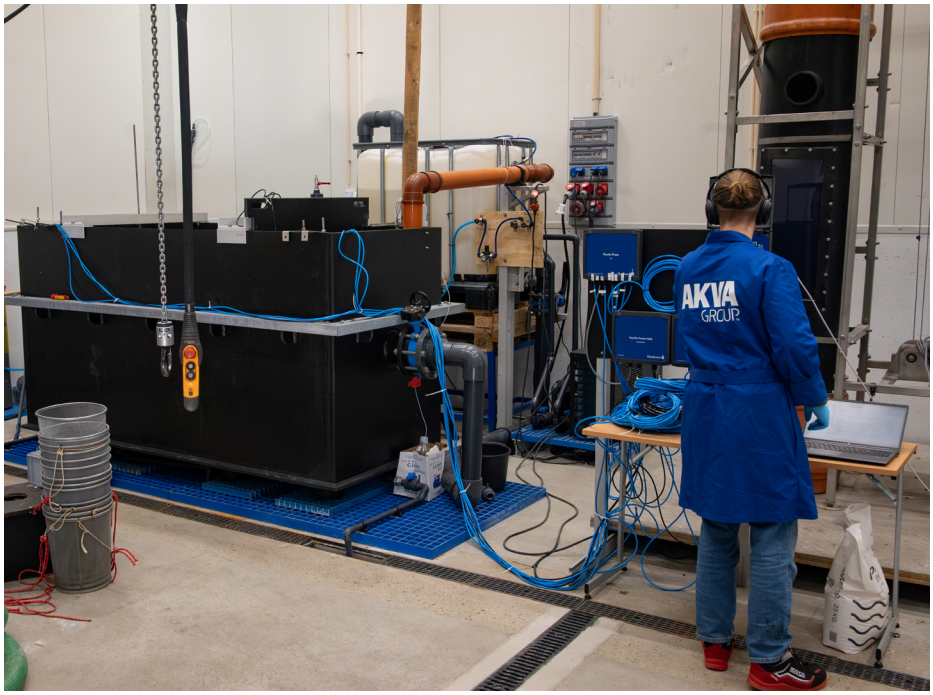
In recent years, an industrial laboratory has also been built up at the premises at Klepp.

"Water quality is one of the most challenging factors to experiment with. We can test a lot at the customer's site, but we can't vary the pH, salinity and temperature to analyse the effect on a CO_2 aerator in a facility where fish are actually produced. However, we can test that here," says Gjesdal.

He adds that AKVA Land Based have also professionalised the supply chain in their deliveries.

Automation of various processes and utilisation of data to improve production will be essential going forward, says R&D and engineering director Jan Christian Kerlefsen. Here he shows a feeding facility in the newly built land-based lab.

Siri Tømmerås from AKVA group stands by the mini-CO_2 degasser, which is used to test how factors such as alkalinity, pH, salinity and temperature affect degassing efficiency. Photo: AKVA group



Water quality is fundamental for different types of operation and capacities. And it cannot easily be experimented with in plants in commercial production. Therefore, facilities have been built to carry out tests that show how, for example, CO_2 aeration is affected when parameters such as temperature and salinity change.

"That's why we've hired people like Kerlefsen, who come from other industries."

Gjesdal says that the company has relatively few patents of its own.

"Our IP (Intellectual Property, editor's note) lies in the dimensioning and design of the water treatment and recycling technology, which has been scientifically documented. That's why we buy most things from external suppliers and assemble the components according to our guidelines and specifications to create a well-functioning system."

"A lot has happened in the industry in recent years," says Tømmerås. "In the past, these 'Lego bricks' were pressed into existing buildings. Fortunately, the building is now being adapted to the processing plant, not the other way around.
"The fish farmers now have a significantly higher level of ordering expertise. The specifications are far clearer and more precise, and that is a positive development."

The way forward

But what happens in the future? The industry is building post-smolt facilities and plans for food fish facilities on land are being realised both in Norway and the rest of the world. Professionalisation has reached the supplier industry in full. Is the rest just a steady course?

"We have a plan," says Gjesdal with a smile.

"What we have built so far is a solid foundation for further growth. We now have a fully integrated global organisation within AKVA group's land-based department, with departments in Norway, Denmark, Chile, and China. Our ambition is to be the market leader in post-smolt globally. At the same time, there is still a lot of untapped potential in the edible fish segment." Therefore, the company is ready to take a step up to a new level of innovation.

"We believe there will be changes in the industry in the future that will be disruptive. The core of water treatment has remained the same for many years, but now we are seeing new technologies with a smaller footprint and significantly lower energy use. We need to think smarter and find better solutions," he says.

One of the things Gjesdal envisions is full automation of production.

"A salmon factory generates a lot of data, and will generate even more in the future. We will use this data to optimise production and create even greater value for the customer."

Kerlefsen points out that what they are doing should not be basic research.

"It is market-driven innovation, and all our innovation projects must have a customer at the other end."

The result of this development has been called Landbased 4.0. The name plays on the concept of "Industry 4.0", which is about taking cost-efficiency and productivity to the next level, while at the same time opening up for new business models and customer platforms through,

among other things, the digitalisation of products and services.

Where do you think the industry will stand in ten years?

"In ten years, I think food fish production will be greater than post-smolt, globally. Some reports have predicted several hundred thousand tonnes of edible fish as early as 2030. I believe there will now be strong growth in the future and that if we take into account both production and facilities under construction, 200,000 tonnes is realistic in 2030. In addition, we have great faith in the post-smolt segment. There are many large applications and projects under way here," Siri Tømmerås points out.

"One of the best things you can do for fish health and volume growth at existing sea locations is to produce large post-smolt. Therefore, there will be a lot of construction in Norway in the years to come," says Johan Fredrik Gjesdal.

The Chilean market, on the other hand, has not been as strong in recent years.

"The regulations there do not provide as strong an incentive for post-smolt, as it is not as easy to extract similar volume growth in sea locations as in Norway. But the Chilean fish farmers are starting to see that post-smolt production provides greater flexibility in production, while shorter time in the sea reduces lice infestation and the risk of disease. That is why we are in dialogue with many players in the industry about future development," he says.

But despite a not too great post-smolt enthusiasm in Chile yet, AKVA group still secured a contract with Cermaq Chile earlier this year for the construction of a RAS facility that will be able to produce 14 million smolts – albeit no larger than approximately 150 grams. The contract value is as much as NOK 350 million (US $32.2m).

When it comes to food fish production, Gjesdal believes that the largest facilities will primarily be built outside Norway.

"Such facilities must be built close to the consumers. We see that when Nordic Aqua in China manages to produce fish weighing 7 kg with less than 2% mortality, no sexual maturity and a 99% superior proportion, it makes sense. The consumers of the future will not accept that the fish is transported by air. Land-based food fish production is not a threat to production in Norway. The sea-based food fish production here will still be able to serve a growing market in Europe very efficiently with road transport, as it does today," he says.

Finished components ready for transport to the customer.

Siri Tømmerås, commercial director at AKVA group Land Based, says that they see an increasing need to be a partner that helps the fish farmers ensure quality in fish production – not just a supplier of the facility.

Stepping up investment in land-based aquaculture

German Silikal supplies industrial floor coverings to the whole world. Through their European dealer, Norway's Silikal Nordvest, they have gained a foothold in land-based fish farms. Now they are taking the investment a notch further.

Pål Mugaas Jensen (Text and photos)
pal@landbasedaq.no

Several customers, subcontractors, consulting companies, and national and international press were invited to Silikal's factory in Mainhausen, Germany, to get an insight into how to develop and produce one of the coatings offered to the growing land-based aquaculture industry both in Norway and the rest of the world.

The Norwegian company, Silikal Nordvest, also took the opportunity to pre-launch their new concept for different coatings for land-based farming, which they have called "Silikal Aquaculture Solutions".

"We hope what we are now doing will establish a new form of standard in land-based farming," says general manager of the company, Christian Aas, son of founder Håkon Aas.

The product range they have launched consists of different coating systems, each of which comprises different layers and membranes put together into a unified coating with properties developed specifically for land-based fish farms.

"The coatings are based on experience from the industry, based on real issues, and have been specially developed with help from the industry," says Aas.

Research-driven

The manufacturer of the chemistry behind it, Silikal GmbH, gave the participants an introduction to the research behind the solutions during the event at the factory.
"We have a research department with chemists and technologists who really

Silikal demonstrates their products for the land-based aquaculture industry. Applying the coating is an art, and for Europe, only Silikal Nordvest is allowed to do this out in the industry.

Silikal GmbH

- German company that was founded in 1951 in Frankfurt am Main.
- Originally started in screed construction. Developed new synthetic resin-based products throughout the 1960s, mainly for floor coverings.
- Today, they supply products made of MMA (methyl methacrylate), epoxy or PU (polyurethane).
- Delivers to all continents.
- Around 60 employees at the factory in Mainhausen, about 30 minutes southeast of Frankfurt.

Silikal Nordvest

- Founded in 2014 by Håkon Aas.
- Head office at Sistranda on Frøya, Norway.
- Approx. 30 employees.
- Dealer for and installs industrial flooring and silica coatings for industry and other commercial companies.
- Has customers such as Ikea, McDonalds and Tine, and gradually they have gained customers in the aquaculture industry such as Mowi, Lerøy and Bakkafrost.
- Has launched its own product lines for land-based aquaculture, both coatings for fish tanks, but also for RAS systems and biofilter tanks.

Christian Aas is the general manager of Silikal Nordvest.

get into the various issues. We have to do that if we are to be able to compete in the global market," Henning Simon, chief executive of Silikal GmbH, tells the visitors.

He explains that the basic idea behind the development of the coatings is that they should withstand extreme conditions, while ensuring optimal hygiene and long-term protection of the facilities.

"Therefore, special requirements have also been set for mechanical strength and chemical resistance."

Different areas

Christian Aas says that the coatings are specially adapted to the different areas of land-based farming, with their own systems for e.g. RAS, fish tanks, and flooring.

"By targeting further development towards specific types of thoughts and challenges, it will be possible to develop even more specialised solutions for the aquaculture industry," he says.

Methylmethacrylate

The products that Silikal supplies to land-based aquaculture are based on so-called MMA (methyl methacrylate). This is a substance that has a wide application.

Henning Simon, managing director of German Silikal GmbH, explains the structure of the coatings.

Products based on this are used both as a filler for cavities at the dentist and as a bone replacement in orthopaedic surgery. It is also used to make contact lenses. And to make industrial coatings.

When the coating is to be applied, it is mixed with a hardener/activator (preferably hydrogen peroxide) on site, and then the different layers are applied with a roller.

"MMA has several good qualities in the context of aquaculture. It adheres very

Silikal's Frode Reppe, left, explains to both the press and people from both the producer and the supplier level.

Head of Silikal GmbH Henning Simon, left, discusses with Preben Mørner-Bartnes at Aquatiq how surfaces can best be cleaned and disinfected.

Håkon Aas is the founder of Silikal Nordvest, and father of the current manager. At the age of 70, he still finds building businesses both fun and rewarding.

well to substrates such as concrete and even polypropylene. It can be applied even in relatively cold environments, it is not sensitive to humidity when applied, and it cures in a short time, preferably as little as 20 minutes," explains Dr Peter Loh, head of the R&D department.

He says when a new layer in the coating system is applied, it activates the surface of the underlying layer, so that the layers are almost "welded" into each other.

"This makes it both strong and flexible, and can withstand both vibrations and even earthquakes," he says.

Now, earthquakes are not a big problem in Norway, but for the representative of the Icelandic food fish farm who took part in the seminar and tour, this was useful knowledge.

Washing and disinfection

Another important feature of any surface in a land-based fish farm is that it must be easy to wash and disinfect.

"Therefore, it must be able to withstand both strong acids and strong bases (alkalies). And it must be able to withstand being high-pressure washed." This is explained by Preben Mørner-Bartnes, project manager at Aqualtic.

His company are experts in industrial hygiene. In the context of aquaculture, they have close contact with the company Niro Gruppen, which among other things carries out the practical aspects of industrial cleaning and disinfection.

"If we are to be able to do our job properly, we need to know what such coatings can withstand. Therefore, on our own initiative and at our own expense, we have stress-tested Silikal's coating," says Mørner-Bartnes.

They brought with them to Germany the results of a very recent, independent test they had done on the coating. Even Silikal did not know what Mørner-Bartnes wanted to present, and therefore the relief was noticeable among the Silikal representatives from both Norway and Germany when they heard the test results. "We are impressed," was his overall conclusion.

Installation requires special expertise

After the seminar, the participants were allowed to enter the test lab in the factory. Here they were able to demonstrate both the application of the coating and the physical properties it has with adhesion to both concrete, steel and PE/PVC.

To demonstrate application and hardening, a "light wall" had been rigged up. The product was mixed with a drill and applied with a roller.

"Installing the coating may look simple, but it requires a lot of knowledge and experience for it to be done correctly and professionally. Therefore, only Silikal

In the laboratory at the factory, both development and quality control take place.

"By targeting further development towards specific types of thoughts and challenges, it will be possible to develop even more specialised solutions for the aquaculture industry," says Christian Aas, head of Silikal Nordvest.

Should it be a fish tank in red, or maybe a biofilter in green. The imagination sets the limits.

Nordvest is allowed to carry out this job at land-based fish farms in Europe," says Silicon manager Henning Simon.

He also says that as of today, the roller is the main tool for application, but that they are also working on developing it for application by sraying.

Starting his biggest project

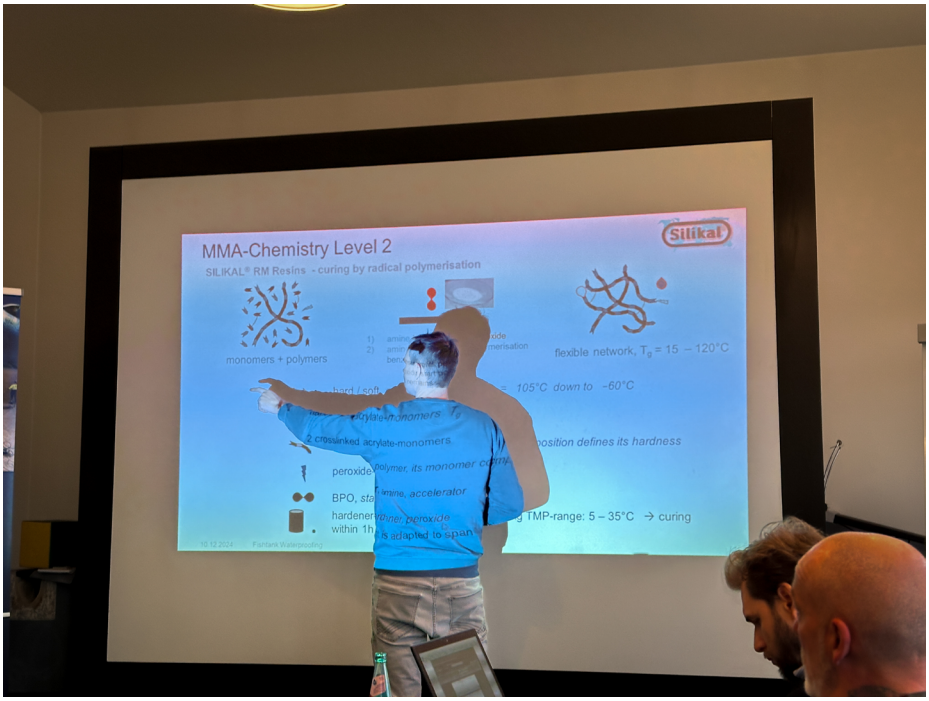
At the test lab, many of the participants expressed the usefulness of seeing the product up close.

The leader of Silikal Nordvest, Christian Aas, was also very pleased with the session.

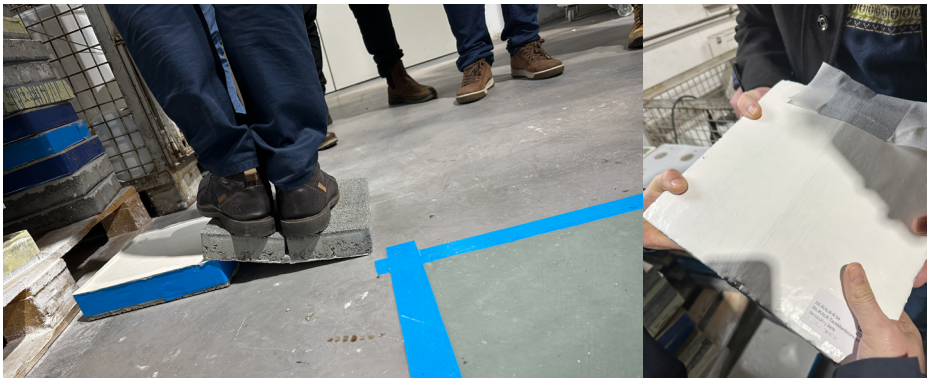
"Our new product range undoubtedly strengthens our position as a supplier to the land-based aquaculture industry. I think our journey into that industry has only just begun."

He says they have recently started their largest installation of special facilities so far, at Cermaq's smolt facility on Sørøya.

"This project is an important step in showcasing our solutions for demanding environments in land-based fish farms," he says.



There is a lot of advanced chemistry behind a surface coating. Here, head of the R&D department Dr Peter Loh explains.



Testing of product features was also on the plan for the visitors.

Silikal's factory is located in the small German town of Mainhausen, not far from Frankfurt.

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This is what nanobubbles do to the water quality in a RAS facility

What happens to the water quality in a RAS facility if you add nanobubbles? And do you see other exciting effects on the performance and health of the fish? These were some of the things the technology company Moleaer wanted to find out when they took a scientific approach at Lødingen Fisk.

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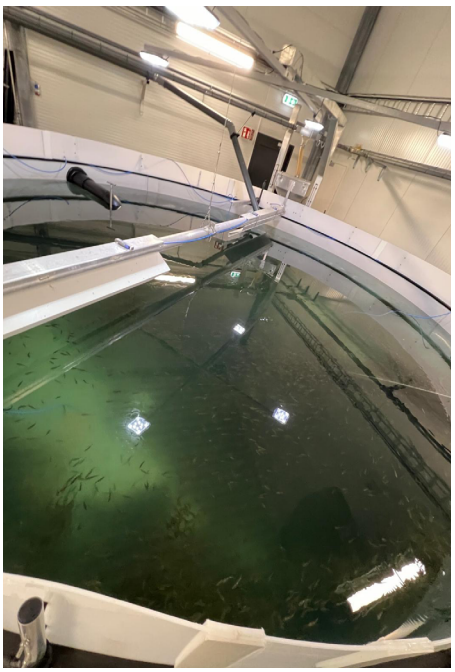
The testing Moleaer did at Norwegian smolt producer Lødingen Fisk has resulted in a report called "Effect of oxygen nanobubbles on performance and water quality in recirculating aquaculture systems (RAS)". In this article, Federico Pasini, senior R&D scientist at Moleaer, explains a little about the results they got.
He says the goal of the study was to quantify how the introduction of oxygen nanobubbles can improve water quality and reduce energy and water consumption through improved oxygenation, better particle removal, increased nitrification rates and prevention of biofilm.

The study was carried out in two rounds to evaluate the short- and long-term effects on RAS.

The first was performed to characterise the effect of nanobubbles on the process within 48 hours of starting up the nanobubble generator (NBG). The second round of measurements was after 50 days of continuous operation of NBG, with fish that were much larger and with a significantly higher oxygen requirement, during a period when the facility was at 60% of full capacity.

"We also studied what happened and how the process responded to the presence of nanobubbles. Finally, we also tried to look at what happened to the fish, although we still have questions about that. Nevertheless, we identified some interesting points for future studies," he says.



The water quality in the tanks was significantly improved after nanobubbles had been allowed to work for 50 days. Photo: Moleaer

Lødingen Fisk is located in Vestbygda in Lødingen municipality in Nordland.

Results from the short-term study

Determining the presence of nanobubbles

"What happened immediately after you started the nanobubble generator?"

"As expected, we were able to detect oxygen nanobubbles in the process. Measuring nanobubbles or nanoparticles is not entirely simple; there are many variables, and precision and a strict protocol are required. We measured nanoparticles usually before the experiment, as a baseline without nanobubbles, i.e. before the generators were started. We then continued to collect samples after the nanobubble generators were started, and we measured a net increase in each step of the process (**Figure 1**), averaging 60 million per ml," he says.

"And we know from our experiments in the laboratory and other experiences in the field that this concentration is definitely sufficient to see an effect on water, biology, and to some extent biochemistry. We therefore know that in general, regardless of which water system we treat, we expect a reaction at that concentration," says Pasini.

He says they saw that in about three hours there was a net increase of about 140 million nanobubbles per millilitre, with a size of an average of 170 nanometres. These nanobubbles disperse and dilute throughout the system, resulting in this average concentration in the process.

High dissolution efficiency of oxygen

He explains that by creating small bubbles and a high residence time, we can ensure a very high oxygen release efficiency, which is shown immediately through the response in the four sampling points.

"We had an immediate increase in oxygen at all stages of the process."

But a very interesting and clear effect was also seen on scrubbing and removing biofilm (**see also fact box**).

"We know nanobubbles will be involved in one way or another in everything that has to do with surface interactions. In this case, this causes some of the biofilm and some of the old coating on the surfaces of the tanks and pipes to loosen. Within 24 to 48 hours, we see an increase in solids, which then dissolve over time, which in turn results in less need for ozone."

Nanobubbles therefore create a scouring effect where certain types of biofilm detach from surfaces, go into the water and can be filtered out.

The nanobubbles themselves have a very hard surface. This contributes to their mechanical property, and with the speed they have, they are able to scour loose biological material, so that it is suspended in the water stream and can then go to the drum filters where it is taken out.

"This is why we see an increase in TSS (total suspended solids) at almost every step of the process, especially from the fish tank. We can see that during 48 hours there were more solids, indicating the release of more particles. The feeding rate was the same, so it wasn't because of any other conditions in the tank.

"We also tested the oxygen release efficiency, and we measured an efficiency of over 90% at that gas injection, which was low at the beginning of the process. We also saw indications of improved disinfection, which was later confirmed by the UV and ozone data," he says.

Effect on nitrification

"The most interesting thing, in my opinion, was the beneficial effect on the biofilter, especially on nitrification," he says. **See also Figure 2**.

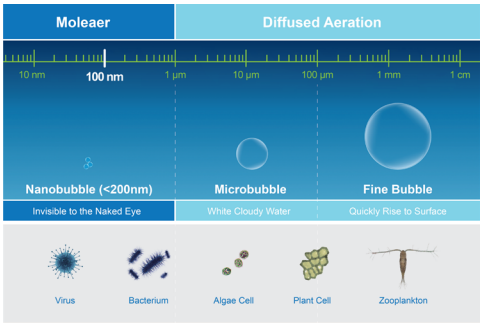
Because in the end, it is nitrification that determines how much load the plant can withstand.
"Even though you can add more oxygen, increase feeding and increase fish

Moleaer

- American-owned company headquartered in the Los Angeles area.
- Founded in 2016 with the goal of developing technology to treat wastewater.
- Has developed patents for nanobubble technology, which is used in everything from aquaculture, via wastewater treatment to oil extraction.
- Has a factory in Spain and offices in Norway and Chile.

Nanobubbles

- Nanobubbles are typically between 80–200 nanometres in size and are thus the size of bacteria and viruses.
- Nanobubbles behave differently when it comes to stability, surface charge, neutral buoyancy, oxidation, etc. because they are nanoscopic.
- Nanobubbles have neutral buoyancy and can remain suspended in liquid (most commonly water) for several weeks without rising to the surface and disappearing.
- With their nanoscopic size, nanobubbles ensure that a huge total bubble surface remains in contact with the water – altering and enhancing many physical, chemical, and biological processes.
- Nanobubbles have a strong negative surface charge that prevents them from merging and enables them to physically break up emulsions and coagulate small particles – such as emulsified fats, oils, and lubricants – from water.



That's how small nanobubbles are compared to various small organisms. Photo: Molear.

density, you will still need a stronger and more efficient biofilter to handle all the ammonia, so you don't create any risk to fish welfare."

They saw that the presence of nanobubbles immediately had a positive effect on nitrification performance.

Biological nitrification is a process that involves specific types of bacteria, divided into two categories that perform two different steps. First, AOB bacteria (aerobic bacteria) that use oxygen to break down ammonia into NO_2 (nitrite). Then, another group of bacteria, called NOB (nitrite-oxidizing bacteria), takes this nitrite and converts it into NO_3 (nitrate), which is the end product of biological nitrification.

Nitrate is the least toxic form for fish, while nitrite is highly toxic at low concentrations.

"It is therefore very important that we prevent the accumulation of nitrite, which is a symptom of a partial nitrification process. We show that with nanobubbles, we help to complete the step that was previously limiting, and overall we have a positive effect on water quality, which is very important since nitrite is so toxic to fish," he says.

Results from the long-term study

Clearer water

The effect achieved from the start, where biofilm was removed from the pipes and surfaces, gradually resulted in clearer water in the plant. **See also Figure 3**.

The nanobubbles adhere to surfaces and create a gas coating on them.

"We can see this as a beneficial effect on turbidity. After 50 days, when the fish were much larger and they were given much more feed, we had a much clearer water than when we started," says Pasini.

Economically beneficial

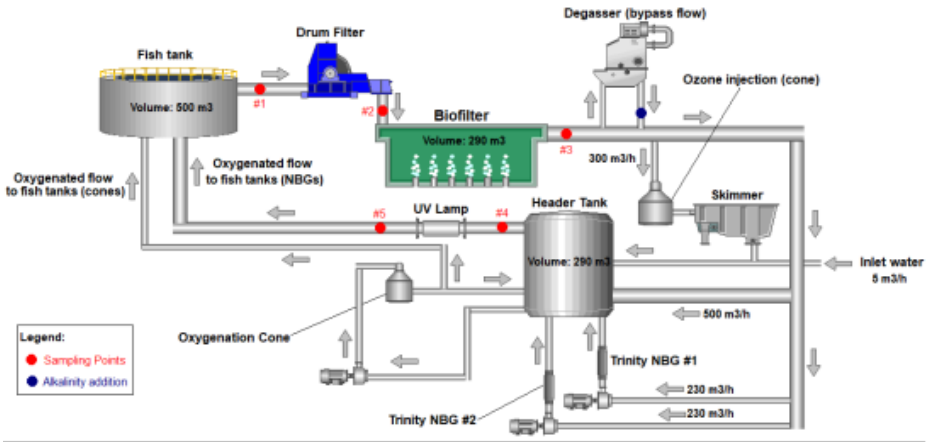
Another valuable observation that is highlighted is that the dissolved oxygen increased at each stage of the process.

"And what is more relevant is that we increased the utilisation of the oxygen by 60% compared to just constant oxygenation. We were thus able to save a lot of oxygen compared to what they would normally do in the plant. This is a very strong economic argument for this type of technology," he says.

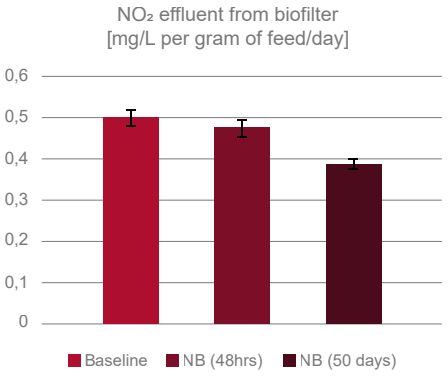
Improved nitrification

Federico Pasini says they also confirmed that nitrification was improved with nanobubbles in the water. **See also Figure 2**.

"The most important source of ammonia in the process is the feed, and the feeding increased throughout the experiment. But we saw that nitrite levels were getting lower and lower, which means that the performance of the biofilter has improved. "We also saw that CO_2 levels followed roughly the same trend, so it may appear



Figur 1. Schematic overview of the RAS facility at Lødingen Fisk in Vestbygda.



Figur 2. Specific nitrite (N-NO_2) in the biofilter outlet, before (baseline), after 48 hours of initiation of nanobubble generation (NB, 48 hours), and after 50 days of NB generation (NB, 50 days), expressed in milligrams per litre per gram of feed per day. The figure shows a beneficial effect of nanobubbles (NB) on the activity of NOB bacteria (responsible for the oxidation of nitrite, N-NO_2 to nitrate, N-NO_3).

that it also has a positive effect on degassing, probably as a result of a better carbon conversion in the biofilter. So overall, we improved the water quality and reduced oxygen consumption," he says.

The efficiency of the biofilter, measured as nitrification rate, was found to increase by over 60%.

As a result of the cleaning and cleaning effect and the reduced turbidity, the overall specific consumption of ozone per tonne of biomass also decreased by almost 70%.

"This confirmed that we had a positive effect on biofilm prevention, surface cleaning, disinfection and the overall turbidity of the water," says Pasini.

Improved fish welfare?

The effects on water quality also led to some interesting observations, which Pasini says they will continue to dig deeper into.

"More studies will be required to really understand what is happening when it comes to fish welfare. But in general, we saw indications of positive effects on fish welfare in terms of feed factor and relative growth index. Despite the observations we made and the data we collected, we absolutely need to investigate further before we draw any final conclusions," he emphasises.

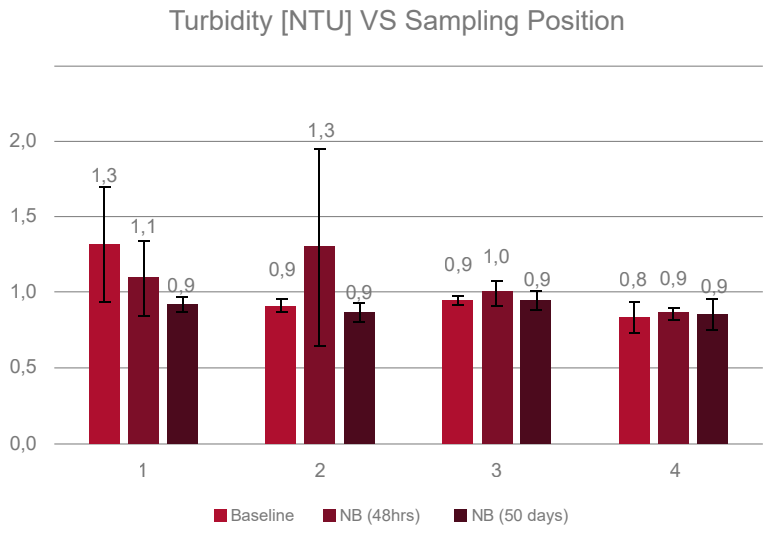
"What we can conclude from the studies is that we generally had higher stability in dissolved oxygen (DO), as the oxygen content was higher overall and less variable throughout the process. This can certainly have a positive effect on fish welfare."

The fact that the turbidity in the fish tank was reduced can also have a positive effect on fish welfare, as well as prevent fouling and bacterial formation for disinfection purposes to a certain extent.

"The improved biofilter efficiency, generally lower concentration of ammonia and nitrite, as well as lower CO_2 concentration are all parameters that mean a healthier environment for the fish." Pasini says when it comes to further research efforts related to fish health, they will collaborate with other research institutions that have the expertise to study the medical and more metabolic aspects of fish growth in general.

"We will do our best to give them as much knowledge about nanobubbles as we can offer, to try to solve this puzzle," he concludes.

Nanobubbles coagulate particles and increase the performance of mechanical filtration systems. Foto: Moleaer



Figur 3. The figure shows the average water turbidity at four different sampling points, measured at 09:00, 11:00, 13:00 and 15:00, before (baseline), after 48 hours of nanobubble generation (NB, 48 hours), and after 50 days of nanobubble operations (NB, 50 days), expressed in NTU (Nephelometric Turbidity Units). The turbidity of the water in the outlet from the fish tank was reduced by 30% after 50 days of nanobubble oxygenation (from 1.3 to 0.9 NTU), while no statistically significant variation was measured in the final outlet, before return to the fish tanks.

The scouring properties of nanobubbles

- Nanobubbles have a very hard surface that can mechanically tear off biofilm at speed.
- Think of a nanobubble with oxygen like a balloon. A balloon is filled with gas covered by a shell of elastic plastic that holds the gas in. In a nanobubble, the shell is replaced with a small layer of OH ions around the gas. They are electrically charged and specifically attract the water around them through hydrogen bonds. This gives the bubbles a very hard shell because it is effectively made of ions and electrical charge that holds the bubble together.
- And since you are at the nano level, the forces are greater in relation to the size. The scale of the curvature around the bubbles is small enough for the water structure itself to be interesting.
- One of the things that happens is that the surface tension in the water changes locally so that you get a reorientation of the water molecule. From the outside, you will see this bubble as usually negatively charged, because you have more OH- facing outwards in the water molecule. Therefore, they bind to different ions, they participate in reactions, both chemical and biological, and one can think of them as carriers. In other cases, since they are charged, they are very interactive with surfaces, such as biofilm.

Low particle load in RAS is good for both salmon and operations

Recirculation systems (RAS) rely on water purification to remove waste products and particles. However, the small particles are difficult to remove, and commercial RAS therefore often have a high particle load. In the recently completed project MikroRAS, we investigated how particle loading affected water quality, microbiota, and salmon health and growth.
The results indicate several challenges with elevated particle loads, but also a number of practical advantages with low particle loads.

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The microRAS project

- Project: Microbiota associated with Atlantic salmon in the transition from freshwater to seawater in RAS: effect of high/low particle loading and consequences for fish welfare and health (MikroRAS)
- A collaboration between NIVA, NTNU, UiB and Marineholmen RASLab.
- The project has recently been completed and has been funded by the Norwegian Seafood Research Fund (FHF).
- Read more about the project in FHF's project database: www.fhf.no/prosjekter/prosjektbasen/901735/ and on NIVA's project page; www.niva.no/prosjekter/mikroras.

Scan the QR code and read the project report (in Norwegian PDF only):

Recirculating aquaculture systems (RAS) are complex systems and there are a number of processes that are dependent on each other and affect both water quality and fish growth. The understanding of this complex system is slowly but surely improving, and constantly improved procedures and guidelines are being established for the best possible operation and fish production. Nevertheless, there is great variation in how RAS are operated and how successful fish production is.

Most fish farming companies that produce salmon in RAS experience challenges with elevated particle levels in the water despite continuous drum filtration of the operating water. Such particles largely consist of organic material that is added to the water via the feed and the fish's faeces. From previous studies and experience, it is known that such organic material provides a breeding ground for increased growth of bacteria and other microorganisms in the biofilters and in the water. This can lead to reduced biofilter capacity and increased growth of fast-growing bacteria in the water that can have negative effects on the health of the fish. Furthermore, it can lead to the production of adverse metabolites such as geosmin and toxic H_2S (hydrogen sulphide). In addition, reduced visibility in the water can affect the salmon's feed intake and the farmer's ability to observe the fish. However, exactly what direct and indirect effects particles and organic matter have on the fish is uncertain and is discussed in the industry. Increased knowledge in this area will make us better at assessing which measures are good for the salmon and the operation of RAS.

Long-term experiments in RAS and simulated deployment to sea facilities

To study the effects of particle loading on salmon in RAS, a long-term experiment was carried out in six RAS units and then a simulated transport and simulated release to sea facilities. In the RAS phase, a particle load was chosen that corresponds to conditions commonly found in commercial RAS (approx. 7 mg TSS (total suspended solids) per litre, called high TSS/HTSS) and conditions that perhaps more people would like to achieve (1-2 mg TSS/l, called low TSS/LTSS). We increased the particle load in the HTSS group by returning particles from the swirl and drum filter, and each RAS had the same biomass and feeding intensity. A detailed description of the experiment can be found here: https://www.landbasedaq.no/mikroras-niva-ntnu/er-lav-partikkelbelastning-i-ras-fordelaktig/1610255 and in the final report from the project MikroRAS (in Norwegian).

Main findings

Particle levels commonly found in commercial RAS can lead to negative effects on salmon performance, such as increased feed factor, reduced fitness factor and growth, and can delay

smoltification. Compensatory growth in the sea phase indicates that the particle levels/conditions tested are within the fish's scope for adaptation and compensation, but that this costs the fish energy. Histological examinations showed no pronounced negative effects on gills and skin health. On the other hand, gene expression of inflammatory markers increased in fish exposed to high particle loads in both gills and skins, especially at the end of the RAS phase. This may be an early sign that more profound harmful health effects are developing.

Levels of suspended solids (TSS) around 7 mg/l in RAS led to significantly reduced visibility in the water (**Figure 1**) and reduced nitrification. There was an increased occurrence of heterotrophic bacteria in water and biofilters in the transition to brackish water, and we observed higher concentrations of ammonium and nitrite in RAS with higher particle loads. This indicates reduced biofilter capacity, probably due to outcompeting nitrifying bacteria in the biofilter. Low particle load can also lead to a number of practical benefits, such as easier cleaning and easier observation of the fish, as well as a better effect of the water treatment (ventilation of CO_2, disinfection, nitrification, etc.) and probably a reduced risk of bacterial production of unwanted metabolites (e.g. H_2S and geosmin).

There may be several reasons for reduced fish growth under elevated particle loads. During suboptimal water quality, the fish use more energy for compensatory physiological adaptations to maintain a stable internal environment (homeostasis). How much energy is used to find and possibly compete for feed, in an environment with limited visibility, is unclear. It is conceivable that the delayed smoltification is due to uneven and reduced light and/or that particles had direct disruptive effects on the function of the chloride cells of the gills. In addition, production intensity, temperature and elevated levels of other waste products and metabolites may have a negative impact on fish production.

Since there is great variation in how RAS are operated and how successful fish production is, it will be important to ensure a common understanding of several such key factors and identify premises for the operation through exchange of experience and further research. These are all important pieces for the best possible fish production.

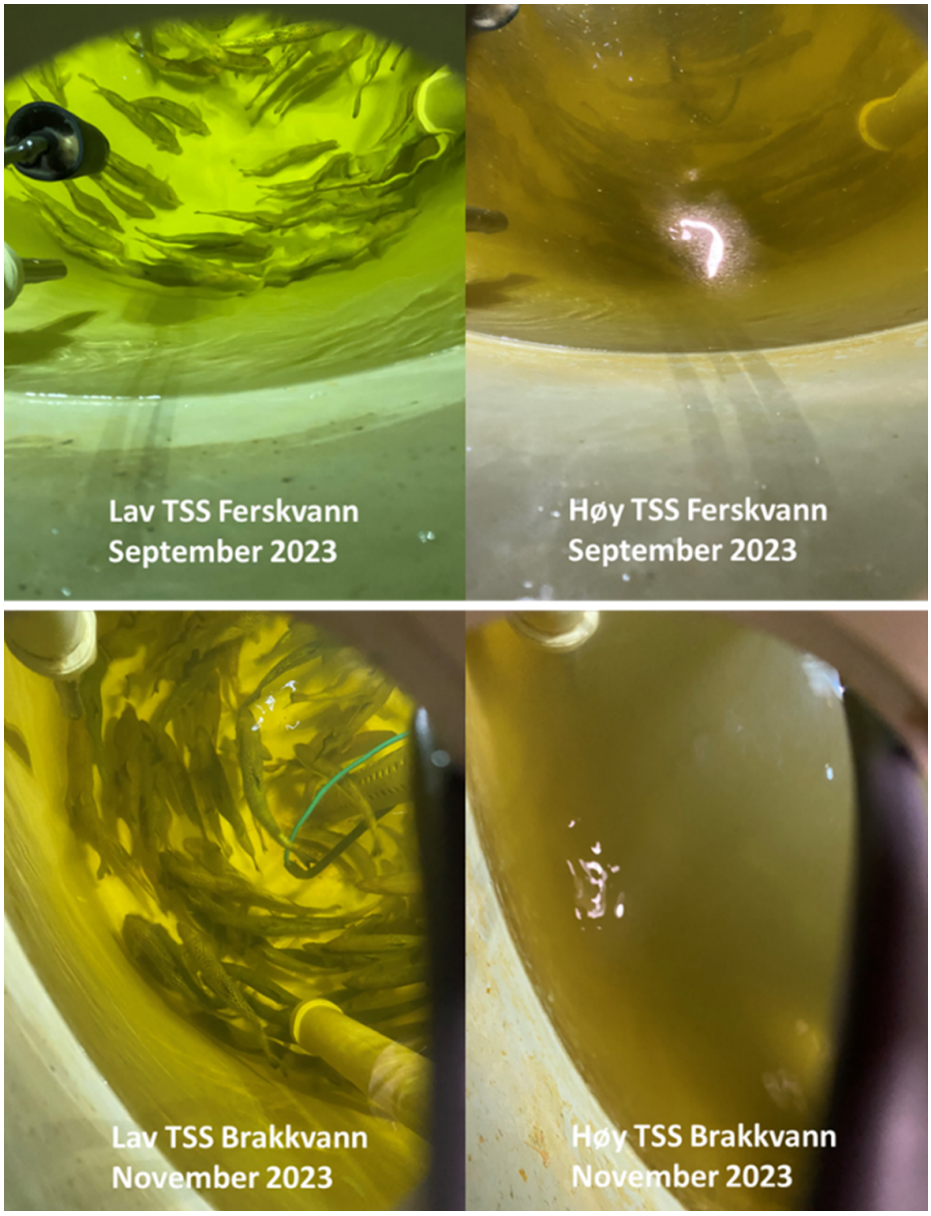

Figure 1. Visibility in the water in the freshwater phase (top) and in the brackish water phase (bottom) at low TSS (left) and high TSS (right), at two different times.

Significance for the industry

The findings from MikroRAS indicate that particle levels commonly found in commercial RAS negatively affect the performance of fish in RAS and may delay the timeline for smoltification. Thus, it may be worthwhile to introduce measures to reduce the input of organic matter to the water and improve particle removal. Relevant measures may be optimisation of a RAS operator's own operations and contribution to methodological innovations, as well as the development of equipment that ensures better particle removal.

Master's theses

- Ludvik Wolfgang Forbord Fiksdal 2023: *Comparative Assessment of Water Quality and Biofilter Performance in Recirculating Aquaculture Systems (RAS) Exposed to High and Low Particle Loading*. Master's thesis UiB, https://bora.uib.no/bora-xmlui/handle/11250/3074609.
- Leif Refsnes Bø 2023. *The effect of high and low particle load on smoltification of Atlantic salmon (Salmo salar) in RAS*. Master's thesis UiB, https://hdl.handle.net/11250/3108575.
- Stian Ringbakken Stenhaug 2023. *The effect of organic load on the rearing water and biofilter biofilm microbiota across the freshwater and brackish water phases in RAS with Atlantic salmon (Salmo salar)*. Master's thesis NTNU, https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3096231.

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