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Aquaculture 2.0: RAS Is Driving Change

Land-Based Farming Is Set to Disrupt Salmon

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Summary

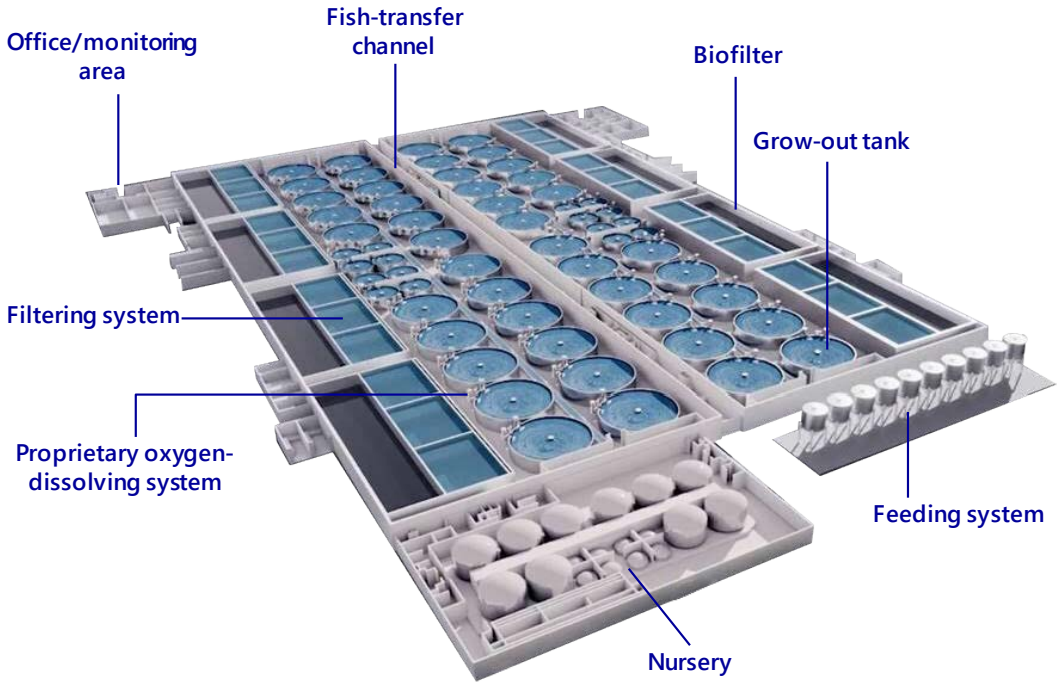
We see the tide turning for recirculating aquaculture systems (RAS) and see potential for this emerging technology to change the aquaculture game over the next decade. An increasing number of proposed RAS projects, particularly for salmon-farming, are in the process of building a platform for future success. If the risks within RAS operations are managed effectively, in our view, RAS will disrupt aquaculture trade flows, supply chains, and the marketing of salmon within the next decade. For those in the salmon industry and other aquaculture value-chain operations, now is the time to decide if they should invest in RAS or invest to ensure they stay ahead of RAS, as this technology matures, grows, and disrupts the market.

The number of proposed projects to farm various seafood species on land using recirculating aquaculture systems (RAS) is increasing day by day. Most of these announced projects focus on salmon-farming. So far, we have identified more than 50 RAS proposed projects (and counting) to farm salmon on land. The total estimated production of these announced projects up to 2030 is equal to 25% of total current salmon production. Although the RAS concept is still under development and the future holds uncertainties, in our view the future of RAS operations is positive. We evaluate four different scenarios for RAS up to 2030. If the risks within this technology are managed effectively through key success factors, RAS salmon production could make up to a quarter of the expected growth in production out to 2030.

Why Is Land-Based Salmon-farming in the Spotlight Now?

With RAS, fish and shellfish can be farmed in recirculating tanks in closed production facilities on land. Production tanks, pumps, fish transfer channels, and oxygen control, filtering, and feeding systems are the main components of RAS operations (*see Figure 1*). The water used to farm (shell)fish is recycled through filters and other water treatment systems. Water circulation rates of RAS farms change between 30% to almost 100%, depending on the farm design. If done successfully, RAS technology can bring sustainability and biosecurity benefits due to its closed-farm system. The farm's proximity to end markets is another big advantage, as it decreases transportation costs and eliminates import tariffs. However, these projects are highly capital intensive.

Figure 1: General layout of a 10,000-salmon capacity RAS facility of AquaMaof Aquaculture Technologies



Source: AquaMaof, 2019

So far, RAS operations have struggled, and the success rate has been low. However, the technology seems to be improving, main challenges have been overcome, and commercialization has started.

Given the high price point and large market size of salmon and the supply constraints of sea-based farming, the industry is trying to increase salmon output by exploring alternative farming techniques, including RAS farming. We see the number of proposed RAS projects to farm salmon increasing steadily.

Where Are the Announced Projects Set and at What Scale?

So far we have identified over 50 publicly announced RAS projects (and counting) around the globe for salmon-farming, with a total estimated production of more than 700,000 metric tons within the next decade. This proposed target volume constitutes around 25% of today's global salmon production.

Though the projects are spread around the world, the majority of land-based salmon farms are planned in Norway, due to the know-how around salmon-farming and the existing cold chain and logistics infrastructure in the region (*see Figure 2*). However, total proposed production volumes are the highest in the US, followed by China – mainly as a result of the high growth in demand in the regions.

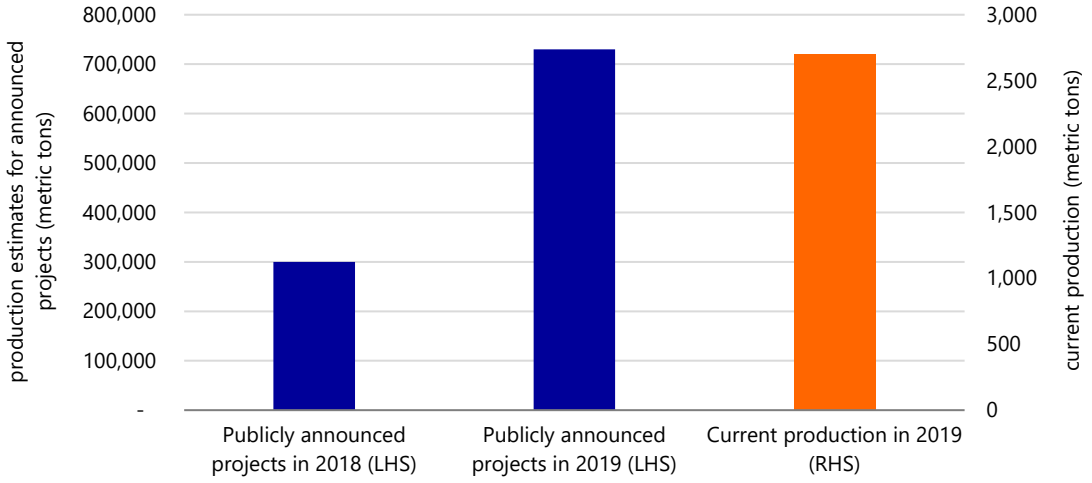
Figure 2: Salmon-farming with RAS is set at an industrial scale around the globe

Source: Rabobank 2019

One-third of the proposed RAS projects that we mapped target a production volume up to 5,000 metric tons by 2026 or at a later date. The majority of the projects aim for a production volume between 5,000 to 35,000 metric tons. Among the relatively larger-scale projects, Atlantic Sapphire is planning the highest production volume in a single RAS facility so far, with 220,000 metric tons targeted for a facility in the US. Following Atlantic Sapphire, Pure Salmon targets a volume of 260,000 metric tons of salmon globally – of which 100,000 metric tons are planned in China. The other relatively smaller-sized announced projects are spread around the world.

Some of these planned global projects are at the financing stage. Some are busy with getting permits. Some are constructing their facilities. Only a few are already harvesting and showing early success. Despite the large volumes of planned production, current volumes coming from salmon-farming with RAS are minor, at around 3,000 metric tons (*see Figure 3*). At the time of writing this report, none of the currently active companies' production exceeds 1,000 metric tons.

Figure 3: Current vs. planned land-based salmon production volumes



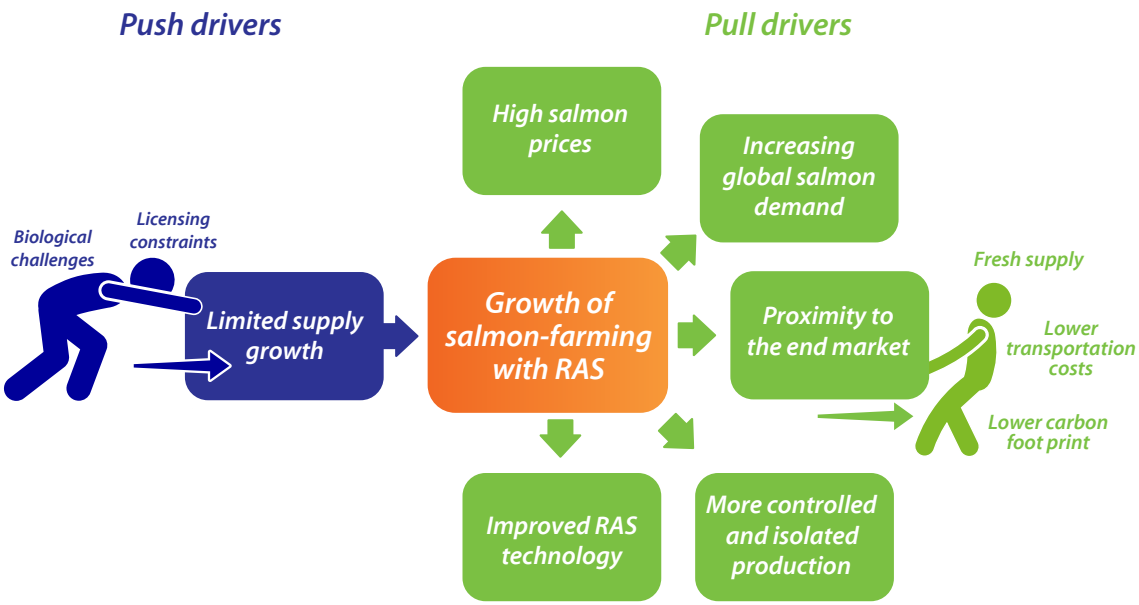
Source: Rabobank 2019

As the number of publicly announced RAS projects to farm salmon increases day by day, planned production volumes also rise. We saw the number of announced projects increase from 30 to over 50 from 2018 to 2019 – more than doubling the planned production volumes. With this pace of growth, it is reasonable to expect that more proposals could be added to the pipeline that might increase planned volumes up to 1m metric tons next year.

The Growth Factors: Push and Pull Drivers

Currently, salmon-farming is primarily carried out in open-net pens or cages in coastal zones. While the global demand for salmon continues to increase despite high salmon prices, growth in conventional salmon-farming on the sea is seen as limited, mainly due to licensing constraints and biological challenges. Consequently, limited supply growth is the main push driver towards RAS (*see Figure 4*).

Figure 4: Push and pull drivers of land-based salmon-farming using RAS



Source: Rabobank 2019

Another challenge of sea-based salmon-farming is the farm's exposure to external aquatic environments, which may lead to biosecurity and sanitary issues. The possibility of a more controlled and closed production system with RAS operations can decrease the risk of disease outbreaks and can protect farms from sea lice and algae blooms. This is one of the main pull drivers for RAS operations. The potential impacts of climatic conditions are also eliminated with this system. The whole environment is controlled from the water temperature to oxygen levels, which can, in turn, positively impact fish health and growth rates. The closed system can also potentially lead to more efficient use of feed, as direct feed loss can be prevented. Furthermore, the closed RAS farms on land have no impact on marine environment, and fish escapees are not possible.

The other main pull driver for RAS is the possibility to have production close to the end markets, where local supply is not possible. For instance, it is possible to farm tropical species in Europe or to farm salmon in China. This specification of RAS makes the farmed product local and more sustainable, and it lowers the environmental footprint due to reduced transportation costs. Also, import tariffs are avoided with local production. At the same time, RAS enables fresh supply, and the fresh value chain also gets shorter, particularly if the farms have the hatchery and the processing capacity in the RAS facility. Shorter value chains can also make traceability and digitalization easier.

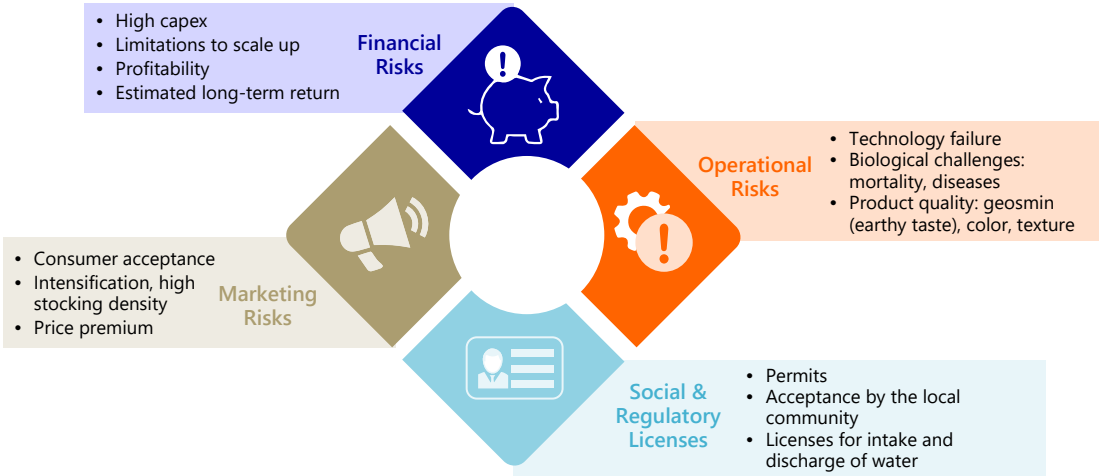
The push and pull drivers for the growth of RAS salmon-farming are clear, and they explain the high number of proposed land-based salmon aquaculture projects. However, in our view, not all of the announced projects in our list will be able to succeed and reach their target volumes, due to potential operational or financial challenges.

Four Sets of Risks to Be Managed Effectively

Although RAS technology is currently used for smolt production, full-cycle salmon growth in RAS is still not completely proven to be commercially viable. This system is still being tested, and technology for large-scale production is still developing. The production volumes of farms using RAS that can be regarded as successful don't have any volumes over 1,000 metric tons yet. Furthermore, the profitability of these farms is still not proven.

We see four sets of risks that RAS operations need to manage effectively (*see Figure 5*). First of all, RAS is more capital-intensive than other more conventional aquaculture systems, and one of the biggest challenges of RAS operations is the required upfront capital expenditure (capex). Building and construction of facilities account for most of the development capex. There are still many unknowns in RAS farming, including the future cost of production and, therefore, the profitability of RAS projects. Moreover, the period between the investment in and the revenue from the RAS farm is relatively long, and it requires some financial flexibility, as several unexpected production and technological challenges can occur. Extra financing might also be needed while ramping up the production volumes.

Figure 5: Four sets of risks exist for RAS operations



Source: Rabobank 2019

Over the last ten years, significant developments have happened in RAS technology that have lowered the costs and enhanced the efficiency of the systems. Currently the technology seems to be improved, and some of the challenges seem to be overcome. However, the possibility of some biological and technological setbacks still prevails. Looking at RAS history, we have seen more failures than successes, many of which were caused by operational setbacks that can be traced back to technological failures, biological challenges (such as diseases and mortalities), and product-quality risks from the taste, texture, and color of the fish. RAS is a technical and complex farming system, in which the exact marine environment needs to be replicated. Hence, everything in the farm needs to be controlled, from the water-quality parameters (such as the alkalinity, dissolved oxygen, salinity, and temperature) to the lighting.

Permits are still necessary to set up land-based fish and shellfish farms, and licenses are required for the intake and discharge of water. And in some cases, it might not be straightforward to get the support of the local community where the RAS facility is planned. In this case, open and transparent communication between the industry and the local authorities and communities is necessary.

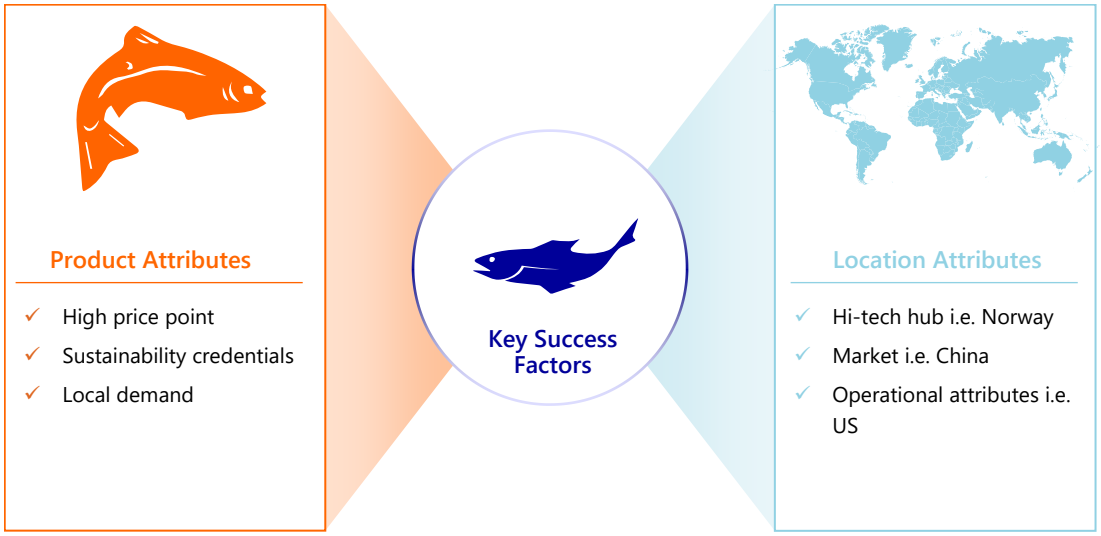
Currently, salmon production with RAS is not available on a commercial scale, which makes it hard to anticipate consumer acceptance of land-based salmon. While RAS farmers argue their products would be local, more sustainable, and environmentally friendly, sea-based salmon farmers could argue that their fish come from pristine open waters – the natural habitat of salmon. Stocking density and intensification of systems with RAS can also raise the question of fish welfare. In the end, consumer acceptance will determine who will win this marketing game and get the price premium.

Most of these risks can be managed by following key success factors regarding location and species selection and by focusing on the business and marketing strategies as well as a good team.

Product and Location Attributes Are the Key Success Factors

It is theoretically possible to farm any type of seafood species in any part of the world by using RAS. However, species and location choice are key factors that can mitigate the four types of risk that come with RAS operations and determine an operation's success (*see Figure 6*). A seafood category with a high price point combined with sustainability credentials is essential in species selection. But in location selection, know-how of aquaculture, the market of the selected species, and the operational attributes in the region (such as subsidies, infrastructure, and access to resources) impact the success rates of RAS farms. These factors are interrelated, and at least half of these boxes should be checked for a successful operation.

Figure 6: Species and location choice can help to mitigate the risk of failure of RAS operations



Source: Rabobank 2019

Products With a High Price Point and Sustainability Credentials Are Necessary

The fish and shellfish selection in RAS farming is particularly important, due to the economic performance of the (shell)fish. With the right farm setting, any seafood category that can be

farmed in a marine environment can theoretically also be farmed with RAS. However, growing fish with higher growth rates and higher economic value can mitigate the high production costs.

One of the main advantages of RAS is the ability to set up a farm in the end market, where there is local demand but no local production. So, for RAS operations to benefit from the sustainability credentials that come with local production and decreased shipping distance, the market for the farmed species is also one of the key success factors. Operations that aim to produce a product with attributes that can achieve a price premium in the right market can mitigate some of the financial, operational, and marketing risks, and hence have a higher chance to succeed.

Location Choice Is Critical Due to Three Factors

We identify three factors regarding the location of the RAS farm that could impact the success of the operations by mitigating risks related to social license and operational and financial challenges. Ticking the boxes below is necessary for a successful RAS operation.

1. **Hi-tech hub:** Aquaculture know-how is particularly important for RAS operations, as this is still a developing concept. It will be easier to solve the expected and unexpected operational set-backs that might arise if the farm is located at a knowledge hub. Norway is the innovation and knowledge hub for salmon-farming. That is a main reason why many RAS projects are proposed to take place in Norway. Additionally, RAS farms here can potentially benefit from the existing advanced logistics and cold-chain systems in the region.
2. **Market size:** Regions with no local salmon supply but with high salmon demand are the main targets for RAS projects, as bringing a premium and niche product where there is no local supply is one of the key success factors for RAS operations. For example, a couple of companies have initiatives to farm salmon on land in the US and China. If all the projects that have been publicly announced so far are realized, over 300,000 metric tons of salmon would be farmed in the US within the next ten years, and that would be equal to the current salmon imports of the US from Norway and Chile. In 2018, the US imported 67,000 metric tons of salmon from Norway, and 267,000 metric tons from Chile.
   On the back of premiumization and the rise of the middle class in China, salmon consumption is expected to increase. Currently four big projects are planned in China, which could result in a production of nearly 140,000 metric tons. That is more than China's 2018 salmon imports. As RAS can shorten shipping distance, prevent import tariffs, and enable fresh supply, whoever manages to farm salmon successfully on land in China would have a comparative advantage.
3. **Operational Attributes:** Site selection is also of great importance and covers a wide range of factors, such as legislation and permits to set up a RAS facility, access to water, water-charging and -discharging licenses, potential subsidies, logistical infrastructure, access to energy resources, and the right labor force in the region. For instance, that is why some of the proposed projects in the US chose Florida or Maine to set up RAS farms. Furthermore, as RAS is still a developing concept, cooperation with nearby universities or other research institutes could facilitate the success rate. However, stand-alone operational attributes are not enough for a successful RAS facility, and it should be combined with one of the two factors above.

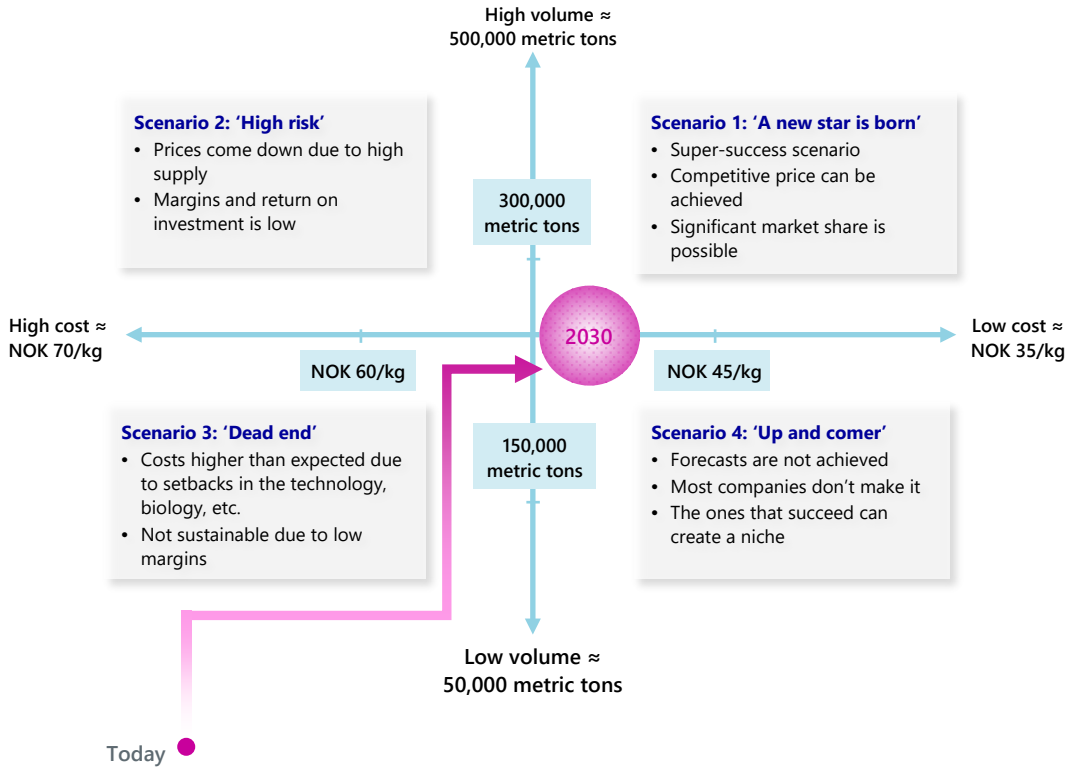
It's Not a Question of 'If,' but a Question of 'How Much'

Despite the uncertainty, RAS operations have the potential to produce around 250,000 metric tons of salmon by 2030. Currently, a lot of investment and attention is going into RAS operations, particularly for salmon aquaculture. As previously discussed, there are many projects in the pipeline at different stages of realization, and the number is increasing. We don't expect the volumes from land-based salmon-farming to reach 700,000 metric tons in the next ten years, as is currently proposed. Financial bottlenecks, the wrong business or marketing strategy, the wrong

choice of location or species to farm, or postponements in permits could delay the volumes coming from RAS.

Although RAS technology is improving, there are still many unknowns in terms of realistic production volumes, production cost, market price, and consumer acceptance, which makes it hard to quantify our expectations. We see four potential scenarios for the future of salmon-farming using RAS out to 2030 (*see Figure 7*). In our scenarios, the high end of production volume is 500,000 metric tons, and the low end of volume is 50,000 metric tons. For the cost of production, we assume a range between NOK 35/kg to NOK 70/kg.

Figure 7: Potential scenarios for RAS salmon projects by 2030



Source: Rabobank 2019

- Our first scenario, 'a new star is born,' is the super-success scenario. In this one, most of the RAS operations – the large ones in combination with smaller ones – reach their target volumes, and together they are able to produce around 500,000 metric tons. At the same time, they achieve low cost-of-production due to less-than-expected operational or financial setbacks. In this scenario, RAS salmon manages to capture a market share with significant production volumes. High supply could lead to lower market prices. However, this could increase the competitiveness of land-based salmon in comparison to sea-grown salmon. So, RAS salmon would become the new star.
- The second scenario is our 'high risk' scenario, in which we assume RAS operations would have high production volumes, but at the same time high cost-of-production per kilogram. In this scenario, the prices of land-based salmon could still come down due to high supply. As a result, high costs and lower prices may lead to an unfavorable financial situation for RAS farmers, and some farms may go out of business due to low margins and low returns on investments. High costs could also prevent competitive pricing (unlike Scenario 1), unless RAS salmon farmers can reduce their production costs.
- A low-volume/high-cost scenario is our third and 'dead-end' scenario. This scenario could happen if the RAS technology doesn't progress as planned. From bureaucratic delays to technological setbacks to skilled-labor shortages, a wide range of reasons could lead to low harvest volumes at high costs. Under this scenario, we assume operations would generally

perform worse than expected. RAS salmon businesses may not be sustainable, due to low margins, and possibly not competitive with salmon farmed in a marine environment.

- In scenario four, 'up and comer,' we assume that RAS farms would have a production volume around 50,000 metric tons, which shows that most of the current proposed projects in the pipeline would not be realized. However, if the cost of production happens to be lower than currently anticipated, the companies that manage to produce could create a niche for land-based salmon. Moreover, the production volume could be increased in the future, which would make RAS salmon an 'up and comer.'

Currently, we are at high costs with very low production volumes. Our expectation up to 2030 is somewhere between the 'up and comer' and 'a new star is born.'

Conclusions

RAS Could Be a Disrupter in the Next Ten Years

RAS operations have the potential to represent up to 25% of the expected growth in the total salmon supply out to 2030. If the risks within RAS operations are managed effectively, RAS could be a disruptive aquaculture technology in the next ten years – not only in terms of adding volumes to salmon production, but also by potentially disrupting trade flows, supply chains, and the marketing of salmon.

We don't expect all of the publicly announced RAS projects to materialize, and we expect many more proposals to be announced. We expect to hear stories of failure as well as success stories. In our view, we will only see small volumes coming from RAS within the next five years. Given that, we don't expect RAS technology to entirely compete with sea-based farming or impact salmon prices in the next five years.

However, RAS is emerging as a novel aquaculture technique and could disrupt traditional sea-based farming in the next ten years. We see four potential scenarios for the growth of land-based salmon projects up to 2030, ranging from success to high risk. The profitability of the projects will depend on production volumes, costs, prices, and consumer acceptance of land-based salmon. How large-scale RAS farms operationally and financially develop over time will determine the production volumes and cost of farming. Land-based salmon could almost be a mainstream product in the next decade if the proposed RAS salmon projects can more or less achieve their ambitious harvest levels and successfully produce a volume of around 500,000 metric tons. If RAS operations manage to produce salmon at around NOK 40/kg to NOK 50/kg, even with less-than-expected volumes of production, they can still create a niche.

In addition to how RAS will do in the long term, how the biological challenges within traditional open-net salmon-farming are managed will also impact future market penetration of land-based salmon. The volumes that would come from RAS would be even more critical if the biological and environmental challenges of sea-based salmon-farming expand.

Another important question is where we will see RAS farms successfully operating. A volume of less than 10% of the expected salmon production could sound relatively minor for large salmon producers like Norway and Chile. However, the ability to locally farm salmon in regions such as China, where there is no local salmon production, could change the current trade dynamics.

We also believe that every project is unique and needs to be evaluated separately. There is a high chance that some of these projects will succeed if they have at least half of the key success factors regarding the species and location selection. The companies who achieve this will be the frontrunners in land-based aquaculture. RAS technology is here. The big questions are where and when mainstream land-based salmon production start – and who will start it.

Off-Shore and Post-Smolt Are Also Here to Increase Supply

RAS technology is emerging, but other alternative techniques to increase salmon supply are also being explored. However, like RAS operations, off-shore salmon-farming is at an experimental stage, and significant volumes from off-shore salmon-farming are not expected in the next five years. The number of projects for off-shore salmon-farming is also lower than the number of RAS projects in the pipeline.

In the next decade, the majority of the salmon supply will come from the sea, but we will see more applications of post-smolt in traditional sea-based farming. Post-smolt can shorten the time salmon spends at sea, so the biological risks can be reduced and biomass can be maximized within a given license.

Neither of these alternative techniques have the advantage of proximity to end markets that RAS systems have. To some extent, off-shore systems can provide salmon where local supply is not available (e.g. China), but post-smolt can only be applied in the salmon farms that already have production licenses.

Land-Based Salmon Could Be the Beginning of a New Era

Currently, the focus of RAS is on high-value, premium, and niche products, such as salmon and, to a limited extend, kingfish, sole, sturgeon, turbot, barramundi, and steelhead. With technology advancing, there might be opportunities for other seafood categories as well in the future, although the focus will always be on the categories with a higher price point for some time. Generally speaking, successful RAS operators will be pioneers in what could be a new and booming aquaculture industry.

Imprint

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