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Background

HELCOM CG Aquaculture has a task to discuss and define what are Best Available Techniques (BAT) and Best Available Practices (BEP) for the Baltic Sea aquaculture. As a part of the process, The German Environment Agency commissioned a work by AquaBioTech Group to produce a background report including an overviewing report of aquaculture in the Baltic Sea region. The report made proposals for BAT/BEP to avoid or minimize nutrient pollution from aquaculture, specifically looking at the topics discharge limits, waste management practices and fish feed composition. Due to extensive topics of the report, RAS technology as well as the status of commercial projects was not discussed in detail. Therefore, Natural Resources Institute Finland (Luke) offered to prepare an internal working document on technology, environmental performance, and economics of RAS for further discussions at HELCOM CG Aquaculture.

In this report, current status of RAS sector especially in the Baltic Sea region but also in the global perspective is reviewed. Nutrient abatement technologies and typical nutrient discharges are presented. Thereafter we give an overview of various RAS technologies. In the third part, RAS cost items are presented, whereafter both literature feasibility studies and RAS company accounting data are used in the economic analysis for discussion what can be considered as BAT in the Baltic Sea aquaculture.

Action requested

The Meeting is invited to take note of the information and discuss the content of the report.

Current status of recirculation aquaculture systems (RAS) and their profitability and competitiveness in the Baltic Sea area

A report draft for HELCOM CG Aquaculture

26.5.2021

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Natural Resources Institute Finland (Luke)

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2. Status of the global RAS sector

RAS sector is rapidly growing although still forming only a fraction of global fish farming. Conventional salmon farming companies are investing hundreds of millions of euros to build RAS farms for salmon smolt production in especially in Norway, Scotland and Chile. By RAS smolts, cage farming phase can be shortened which is beneficial for many reasons, not least to ease the problems caused by the sea lice. In addition to growing fish to 150-200 gram smolts, some companies produce so-called post smolts, which can be over 500 grams before transferring the fish to the net cages. In addition to shorter production cycle, RAS is essential due to the shortage of fresh water supply for the smolt production. The ability to control nutrient discharges is not a strong driver in salmon smolt RAS development.

With some changes, similar RAS technologies can be used to grow salmon (and large rainbow trout) to the market size of appr. 3-5 kg. During the last couple of years, new projects have been published on a monthly basis (IntraFish 2018, Undercurrent News 2020). Planned land-based salmon projects would increase global salmon production by some 60% (app. 1,5 million tons), if full capacity will be achieved, and it would require over almost 20 billion € investments. However, several of these projects are still at very early planning phase and may not be started. As of 2020, projects are summarized in Figure 1. EU perspective on RAS production has been recently reported by EUMOFA (2020).

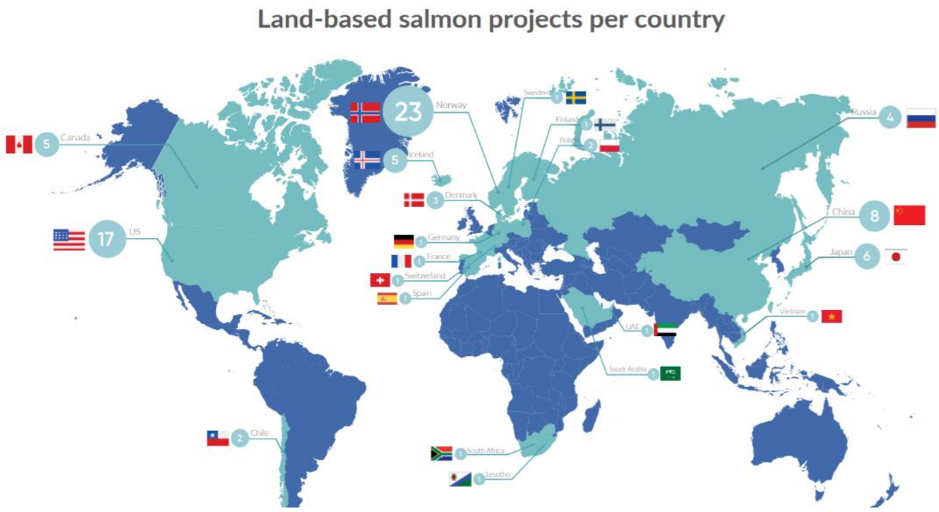


Figure 1. Land-based salmon or large rainbow trout projects per country in 2020 (Undercurrent News, 2020).

3. Status of the RAS sector around the Baltic Sea countries

Denmark

Various forms of recirculation aquaculture have been developed for several decades in Denmark, and currently Danish production forms appr. half of the EU RAS production (EUMOFA 2020). Denmark was the European pioneer of rainbow trout farming and the sector dates more than a century back. Basic land-based farming technologies were employed until the first sea cage farms were established in 1956, while the cage farming increased more rapidly in 70's and 80's. Eel farming started to grow in the 80`s and many Danish aquaculture technology companies have strong links to the eel sector, where experience in aeration, oxygenation, particle removal and biofiltration have been employed to save the water heating costs. Since then, the eel sector has decreased and currently produces mostly juveniles for restocking purposes.

During the 80's and 90's limited water availability stimulated the adoption of aeration and oxygenation systems in the land-based rainbow trout farming. Furthermore, the Danish licensing included early forms of incentives as farms were regulated by feed quotas instead of regulating the early production. The next step towards more intense production was taken during in 2010's, when the concept of so-called "model fish farms" was developed as a collaboration between aquaculture companies, research and administration (Svendsen et al. 2008). From the regulation perspective, land-based farm regulation evolved to be discharge limited for those farms investing in the model fish farm technologies, and by decreasing the nutrient discharges, farms were allowed to increase the production (Nielsen 2012). Alternatively, farms with feed quota under 100 tons can choose to remain to be regulated by the feed quotas and stay using more traditional technologies. Model fish farms are almost exclusively located outdoors. The current trend in Danish RAS sector is that water use is getting more intense and new technologies such as denitrifying woodchip reactor are being used (Pless-Jesner, pers. comm.). This is due to the Danish discharge-based regulation, which encourages companies to increase the production by implementation more technology, so that increased revenues would cover the investments. In 2019 there were 118 traditional, 17 Model 1-type and 16 Model 3-type fish farms, and 19 cage farms in Denmark (Danmarks Statistik online data). Model 1- and 3-type farms differ in water use intensity, with type 1 farms using more water and thus not necessarily having need for biofiltration.

Currently, there are two indoor RAS farms producing market size Atlantic salmon in Denmark. Danish Salmon and Atlantic Sapphire, former Langsand Laks, both started their activities in early 2010's. Exact production volumes are not available in public, but the production volume is in the range of 1000-2000 tons. Both of them have had periods of no production due to various technical reasons. In addition to these two RAS farms, one large salmon RAS farm is under construction in Skagen. One RAS farm produces market size pikeperch (AquaPri, company also having rainbow trout farming) and one RAS farm produces Seriola species for the European sushi markets (Sashimi Royal). Model fish farm type indoor farms producing rainbow trout juveniles have also been constructed, such as by FREA Aquaculture, which can be classified as a RAS farm. Finally, it should be noted that all marine RAS-farms and a significant part of freshwater farms discharge to the North Sea or Skagerrak, not in the Baltic Sea.

Finland

First RAS farm in Finland started in 90's as a hatchery for Arctic charr farming. Various RAS technologies have been tested and developed at the site, and it currently serves as juvenile production site for Nordic Trout until 2023, when it will be closed down due to municipality well water use. During 2010's, several RAS farms were constructed with a total of 11 RAS farms in operation at the peak. However, five of them are either in bankruptcy or have ended the production (Table 1). In addition to these farms, two companies have received environmental licenses: one to produce rainbow trout juveniles for cage farming (RAS Fish Oy; 100-150 tn production target) and the other to produce market size salmonids in larger quantity (HTM-Yhtiöt; 3000 tn production target).

Table 1. Finnish RAS companies. Size of the operations is an estimation and based on public financial statements, environmental licenses and news.

Company	Production	Status
Nordic Trout (Myrskylä)	First Finnish RAS farm established in 1998 and new RAS built in 2005 by former company Myrskylän hautomo, currently producing rainbow trout juveniles < 50 tons	In operation
Imatran Kala ja Kaviaari	Farming at pulp mill area started in 2002. Pilot system with 10-50 tn production of mostly sturgeon and pikeperch.	Production ended in 2015
Savo Lax (Rautalampi)	Farming started in 2010. European whitefish and pikeperch appr. 100 tons.	In operation
Finnforel (Huutokoski)	Started 2010 with Arctic charr and brown trout by company Huutokosken Arvokala. Currently rainbow trout juveniles for Finnforel Varkaus site appr. 100 tons.	In operation
Polar Fish	Traditional farm converted to RAS in 2010. Arctic charr 50-100 tons.	In operation
Carelian Caviar (Varkaus)	Farming at the pulp and paper mill area started in 2010. Caviar (and sturgeon) production.	Production ended in 2021
Kuhina (Imatra)	Farming at landfill site (using landfill methane for energy) started in 2011. Pikeperch production 50-100 tons.	Bankruptcy 2016
Caviar Empirik (Ilomantsi)	First sturgeon in 2011, no production before end of operations.	Production ended in 2013.
Sybimar	Farming started in 2011. European whitefish and rainbow trout 100-200 tons. Connected to biogas plant and small greenhouse.	Production ended in 2021
Fifax (Eckerö Åland Islands)	Farming started in 2016. Nominal capacity appr. 3 milj kg of 2-3 kg rainbow trout, production few hundreds of tons.	In operation
Finnforel (Varkaus)	Farming started in 2017. Production appr. 800-1000 tons.	In operation

Sweden

So far, Sweden has no commercial scale RAS farms, but there are several plans for large scale commercial projects. The most concrete project is located at Åre, where company Cold Lake AB has received environmental permit in 2019 for some 4000 tn capacity of Arctic charr farming and earth constructions for the facilities has started. Smögenlax has been given a permit for 6000 tn salmon production in Sotenäs. There is also another, gigantic 40000 tons Atlantic salmon project launched in Sotenäs by company Quality Salmon. The environmental permit for the farm is under the process. Premium Svensk Lax AB has started earth constructions of 10000 tn RAS farm in Säffle. Hushållningssällskapet is preparing an environmental permit application for 10000 ton RAS for arctic char production in Luleå. Finally, company Big Akwa is planning 3000 tn rainbow trout farm in collaboration with SCA paper in Härnösand. (Data for the web and per comm. Erik Olofsson)

Several smaller projects include e.g., Ljusterö Lax o Gös AB, which is a pilot farm collaborating with universities and producing some 5-8 tons of pikeperch per annum. Johannas Stadsodlingar AB was founded in 2018 and mainly aiming at aquaponics production. It has received R&D funding but may not be at production, yet. Cibum Sverige AB started environmental permitting process at Ljusdal but the process has been terminated. OmegaFish i Malmö AB was founded in 2018 with no activities so far. Hamra Fisk AB has started small scale farming and bigger facilities were supposed to be finished by 2020. (Data from the web and pers. comm. Alf-Håkan Romar)

Other countries

According to EUMOFA (2020), Germany and Poland had no registered RAS production prior to 2011. For Germany, statistics show app. 1600 tn RAS production in 2011 which increased to appr. 2300 tn in 2018. In Poland, RAS production was app. 2000 tn in 2018 (EUMOFA 2020). In the Baltic coastline, Jurassic Salmon started RAS production of market size salmon in 2013. Based on the public revenue information, the production is appr. 500 tn. Aqua Maof, an Israeli RAS tech company purchased a tilapia RAS farm near Warsaw and converted it into salmon RAS, farming few hundred tons of Atlantic salmon in order to develop the technologies for Aqua Maof's bigger projects globally. There are also few model fish farm-type RAS operations in Poland.

Information on RAS-operations in other Baltic Sea countries is not complete. In Estonia, three RAS-farms operate at Saaremaa and four RAS-farms at the continental Estonia. They are all small operations producing, sturgeon, rainbow trout or eel. Saaremaa operations have gone through bankruptcy or are currently in liquidation (Margus Rebane, pers. comm.). In 2018, Estonian RAS production was 160 tn (EUMOFA 2020). An Arctic charr RAS-farm, constructed by Finnish Clewer Aquaculture, started operations in Latvia in 2020, while in 2018 Latvian RAS production was 80 tn. Lithuania produces appr. 350-400 tn is RAS (EUMOFA 2020). In Russia, Republic of Karelia, company ZAO Virta produces rainbow trout juveniles appr. 100-200 tn per year in RAS. Belarus has few RAS operations producing rainbow trout and sturgeon. The size of these operations is at maximum few tens of tons per farm.

4. RAS technologies

In this chapter, typical RAS water treatment steps are presented. The technologies vary and especially the intensity of water use defines how the water should be treated.

Good RAS water quality and efficient discharge control starts with properly designed fish tank. Tanks can be round or raceway-type. Round or octagonal tanks can have so-called dual drains, where main water outflow is taken from the tanks side wall, located at the water surface level, whereas smaller part of the flow is taken from the bottom of the tank. The latter flow has high solids and phosphorus contents, and the sludge flow is directed to further treatment. In raceways, solids are removed by sludge cones located at the end of the raceway.

The main water flow from the fish tanks goes through a mechanical filter such as drum filter, which removes particles typically larger than appr. 50 µm. In drum filters, particles are trapped inside of the rotating drum and directed to a backwash area and transported out of the filter to sludge thickening units.

Typically, particle removal is followed by the biofiltration. Biofiltration is a nitrification process, where bacteria transform toxic ammonia first into nitrite, still very toxic to fish and finally to nitrate. Nitrate is tolerated at much higher concentrations than ammonia and nitrite. Numerous different biofilter designs exists, but they all have a carrier media where the nitrifying bacteria form a biofilm. For example, fixed bed filters have carrier media which is not moving. Fixed bed filter can further remove fine particle, whereas moving bed filters do not trap fine particles. On the other hand, moving beds aid in carbon dioxide removal and add some oxygen. Nitrification process consumes alkalinity, the capacity to buffer against pH changes and therefore, alkaline chemicals such as lime or caustic soda are added to maintain pH at appr. 6.5-7. Biofilters are essential to fish welfare, whereas they have a minor impact on nutrient discharge reduction.

Both fish and the biofilter microbiota produce carbon dioxide, which would accumulate in RAS at harmful and toxic levels without removal. CO2 removal is called degassing, aeration or stripping and can be done both in the fish tanks and/or as a separate step before the water flows back to the tanks. Aeration can be done by pumping air into the water, or by pumping water in the air, and several technical principles can be applied in the design. Aeration process has practically no direct effect on nutrient discharge control.

When leaving the fish tank, O2 saturation level in the water is typically appr. 70% and the level is further reduced after the biofilter. Aeration can bring the saturation level up to appr. 90%, but due to the intensity of RAS production, supersaturated O2 levels are used. Oxygen can be added at high pressure in oxygen cones or under lower pressure using systems such as low-head oxygenators. The oxygen cones use more energy (electricity) than low-head oxygenators.

Ozone treatment removes organics and improves microbial water quality. Typically, ozone treatment is followed by UV, which brakes down possibly remaining ozone harmful for fish. The RAS water treatment processes described above are illustrated in Figure 2.

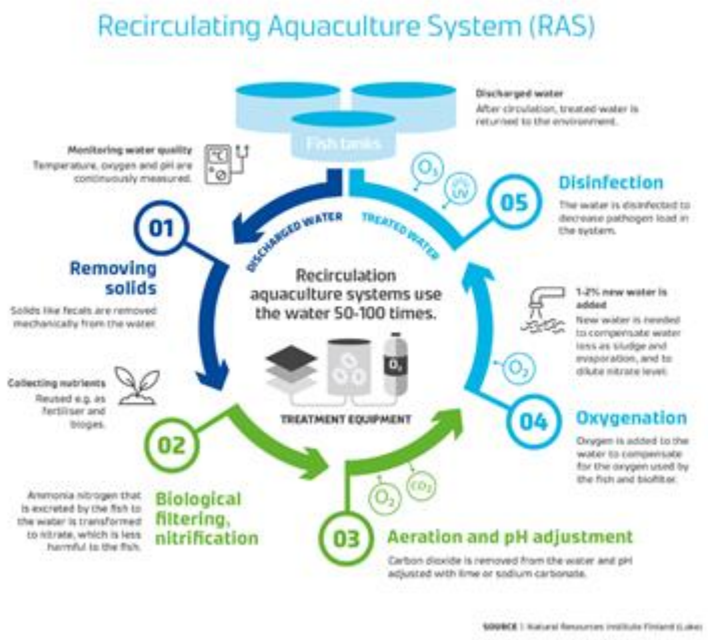


Figure 2. Typical water treatment steps in within a RAS farm.

As noted above, typically RAS has two primary water flows. A smaller volume consists of sludge originating from sedimentation systems, particle filtration and system backflush and has high percentage of phosphorus and organic matter. A larger volume of water has lower solids level but contains most of the nitrogen discharge. These two streams, “sludge” and “overflow”, are typically processed separately to reduce RAS nutrient discharges.

Sludge is further concentrated by sedimentation or filtration processes, typically with the aid of chemicals. RAS farm can have a sedimentation basin or pond, where sludge and pH stabilizing chemicals are combined. Sludge basin is frequently emptied and used as a fertilizer in field or taken to a biogas plant. In more intense indoor RAS, sludge thickening process is carried out at an indoor system. Typical municipal coagulants and flocculants are mixed with the sludge, whereafter concentrated sludge is separated by belt filters, flotation or screws. Depending on the regulation, overflow of sedimentation pond or sludge coagulation can be discharged without further treatment or led to a nitrate discharge treatment. In the Danish model fish farm concept, the larger water flow and sludge overflows are led to constructed wetlands and to woodchip reactors, which are efficient at nitrogen removal. Discharge nitrogen can also be reduced by more intense denitrifiers with external carbon source to drive the process.

The degree of water re-use intensity defines the water treatment steps necessary for maintaining good quality water for fish growth and welfare. Water recirculation percentage has been used to describe water use intensity, but more exact way would be to calculate feed used per volume of new water. In typical RAS farms, appr. 500-1000 liter of new water is taken per kg feed used. Danish model farms are less intense, using some 3000-5000 l/kg. The very intense zero-exchange farms replace only the water lost through sludge and evaporation, and water use can be down to 50-100 l/kg (Figure 3).

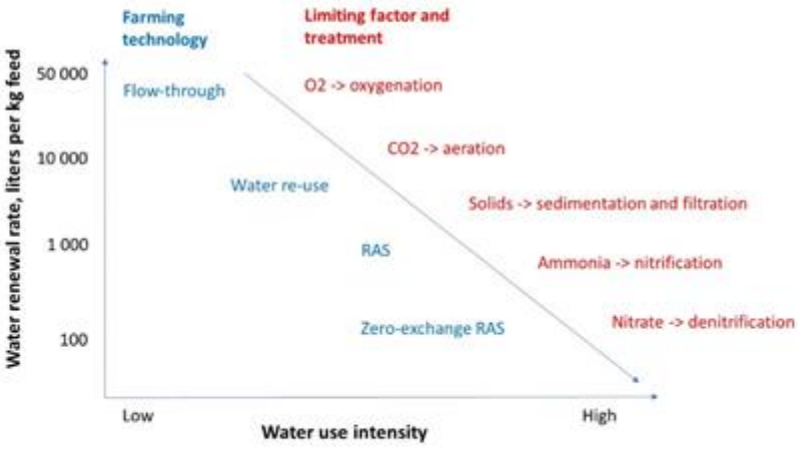


Figure 3. Water use intensity, limiting water quality parameters and applied water treatment technologies in RAS farming.

Nutrient discharges of RAS farms depend selected technologies. Water use intensity plays an important role in the nutrient capture efficiency: the more intense the water use is, the higher are the concentrations of nutrients in the water and sludge streams, and higher reductions are more possible than in larger water and sludge streams. In Table 2, nitrogen and phosphorus discharge estimates for cage farming, Danish model fish farming and intense RAS are provided. The Danish model fish farms can currently have higher nitrogen removal percentages than presented in the table, due to the increasingly common woodchip reactors. In some cases, RAS discharge are led to municipal or industrial wastewater treatment units, where nutrient reduction efficiencies can be even higher than 90%, but performance data of such systems cannot be found in public.

Table 2. Typical phosphorus and nitrogen discharge estimates for cage farming, Danish model fish farming and intense RAS. Discharge reduction efficiencies are compared to cage operations. Data sources are provided in footnotes.

	Cage farming [1]	Model fish farm 3[2]	Intense RAS
P discharge, kg/tn production	4-5		
Reduction, %		76	70-90
N discharge, kg/tn production	35-40		
Reduction, %		50	30-90

[1]Data from the regional authority statistics (Centre for Economic Development, Transport and the Environment, Southwest Finland)

[2]Jokumsen and Svendsen (2010)

CO_2 emissions (carbon footprint) are higher in RAS production compared to flow-through and cage farming operations. This is due to energy intense technologies, especially water pumping, temperature control of the water and building, and other technologies. Few carbon footprint estimates for RAS production are available, and the values depend on system borders and allocations, as well as details of the RAS design such as water lifting heights. Furthermore, the country of production and consumption makes the largest difference. Liu et al. (2016) compared carbon footprint of salmon consumed in USA, either produced in RAS in US or produced in cages in Norway and transported by air freight to US. At producers' gate, carbon footprint of salmon in Norway is half of that compared to RAS salmon using average fossil fuel based electricity. However, carbon footprint of RAS salmon produced and delivered in US the was less than half of that for salmon produced in traditional open net pen systems in Norway that is delivered to the US by air freight. In that study, the most climate friendly alternative of US salmon consumption is to ship frozen salmon from Norway with a modern container ship to US. However, frozen product is not directly comparable with a fresh fish, since they have partially different uses (Liu et al. (2016).

5. Cost structure of RAS farming

Cost structure of RAS farming has been estimated in several feasibility studies. Feasibility studies are prognosis based on best knowledge at the time of writing and specific for the country and type of production. Feasibility studies have been used for business cases or are used at more general level to evaluate the potential of RAS sector or to analyze the importance of single cost items for further improvements by research and development.

Investments include land property, buildings, tanks, water treatment systems, automation, measurement and feeding systems, possible processing facilities and several other items. Investments range from appr. 10 to 20 euros per kg estimated yearly production. Various investments have different true depreciation times, ranging between 5 to 30 years, and interest rates obviously vary.

Feed is usually the major variable cost factor. RAS feeds should not contain certain feed ingredients and are therefore few percentages more expensive than feeds for open system farming. The price of fingerlings becomes relevant factor for profitability especially in the production of table size fish when fish are sold small. The larger the fish are farmed, the less significant becomes the fingerling purchasing cost, because less fingerlings are needed for producing the same tonnage. Other variable costs consist of electricity, oxygen, and pH control and sludge thickening chemicals, cleaning chemicals, laboratory systems etc. RAS production is more labor intensive and requires more maintenance work and repairs.

RAS operation insurance can become a fairly large cost factor due to higher risks compared to open system farming. Licensing costs are typically related to the size of operation. In Norway, RAS licences are free whereas cage farming licenses have very high prices. Transport and administration costs are similar between traditional and RAS farming. However, for oversea markets, local RAS production can avoid high air cargo costs (Liu et al. 2016).

Bio-economical productivity factors, especially growth rate, mortality and feed efficiency influence the efficiency of production and thus costs. In some feasibility studies, variation on these parameters is included as sensitivity analysis.

Table 3-5 present cost structures for various RAS cases. The products vary from live rainbow trout juveniles to heads on gutted large salmon. In Table 3, production costs for large salmon are estimated within the range 3.5-5.0 euros per kg (HGO, head on gutted).

Table 3. Production cost structure estimates for RAS farming of 4-5 kg Atlantic salmon.

	Summerfelt et al. (2013), USA	Warrer-Hansen (2015), Ireland	Liu et al. (2016), USA	Bjørndal and Tusvik (2017), Norway
Feed	2,08 € / 59 %	1,52 € / 42 %	1,71 € / 34 %	1,58 € / 42 %
Eggs or juveniles	0,1 € / 3 %	0,26 € / 7 %	0,11 € / 2 %	0,03 € / 1 %
Electricity	0,25 € / 7 %	0,24 € / 7 %	0,3 € / 6 %	-
Personnel	0,28 € / 8 %	0,08 € / 2 %	0,47 € / 9 %	0,23 € / 6 %
Oxygen	0,16 € / 5 %	0,08 € / 2 %	0,13 € / 3 %	-
Chemicals	-	0,1 € / 3 %	0,08 € / 2 %	-
Fish health	-	0,03 € / 1 %	-	0,04 € / 1 %
Insurance	-	0,07 € / 2 %	0,16 € / 3 %	0,08 € / 2 %
Maintenance	-	0,02 € / 1 %	0,42 € / 8 %	-
Administration	0,08 € / 2 %	0,05 € / 1 %	-	0,08 € / 2 %
Other	-	0,1 € / 3 %	0,55 € / 11 %	1,11 € / 29 %
Depreciation	0,57 € / 16 %	0,44 € / 12 %	0,52 € / 10 %	0,65 € / 17 %
Interests	-	0,62 € / 17 %	0,58 € / 12 %	-
Production cost, €/kg	**3,52 €[1] / 100 %**	**3,61 € / 100 %**	**5,04 €[1] / 100 %**	**3,79 €[2] / 100 %**

One of the most recent feasibility studies is provided by Marttinen (2020), who built a real-case scenario for juvenile production RAS in the city of Kaskinen, Finland (Table 4). Fairly high cost of over 6 € per kg live fish can be partially explained by the necessary vaccination and by the production cycle of rainbow trout for further on-groing. Due to spiking summer temperatures and freezing winter conditions, fish can be transferred to the sea only during the Spring months and for second time in the autumn. This leads to uneven biomass at the farm and therefore more inefficient use of investments, since RAS systems need to be dimensioned according to the peak biomass. Furthermore, Marttinen (2020) included several cost items often neglected in feasibility calculations, such as property tax and energy costs of other activities than water pumping. Table 5 presents three cases for rainbow trout production in RAS in Finland (2 kg HOG, 500 g HOG and 500 g for further on-growing in sea cages.

Table 4. Cost structure for RAS production of rainbow trout growing from eggs to 360 g fish for further cage farming (from Marttinen 2020). Investment subsidy 40 % is assumed.

	€/kg live fish
Eggs	0.128 € / 2 %
Feed	1.522 € / 24 %
Electricity	0.739 € / 12 %
Personnel	0.721 € / 12 %
Oxygen	0.222 € / 4 %
Chemicals	0.356 € / 6 %
Vaccination	0.440 € / 7 %
Insurance	0.080 € / 1 %
Maintenance	0.200 € / 3 %
Waste disposal	0,060 € / 1 %
Property tax	0.042 € / 1 %
Depreciation, 20 yrs	0,875 € / 14 %
Interests, 5%	0,875 € / 14 %
Production cost, €/kg	**6.260/ 100 %**

Table 5. Cost structure for three RAS cases in Finland. Data from Vielma et al. (2006), Kankainen et al. (2014) and Sinisalo et al. (2020). For portion size and juvenile cases, energy costs are included in other operating expenses.

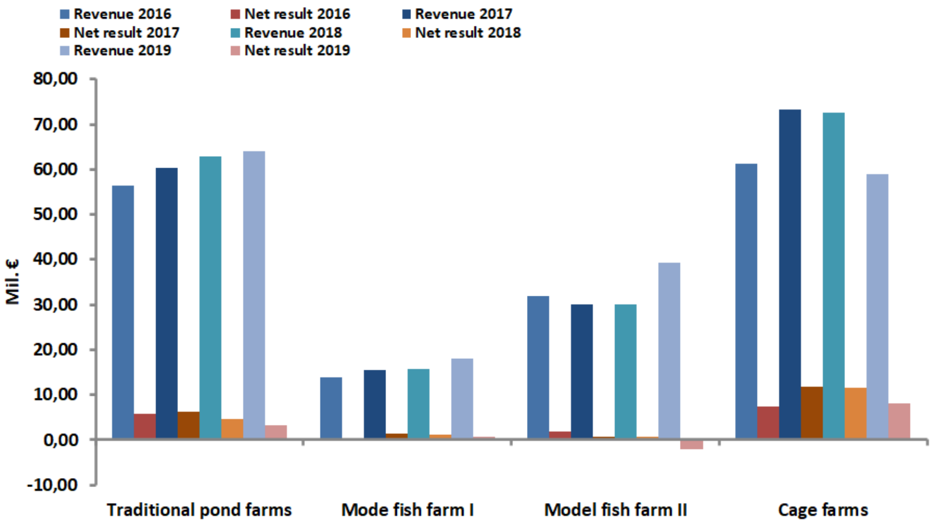
	Large rainbow trout	Portion size rainbow trout	Rainbow trout juvenile for cage farming
Feed	1.21	1.41	1.21
Eggs/fingerlings	0.35	0.74	0.13
Other operating expenses	0.22	0.72	1.01
Personnel	0.68	0.47	0.79
Depreciation	0.98	0.76	1.13
Subsidy impact	0.32	0.33	0.75
Other expenses	0.22	0.18	0.70
Energy	0.57		
Financial expenses	0.18	0.19	0.26
Production cost, €/kg (present value)	**4.73 (5.76)**	**4.80 (4.96)**	**5.98 (5.98)**

6. Economic performance of existing RAS farms in the Baltic Sea area

This section compiles available information on economic performance of RAS farms in the Baltic Sea area, especially in Denmark and Finland, where such data is available.

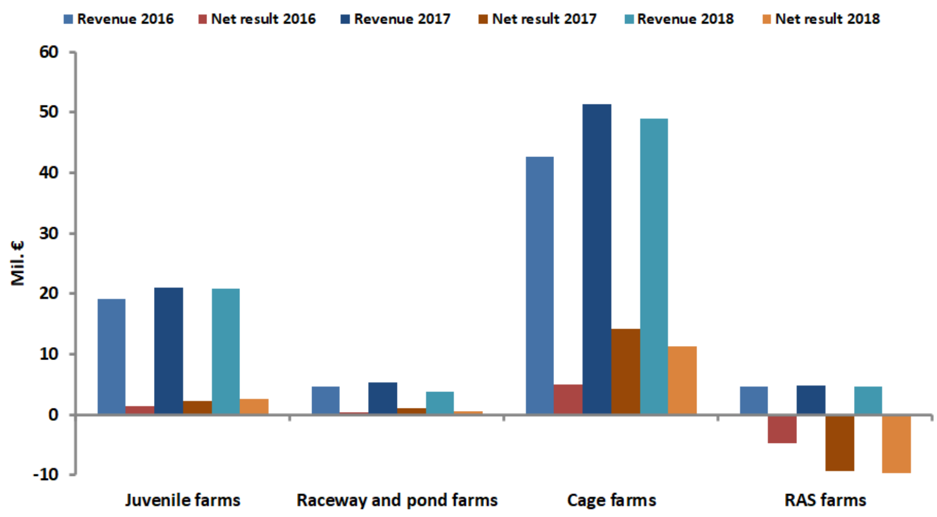
Statistics Denmark presents yearly summaries on the production and economics of all types of aquaculture companies. Data on traditional pond farms, model fish farms and cage farms is presented in the publicly available databases. However, the number of intense RAS is currently too low, appr. five, to publish the information. Therefore, the second part of the economic performance contains available company accounting data from Denmark and Finland.

In Picture 4, revenue and netmargin of traditional pond farms, model fish farms and cage farms in Denmark during 2016-2019 is presented. In 2019, combined revenues of the traditional technologies pond and cage farming was 123 million euros, while that of model fish farms was 57 million euros. Combined net result for the traditional farming was 11 million euros, whereas net result for model farms was 1.3 million euros loss.



Picture 4. Revenue (blue bars) and netmargin (orange bars) of traditional pond farms, model fish farms and cage farms in Denmark during 2016-2019. Data from Danmarks Statistik, www.dst.dk

For Finland, revenue and netmargin of traditional juvenile production, raceway and pond production of large consumer size fish, cage farms and RAS farms during 2016-2018 is presented in Picture 5. The vastly different net results of cage and RAS farms is apparent. Financial analysis of Finnish RAS farms follows in the next chapter.



Picture 5. Revenue (blue bars) and netmargin (orange bars) of Finnish juvenile farms, inland raceway farms, Baltic Sea cage farms and RAS farms in 2016-2018 (Kärnä et al. 2018, 2019 and 2020).

7. Financial statement analysis

Financial statement analysis shows cost structure of true business operations. Table 6 contains financial statements of several RAS companies in Finland, while Table 7 and 8 contain net results from Finnish and Danish RAS farms. In the following, we discuss what costs are included in each cost category and how that particular cost category is reflected in the economic performance.

Turnover of the investigated RAS farms have been lower than expected. The reasons are not detailed in the financial statements, but from publicly available sources such as news and seminars it is apparent that production target has not always been achieved. Turnover can be also weaker than expected due to unexpected mortalities or lower demand at the markets, caused by e.g., quality problems.

Purchasing costs include material and services that are needed to run the operations. In RAS operations, this category consists of e.g., feed, electricity, oxygen, chemicals and eggs/fingerlings. At some farms purchasing costs exceed the turnover and can be as much as three times higher than the revenue.

Variation in stock should be taken into account if company is increasing its fish biomass with same material and other expenses. Recently started large farms have increased the stocks and turnover but the stock values are far from related material costs. In the long run, this cost category’s impact on profit should be of fairly low importance.

External services in RAS may include e.g., sludge treatment and logistics, water treatment by external service providers, and maintenance services. Parent company interventions can also be included as external services. In some companies, external services such as various maintenance and technical work tasks are high, which could be explained by “service interventions” by other related companies.

At the investigated companies, **personnel costs** are high compared to turnover, and can make over 40% of the income at some companies and can be as high as than 2.5 times the turnover at one company.

At the investigated companies, **personnel costs** are high compared to turnover making over 40% of the income at some companies and can be as high as than 2.5 times the turnover at one company. It appears that the efficiency of work should be improved, which may be the case if the maximum capacity of the farm is reached.

Investment deprecation is the share of investment value that is annually decreased from the profit account, thus showing the cost impact of investment without interest. Deprecation periods vary between items. The rule of thumb is that investment's value should be decreased to zero during its operational life time. Real estates normally have long deprecation periods of e.g., 20 years, buildings and robust construction items 10 years and more sensitive technologies 5 years. In accounting, company can to certain extent adjust how much it decreases the investment value.

Subsidy can impact the investment deprecation, if the e.g. public subsidies are included in the balance sheet by decreasing the value of investment. Role of subsidies is further discussed in the next chapter.

Other operating expenses include overall costs such as marketing, management, rents and agreements, energy costs and licenses. Thus this category can include costs that vary with the production volume but mainly these costs have fixed character. Feasibility studies show that the energy cost in RAS can be a significant factor.

Financial expenses depend mainly of the interest rate and the deprecation period. With long depreciation period yearly deprecation is small but financial expenses large Currently, interest rates are low. If a company wants to improve the short term profit, it can delay the investment deprecation period. If company uses own equity in investment, the cost of interest is lower. Obviously, production volume has a significant effect on the financial expenses.

Profitability can be examined at different levels of the financial statement. **Gross margin** determines whether turnover covers material costs. In almost all Finnish RAS farms material costs exceed the loss level. If further variable costs such as energy is added to this cost category, it can be argued that each produced fish increases the loss in RAS system.

Operational profit should cover all costs for the operational business when loans are paid. Therefore, in case of negative result there is no tax to pay for the community for the shareholders from **Profit before taxes**.

Regarding the two existing companies producing rainbow trout for the consumer markets, financial statements indicate that calculated production cost are still 3-7 times higher than the market price. Two Finnish RAS companies have had a profitable years. These companies specialize in the production of high value species.

Table 6. Financial statements of three RAS companies in Finland. Two of them are producing rainbow trout for consumer markets while one is producing higher valued species for consumer markets.

RAS company	Company A		Company B			Company C			
Year	2018	2019	2018	2019	2020	2017/16	2018/17	2019/18	2020/19
Turnover	1 181 536	2 660 584	332 271	701 211	1 241 616	864 024	1 066 196	972 566	728 435
Other income	25 802	35 703		17 014		234	19 599	202 970	137 139
Material costs									
Purchasing	-1 686 548	-2 419 766	-2 237 184	-2 745 302	-3 022 823	-367 827	-430 503	-370 035	-291 253
Variation in stocks	92 091	-176 618	398 333	555 542	-256 019	59 284	13 354	-197 911	62 630
External services	-965 196	-860 150	-22 351	-41 547	-76 597	-23 246	-13 359	-43 171	-28 649
Personnel costs	-567 486	-1 008 216	-919 782	-1 012 745	-1 381 398	-214 277	-244 456	-243 532	-226 200
Investment depreciation	-511 591	-702 917	-819 688	-1 004 013	-1 150 420	-55 349	-53 964	-59 666	-60 301
Other operating expenses	-1 531 957	-1 758 400	-2 071 441	-2 757 949	-2 644 635	-237 080	-252 941	-264 133	-277 522
Operating profit/loss	**-3 963 349**	**-4 229 780**	**-5 339 842**	**-6 287 789**	**-7 290 276**	**25 763**	**103 926**	**-2 912**	**44 279**
Financial expenses	-187 337	-281 788	-734 452	-750 833	-1 104 710	-65 830	-81 379	-75 266	-70 179
Profit (before aproprication and taxe	**-4 150 686**	**-4 511 568**	**-6 074 294**	**-7 038 622**	**-8 394 986**	**-40 067**	**22 547**	**-78 178**	**-25 900**
Total Costs (TC)	-5 358 024	-7 207 855	-6 406 565	-7 756 847	-9 636 602	-904 325	-1 063 248	-1 253 714	-891 474

Table 7. Net results of Finnish RAS companies based on financial statements.

Company	2011	2012	2013	2014	2015	2016	2017	2018	2019
A	-602 000	-1 246 000	-954 000	-1 085 000	-648 000	-589 221	-663 672	-462 000	-844 000
B	-242 118	-769 555	-218 297	-219 728	-947 000	192 000			
C	-85 000	-265 000	-350 000	-86 700	-10 000				
D	-193 000	-230 000	-282 000	-179 000	-122 000	-121 000	-40 000	23 000	-78 000
E	-406 000	-382 000	-322 000	-649 000	-1 176 000	-594 205	-1 300 000	-273 000	-1 017 000
F			-35 000	-327 000	-492 000	-3 080 000	-4 425 000	-6 088 959	-7 038 633
G					-11 000	-57 000	-393 000	-2 985 287	-4 532 691
H							199	99	123

Table 8. Net results of Danish RAS companies based on financial statements

Company	2011	2012	2013	2014	2015	2016	2017	2018	2019
A	- 111 990	-270 437	-842 086	-2 123 173	-1 123 506	-1 565 925	-2 535 479	-2 800 748	-5 550 843
B		-36 568	-134 401	-1 948 191	-3 700 042	-1 527 215	-426 365	17 906	-336 015
C			-4	-13 798	218 699	453 778	1 167 467	1 954 025	1 321 458
D						-116 988	-277 874	-1 686 555	-1 296 091
E				-141 948	-752 275	-485 235	-608 972	-1 020 268	-629 887

Discussion

General

The major observation and of utmost importance for the HELCOM BAT discussion is, that economic performance of RAS companies is much poorer than estimated in feasibility studies. Despite the European Maritime and Fisheries Fund support for the investments, varying between countries and projects but which are likely in the range of 20-40 % of the investment, RAS farms are heavily on red and several have terminated their activities or are bankrupt. The only form of RAS production, which systemically seems to be able to have positive net results, is the Danish model fish farming.

There are several potential reasons behind the economic losses. To our best knowledge, the main reason is that RAS farms have not reached the nominal production capacity used in the business planning phase. Causes of lower production are manyfold, and include faults in the technical design, unexpected technical failures of critical systems and inadequate quality and quantity of intake water. Although management and operative workers at farms do their best to reach full capacity, the technology is sensitive and still developing, and biology brings about surprises.

Competitiveness

Economic result is very much connected to the competitiveness of the selected business idea of each RAS project. Besides the technical and operational issues, several factors influence competitiveness, such as choice of product, economics of scale, location and subsidies.

Fish markets are integrated (Setälä et al. 2007) meaning that import products affect the value of domestic products, also in the Baltic Sea region. Therefore, local production should be competitive in comparison to the imported production. If that is not the case, substitute products will enter the markets, causing market prices to decrease, which eventually will decrease the profitability of less competitive production methods. For example, Danish model farms produce portion size rainbow trout, which is also produced in large quantities in Turkey and imported to the North European markets. As a result, Turkey imports have caused pressure on the profitability of the Danish production. In that very case, Danish products need to demonstrate a better quality or some other attribute if it wishes fetch higher prices and maintain economic sustainability. Similarly, Norwegian salmon is a substitute for large rainbow trout produced in Finland, Sweden and Denmark, and changes in Norwegian and global salmon price influence large rainbow trout farming profitability. During the last few years salmon and trout price has been high but RAS companies have still reported significant losses. Better competitivity and higher net income margins is needed especially during lower global salmon prices.

It has been argued that specialization is one of the solutions towards profitable business and competitive advantage of RAS. However, only a limited volume of production can be based on niche products. If preliminary high value production volumes are increased significantly, value of the product in market will decrease. This is especially possible at limited domestic markets such as for the European whitefish in Finland (Kankainen et al. 2007). As a global example, caviar market prices have decreased due to increased production in countries such as China. A further heavy hit was caused by the COVID-19 pandemic drastically decreasing caviar demand at premium restaurants and airport shops and forced one Finnish company to shut down the activities.

Global RAS projects are getting bigger and apparently, the main reason is the economics of scale. The scale needed for profitability depends on the product of choice. Smaller operations may be profitable for high value products such as juvenile fish or niche consumer product. There are no recent analyses using latest RAS cost structure on the economics of scale for producing a substitute product for the Baltic Sea cage farming. In our discussions with managers of a global RAS technology company, profitability would need some 5000 tn production. That is still 3-5 times higher production than any of the companies operating in the Baltic Sea area have reached so far. It should also be noted that we have not got access to details of such profitability analyses and cannot make conclusions on the robustness of such an estimation. 5000 tn operations would require appr. 40-60 million euro investments and it goes without saying that such business needs significant investments outside the traditional Baltic Sea aquaculture sector. Finally, although economic of scale improves the efficiency of fixed costs, non-volume depended variable cost should first be covered by revenues.

Environmental effects of fish farming depend not only on the production technologies, but also on the location. Nutrient discharges of a huge RAS farm can have local environmental effects, whereas large offshore operations may not have measurable impacts. Therefore, RAS projects located at sensible areas may need to invest in very advanced discharge control technologies, further decreasing the profitability.

EU member countries have been able to support RAS investments through maritime and fisheries funding scheme. As of writing this report, member countries are writing their national plans for the next funding period and certain level of support can be expected. However, considering some of the very large RAS projects that are in pre-planning phase, available fund may not be adequate for high percentage investment subsidy for the largest projects. Therefore, estimating capital costs of future RAS projects is difficult.

Can RAS be considered as BAT for farming salmonids for consumers?

According to article 15(2) of the EU Industrial Emissions Directive, emission limit values and the equivalent parameters and technical measures in permits shall be based on the best available techniques, without prescribing the use of any technique or specific technology. The directive includes a definition of best available techniques in article 3(10):

- "best available techniques" means the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis for emission limit values and other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole;
- "techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- "available" means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

- "best" means most effective in achieving a high general level of protection of the environment as a whole

Based on best available information, economic performance of RAS farms producing consumer size Atlantic salmon or rainbow trout in Denmark, Finland and Poland is alarming. Only the Danish model fish farms have been economically viable to date. Model fish farm technology is simpler compared to what technology at intense RAS farms. The transformation from intensified pond and raceway farms has been gradual and model farms are run by experienced aquaculture entrepreneurs in Denmark. Furthermore, the incentives in the Danish regulation have played an important role in the gradual modernization of the aquaculture sector.

In Finland, most expectations have been laid on the newest large scale RAS companies. Still, several years after operation, companies make large losses. It has been expected that at least one of those companies has several advantages to succeed, such as long experience in RAS farming, synergies at the industrial area, niche product, active marketing and close collaboration with R&D partners. It remains to be seen whether the operations will be economically sustainable in the coming years.

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