Potential for Land Based Salmon Grow-out in Recirculating Aquaculture Systems (RAS) in Ireland

A report to The Irish Salmon Growers’ Association

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July 2015
In July 2014, the author was approached by the Irish Salmon Growers’ Association (a part of IFA Aquaculture) to conduct an “Assessment of land based grow-out of salmon in closed containment systems under Irish conditions” for its ongoing AQUACOMMS communications initiative on farmed salmon.

The client requested that the assessment cover technical and biological requirements, capital and running costs for a farm of commercial size producing 4.5 kg average size weight fish. The client also requested that the assessment deal with specific issues related to land based production in closed containment systems or Recirculation Aquaculture Systems (RAS), such as relevant permissions, implications associated with producing the current Irish output of approximately 15,000 tons and the projected 38,000 tons outlined in Government targets in land based systems. The client also requested that, where possible, the assessment addressed issues such as sustainability and market/marketing aspects.

The author has a degree in Chemical Engineering with membership of the Danish Society of Chemical, Electrical and Mechanical Engineers. He also has a degree in Commerce from Copenhagen Business School.

He started out his career at the Water Quality Institute in Hørsholm, Denmark (now merged with DHI - Water and Environment and being the world’s largest water research institute) working with water chemistry, wastewater treatment and water ecology. He was a co-founder of the Aquaculture Department under the Institute where the first work on RAS took place and he is together with his colleagues there, considered the founders of RAS.

In 1982, he started up fish farming in Ireland and produced both trout and salmon smolt, as well as being involved in salmon farming.

In 1990 he founded Aquaculture Consulting Ltd, a company helping the fish farming industry with feasibility studies, new fish farm design, production enhancements schemes, environmental impact assessments and other legislative issues. He was subsequently in 1993 appointed Chairman of an EU Commission Group dealing with harmonization of EU Environmental Legislation on Aquaculture.

In 1997 he was retained by Skretting, the world’s largest fish feed company, to help their customers with new fish farm design, hereunder RAS, helping customers with production enhancements and all legislative matters.

Since 2004, he has been involved with RAS design and has been instrumental in the innovations seen in RAS design in the last decade or so. He is a frequent speaker at RAS conferences as he basically globally is considered to be one of the most knowledgeable within RAS technology.
Acknowledgements

The technical, biological and economic assessments in this report would not have been possible without the help of a number of people and organisations.

I would like to thank my colleagues in Inter Aqua Advance A/S in Denmark for valuable discussions and help on a functional RAS design for a large commercial production. I would also like to thank a number of colleagues in the industry; Bram Rohaan, manager at Langsand Salmon in Denmark, Cathal Dineen, manager at Namgis, Vancouver Island, Canada for sharing their experiences with me.

I would also like to thank Frode Mathisen, Director of Biological Performance, Grieg Seafood in Norway for valuable insight into the situation in Norway.

I would also like to thank Jan Feenstra of Marine Harvest Ireland for discussing certain production aspects and costs.

I contacted a number of Planning Departments in County Councils with shore access in relation to County Development Plans. I did not receive one reply. I also contacted the Department of the Environment and EPA in relation to environmental requirements for land based production. I did not receive any feedback.

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Discovery consists of seeing what everyone has seen and thinking what nobody has thought, Albert Zsent-Gyorgyi, 1937.
# Table of Contents

1. Introduction
2. Executive summary
3. A brief description of the Irish Salmon Sector
4. Historical background for RAS and it’s role within the Salmon Sector
5. Legislative aspects, licensing, fish culture and other licenses
6. Siting of land based salmon grow-out systems
   6.1. Siting criteria
   6.2. Availability, County Development Plans
7. System design for a 5,000 tons per annum unit
   7.1. RAS processes
   7.2. System design
   7.3. Water environment and growth
   7.4. Day to day operation of a 5,000 tons per annum unit
   7.5. Issues and/or risks related to RAS, biological and technical
8. Supply of smolts
9. Economic aspects under Irish conditions
   9.1. Capital costs
      9.1.1. Land costs
      9.1.2. Plant costs
      9.1.3. Infra-structure
   9.2. Operational costs
10. Market aspects
    10.1. Fish quality
    10.2. Acceptance and image
    10.3. Biodiveristy Interactions
11. Success/ failures of existing trial or commercial land based salmon farming in RAS
12. Appendices
    12.1. Layout for 5,000 tons per annum land based salmon grow-out
    12.2. Description of technology
    12.3. Feed composition and resource management
    12.4. Capital Costs
    12.5. Operational Costs
    12.6. Carbon Footprint
13. References
1. Introduction

The Irish salmon farming industry today produces salmon very effectively, utilizing our natural resources well. The marine portion of Irish production systems are similar to those used around the rest of the world and modified for our conditions, consisting of large net cages made from relatively simple constructions, to give a large production volume at a competitive cost. When these farms can be located in relatively sheltered areas with good water depth and excellent tidal flushing or exchange of water, it is easy to understand why Ireland has such potential for creating a successful industry.

At this time, new technologies are being developed and promoted for salmon production in contained systems, both land-based and in the sea. Contained systems operate on the principle that one has control over the production environment and a potential for waste containment.

The question is if these new technologies can increase or even replace existing production carried out in cages in the sea and if, at this stage, they are a sustainable alternative or investment opportunity under Irish conditions.

As with any other modern food production activity, fish farming has to be undertaken on a sufficient scale to be competitive. In the following report, the planning, the economics and the construction of a land based system with an annual production of 5,000 tons of 5.0 kg salmon will be assessed.

The report describes in detail all technical aspects of RAS production and system design and operations. It also covers important biological aspects of land based salmon production.

The main aim of the report is to assess the viability of land based salmon production in RAS under Irish conditions. This includes detailed information of capital expenditure and operational costs as well as the market situation for salmon.

The report does not make comparisons with respect to economy between land based production and the conventional production. There are two reasons for this 1) there is no comparison data available as the bulk of Irish salmon production today is organic. Land based salmon production in RAS will not be eligible for organic status and 2) to assess if a commercial scale land based salmon production project on its own is ultimately a business proposition in Ireland or anywhere else, i.e. will it be profitable? – the basic criteria for any investment.

The conclusions in this report do not reflect the situation in other parts of the world where markets and prices structures for salmon can be quite different compared to the European market.
2. Executive summary

Core conclusions

- RAS is a proven technology with a valuable role to play in the freshwater part of the life cycle of the salmon. The Irish industry can avail of significant overall efficiencies by using RAS to increase smolt size/weight at transfer to sea. This will enhance productivity with a faster turnover of stock, reduced disease risk (including parasites such as sea lice) and improve overall efficiency of marine site use.

- It is now possible to produce a market-size salmon in RAS. Two pilot-scale and one commercial unit have managed to place on the consumer market approximately 1,000 tonnes over the last few years but this could increase as more small units are brought into production in various countries (The overall global production of salmon from conventional marine sites is approx. 2 million tonnes per annum). Operational costs, exclusive of depreciation and finance, can compare with sea site production. Capital costs are too high, however, and make it difficult to be competitive, especially during those regular periods where production costs rise above market prices. This together with the phenomena of unmarketable early maturing males will dictate that it will still be some time before there is enough evidence to support a move towards an economically sustainable salmon production in land based systems under Irish conditions. From an investment point of view it would be difficult to attract the substantial private finances required, given the advantages of conventional systems, distance to market, scale of current operations and recent scientific work which gives confidence in the sustainability of sea-rearing and the environment.

- Development of new RAS-compatible salmon strains and cheaper production systems will occur eventually. The industry in Ireland is interested and open to new, sustainable technology and embraces scientifically proven methods of improving efficiencies and production systems, Irish farmers will follow closely the progress internationally of full-cycle RAS production and review their strategies accordingly in future.

Background

Salmon has been farmed in Ireland since 1980 and at one stage Ireland was an important producer for the European and US markets. But Ireland has not developed its salmon industry to same extent as other salmon producing nations and, in fact, production has dropped from 25,000 tons in the 1990s to around 10,000 tons at present.

The main obstacle to development in Ireland has been the uncertainty surrounding the aquaculture licence processing and renewal system operated by the Department of Agriculture, Food and the Marine. A combination of events over several years, including the decentralization of government offices, loss of key staff, a European court case against the Government over its failure to implement the Habitats Directives and a lack of coherence between policy and administration, meant the licencing for all aquaculture operations effectively came to a halt. At the time of going to press, there are 600 applications for new and renewed licences for finfish and shellfish currently awaiting decision.
The Irish Salmon Growers’ Association (ISGA) regularly monitors emerging technologies to see if there are better ways for promoting Irish salmon production. One such emerging technology is the use of Recirculation Aquaculture Systems (RAS). This process is being used successfully for a number of fish species, including the juvenile (freshwater) stages of salmon.

A number of full-cycle pilot scale RAS plants, as well as some commercial sized ones, have been built around the world in recent years. This development is still in its infancy, but the ISGA nevertheless commissioned the author of this report to carry out an assessment on the viability and/or potential of land based salmon grow-out in RAS under Irish conditions.

The production systems built today are all of different concepts and not all have been free from problems, as expected. However, based on the experience gleaned from two pilot scale projects in North America, (Namgis on Vancouver Island and the Freshwater Institute in West Virginia), some very important observations have been made. The conclusions of this report is that RAS technology for land based salmon grow-out is available, i.e systems where it is technically possible to produce salmon. The observations gleaned mainly from the pilot scale project on Vancouver Island and at the Freshwater Institute have further shown that it is possible to produce a market-quality salmon in RAS.

An advantage with RAS production compared to ambient systems is the level of control of a number of water quality parameters, including temperatures and oxygen levels. This gives fish growth rate potentials higher than in ambient sea site systems. With the two pilot scale projects and also with one of the two commercial size projects, it has been possible from smolt input to grow market size fish in 12 to 14 months. In sea site systems in Ireland, it takes approximately 18 months.

It must be emphasized, that with the pilot scale and potentially commercial RAS projects constructed to date, there are, still a number of biological obstacles to overcome. The main one is the phenomena of precocious males. There is a relatively large proportion of males that mature early in RAS production, up to 30% of the male population. This happens when the fish are around 1.5 to 2 kg. The problem is that they stop growing (despite being fed) and they lose their silvery color and flesh quality becomes inferior - in other words they are not marketable. This is quite a big loss factor and inconvenient for any operation. The main reason for the early maturation is most likely because of accumulation of female sex pheromones in a RAS. In a self-contained system as in a RAS, there will not be any flushing or dilution effects as in ambient systems. So far, no solution has been found to eradicate pheromone accumulation.

Another reason for the problem of early maturation encountered in RAS systems is the influence of constant higher water temperatures in a RAS compared to ambient coastal waters. If salmon production in RAS with its higher energy consumption is to be successful, these relatively higher temperatures are essential to justify the extra operational cost and achieve as good growth as possible. There are so far no conclusive short term solutions to overcome the problem of early maturation, though some improvements have been made with day length mimicking light regimes. In Langsand, the rate has been brought down to 5%. There is ongoing research to find salmon strains more suited for RAS, but that will be a long process.

It is often claimed that fish growing in an RAS can be kept disease free. In theory this is true, as one can maintain a higher degree of bio-security, i.e. preventing fish pathogens to enter the system compared to that of ambient systems. However, there is never a guarantee, as there are still some potential transmission sources. These include the make-up water if it is from surface waters, improper hygiene with incoming supply trucks (feed) etc. When a disease has struck, it can sometimes be more difficult to clear in a RAS. Langsand for instance, unluckily introduced a bacterial infection, Furunculosis, with devastating effect. In fact, it was to such an extent that they had to close down the plant and start from scratch again.
The study has found that (every other obstacle being overcome) there could be adequate sites available in Ireland which currently do not have planning permission at or within reach of the coast, i.e. one mile from the ocean. In fact, with production modules of 5,000 tons per annum, only 7-8 sites would be needed to reach the 38,000 tons projected target set by the Government.

To be viable, aquaculture, like any animal production, has to be approached on a competitive commercial scale. This study has dealt with a 5,000 thousand tons per annum production. The system design is based on a standalone system with the ability to supply markets weekly.

The capital costs for the 5,000 tons per annum system described in this study is € 33,000,000. This figure corresponds well with capital costs pro-rata with existing RAS projects and other projected ones. In comparison, and when the shorter replacement period for net cage systems is taken into consideration, this is approximately 2.5 times the cost of net cage systems. In the case study undertaken here, smolt input is based on purchase. Also, fish processing and dispatch to markets is anticipated to be done externally.

The operational cost before depreciation and financial costs is €2.56/kg whole weight. With depreciation and financial costs it is €3.62. With an anticipated gutting loss of 12% of whole weight, this equals €4.12/kg head on gutted (HOG), which is the form salmon are sold in. Add to this costs for gutting, boxing, icing and dispatch of €0.72/kg this gives a price to market of €4.84/kg HOG. The standard price, and which is given in the weekly salmon prices and forecasting indices, is delivered to Brussels. In other words, to break even one would need a price delivered to Brussels of €4.84/kg HOG.

The price for salmon varies over the year depending on demand/supply. In Figure 1, the price structure in Norwegian kroner (NOK) over 2014 is shown.

Figure 1. Price index for HOG salmon for Brussel in 2014. Prices for 2015 – until beginning of May. Source FIS.
The maximum price in 2014 was NOK 52/kg HOG, the lowest was NOK 32.00/kg HOG. The average price for the year was NOK 40.81/kg. This equals € 4.84/kg HOG. This is coincidently the same as the € 4.84/kg HOG total production price found here. So at present it will not be possible with a land based RAS to make a profit. As mentioned, capital expenditure is relatively high for RAS with corresponding high depreciation and financial costs, 12.1% and 17.1% respectively, which is one reason why it is difficult to make a profit.

Irish production for all categories of salmon, be it organic, conventional sea site reared salmon or salmon from RAS will be more costly that in other producing countries for a number of reasons: fish feed has to be imported from Scotland or elsewhere, energy costs are high in Ireland and financial costs are relatively high too.

It hasn’t always been easy for the Irish producers of salmon in conventional marine sites, either. Costs have risen sharply in years when losses in cage systems are high. This is one reason why organic salmon is emphasized as it fetches premium prices, which in fact is significant. With Irish land based production of non-organic salmon, as the case would be for RAS, it is clear that one would also need a premium price to be able to make a profit. It is difficult to speculate if one could achieve such an exceptional price and at what level. Salmon produced in RAS is a novelty and would certainly create some market interest in specialist retail and catering outlets but there is no one who can predict how long it would remain a novelty. Salmon is the second most popular seafood after cod in Ireland and one of its main attraction is its low consumer price and availability. Higher priced Irish fish can easily be replaced by lower value imports by price-conscious consumers.

Smolt supply in this assessment is based on purchase. The effect of this model is that an extra cost of a separate smolt unit, in the region of € 2 million, will add on an already high initial capital expenditure. With an own supply of juveniles, the smolt costs would be approximately half price and it is evident that such add on investment would come down the line. With own smolt production, the total cost to market would be € 4.75/kg HOG, i.e. slightly under the average market price (€ 4.84/kg HOG) for 2014. This would still not be attractive to a potential investor.

RAS technology and economics improve gradually all the time, though it is seldom that one sees sudden major breakthroughs. There are however, some recent ideas, the so-called concentric tank concept that could well change the economics in RAS production quite significantly. This new concentric tank concept is based on shared tank walls both inter tank and for treatment system. The plant is erected on a flat concrete slab, with no expensive underground pipe work. There are neither any expensive concrete constructions, which at times has been the “killer” in some RAS construction costs.

The future of land based salmon grow-out in RAS in Ireland:

It can be concluded that it is possible to produce a quality salmon in RAS. At present, operational costs exclusive of depreciation and financial costs can compare with cage rearing had there not been the phenomena/production loss of early maturing males. This phenomena is at present a restraint for land based development. Efforts are being made to find more suitable salmon strains for RAS, as well as looking at ways of minimizing pheromone concentrations in RAS to reduce early maturity. There is no indication at this point in time as to when we will get there.
High capital costs is however at present, also a main constraint for development of land based production. These costs will have to be lowered. The emergence of new technologies, for instance the “concentric tank” concept will be a step in the right direction. If it is enough remains to be seen. There is no reason to believe that this new concept will not be suitable for salmon. However, the design for these new technologies are still in their infancy. There are a few suppliers of RAS working on it at present. When design is completed, and when built, actual trials would be needed before one has conclusive evidence of their suitability.

It can be concluded that it will still be some time before we have enough evidence of feasible salmon production in land based systems under Irish conditions. It would hence be very difficult to attract investment.

Some readers may point to the fact that there are already RAS systems built elsewhere, for instance the two systems in Denmark. These were not very successful in the beginning, but some improvement has been seen. But taking into account their location, they would in any case have greater potential than a similar project in Ireland. They have cheaper fish feed, entailing a 5-7% reduction in production costs compared to Ireland. They would have lower freight and packaging costs as the market is practically on their door step and all by road or rail, a reduction of 8-10% in costs.

Whilst it may not be recommended at this stage to establish land based salmon production in Ireland, what is obvious from this work is that it can be recommended to have a larger part of the salmon life cycle produced on land, i.e. to produce larger smolt for stocking out to the sea cages. This is the trend in other salmon producing areas, especially Norway. Instead of stocking out smolt at the original sizes of say 70-120 gram, sizes of 200-300 gram is the norm now, i.e. more than a doubling in size. This would enhance productivity at sea with a faster turnover and, importantly, would coincidently minimize the very issues that the salmon industry often struggle with such as AGD or lice. This new management strategy would overall have economic benefits for the Irish salmon industry. Importantly, the freshwater RAS systems for smolt production are well established and proven.
3. A brief description of the Irish Aquaculture sector

Irish aquaculture began its major development in the early 1970s and has, at times, been an important contributor to rural economies and employment.

The first finfish species to be commercially farmed were salmonids: rainbow trout (*Oncorhynchus mykiss*) reared on land, followed by cage production of Atlantic salmon (*Salmo salar*) in 1981 when the first 100 tons were marketed. Later, rainbow trout was also produced in cages at sea.

At the same time, Ireland developed a significant shellfish industry, but in economic terms, salmon soon became the main earner. Production peaked in the 1990’s at around 25,000 tons per annum bringing in close to € 100 million annual sales. However, paradoxically as aquaculture is the fastest growing sector within global food production with 6-8% annual growth, production in Ireland has decreased in recent years. Today, the production is only around 10-12,000 tons and sadly, Ireland is hardly mentioned today in global salmon farming statistics.

Small geographical areas, for instance the Faroe Islands and Shetland, both 50 times smaller than Ireland, each produce 3-6 times more salmon. This is a little contradictory as Irish farmed salmon on the world markets is considered a superior product compared to that from for instance neighboring Scotland or Norway.
4. Historical background for RAS and it’s role within the salmon sector today

Recirculation aquaculture systems (RAS) represent a relatively new way to farm fish. The forerunner for RAS were contained systems used for research purposes in capacities of holding fish for experimental work, often at universities or other fish research stations. Ideas for RAS as commercial fish production entities were first fostered in Denmark in the mid 1970’s and the first commercial RAS was built in 1980 at the Water Quality Institute, just outside Copenhagen.

Originally, the idea was to use various sources of waste heat, for instance in the form of industrial cooling water, and try to retain the heat to obtain higher than ambient growth temperatures. In this recirculation of water, a water treatment process took place, oxygen supplementation, etc.

However, it was soon found out that adequate heat could be retained from fish metabolism, pumps, blowers and other electrical appliances if a system was housed in a proper insulated building and was independent of external heat sources.

The first species selected for RAS had to be of high value as these systems bore high capital costs. The first suitable fish candidate for culture in RAS was the European eel. Numerous plants were built in Denmark and then Holland and Germany and later in China and Taiwan.

Much research went into this development and systems improved all the time. The European production reached 8,000 tons around the year 1990. This production has since declined to 3-4,000 tons due to decline in markets for eel and regulations of elver catches.

Especially in Holland, RAS technology took off with other species such as Tilapia and Catfish. Cheap Pangasius imports into Europe put a halt to Tilapia production, but the Catfish is doing well with its 4-5,000 tons annual production.

A number of other species, such as Sea bass, Turbot and Perch have been tried with limited success at the time. With today’s improved systems, these species would have higher potential for success.

The Salmon sector:

Production of salmon smolt in RAS started approximately 16 years ago. This was among other things due to the need for multi batches of smolt per year, which is very expensive for flow-through systems to produce with very costly heating systems. At the same time to meet demands, production intensity increased in flow-through systems with introduction of oxygen injection, re-use of water etc. that one was almost half way to a RAS. Also, and not least, the difficulty in finding suitable sites and getting permissions for flow-through systems has favored RAS production.

RAS for salmon smolt sets higher demands for control of water quality and higher specifications in design than the systems which were successfully used for Eel, Tilapia, and Catfish etc. However, in being able to provide optimum growth temperatures with no active heating of water, being able to operate at optimum oxygen levels and other water quality parameters, the growth achieved enabled multiple batches per year. This meant that to produce a given smolt volume, one only needed a third to a fourth of the tank volume compared to a flow-through system. At the same time, with the arrival of new bio filter concepts and
systems design that have very low pumping heads, it was possible to produce smolt cheaper in RAS than in flow-through systems.

In recent years a growing interest in land based salmon grow-out in RAS has been shown. The main suppliers of RAS have been working with designs for large scale production and a number of pilot scale projects are up and running as well as some commercially sized, see chapter 9.
5. Legislative aspects, licensing, fish culture and other licenses

The issue of aquaculture licencing has been a major topic of debate within the Irish industry for many years. While marine farming, as the larger component, has received the majority of the attention in relation to delays in licence processing, freshwater or land based operators have equally suffered long delays resulting in business disruption, inability to plan forward and reduced investment opportunities.

Land based operators are not impacted by the issue of Marine Special Areas of Conservation, yet this has not prevented long delays in renewing existing licences or applying for new sites to achieve decisions at Ministerial level. The author is aware of a number of projects where grant aid has been unavailable to operators who have been waiting for years on decisions for licence renewals.

The application process for a licence to build and operate a land based recirculation unit has not been described as a stand-alone process in any official documentation. Existing legislation and the accompanying templates and guidance refer to freshwater land based units.

In producing this report, the author has tried to cover all of the requirements but it is prudent, given the experience of the industry in Ireland to date, to state that due to the lack of clarity in this area, the sudden involvement of agencies or Departments with little or no obvious oversight in the area of the rearing of fish cannot be ruled out.

First and foremost, as a land based permanent structure, the farm will require planning permission from the relevant local authority. In fact, the Department of Agriculture, Marine and Food will not process an application for a land based aquaculture licence until planning permission has been granted.

A Foreshore Licence is not be required for the unit itself on private property but will be necessary for the placement of any structures for discharge to the sea below the high water mark such as intake and outflow pipes for seawater.

In the Department of Agriculture, Marine and Food’s “Aquaculture Licence Application Guidelines”1 it states

“Section 3.3.3 Requirements specific to LAND-BASED AQUACULTURE ONLY

The following apply

- The proposed site layout, buildings and equipment will need to be designed to the Department’s satisfaction
- The operation must comply with Local Authority requirements
- Applicants for Land based licences must contact their Local Authority i.e. County Council to enquire if they require Planning Permission and a Licence to Discharge Trade Effluent.

The following must be supplied with an application for Land-based aquaculture

- Sketch of a layout of the site in relation to the river(s), road(s), and building(s)
- Water Quality Analysis Report: Applications for a licence for any type of freshwater land-based aquaculture must be accompanied by a Water Quality Analysis Report which must include parameters (as appropriate) set out in Annex A”

1 http://www.agriculture.gov.ie/media/migration/fisheries/aquacultureforeshoremanagement/formsdownloads/Aquacultureapplicationguidelines250614.doc
In the Department’s **Aquaculture Licence** template for freshwater farms\(^2\) the overall production limited is expressed in terms of standing biomass (not outdated and irrelevant figures such as fish numbers or “harvest tonnage”). This reveals that a level of understanding exists that the main concern for the farm is the impact of its activity on the environment and particularly the quality of water once it is discharged.

In the template, the significant differences in the terms conditions and contents from a standard marine farm licence template are:

4.2 “The Licensee shall provide and maintain such gratings or other devices at the point of water abstraction from the river into the fish farm, and also at a point as near as possible to the discharge of water, as will prevent the admission of wild fish into the fish farm, and shall make all necessary provisions to prevent the escape of fish from the fish farm as specified in Schedule 3.”

And

**Duration, Cessation**

9.1 “This Licence shall remain in force until XX XXXXXXXX, 20XX and only so long as the fish farm complies with the planning permission granted by XXXXXXXXX XXXXXXX Council on XX XXXXXXXXX 20XX (ref XXXXXX), the Local Government (Water Pollution) Acts licence to discharge effluent granted by XXXXXXXXX XXXXXXX Council on XX XXXXXXXXX 20XX (ref XXX-XX) (or a further such licence granted by the said Council or by the Environmental Protection Agency). “

This article clearly shows that precedence is given to the status of the planning permission status of the site and structures and local authority discharge licence over the aquaculture licence. An applicant’s aquaculture licence will be accepted but not processed by the Department of Agriculture, Food and Marine As already pointed out, there is no template currently available for exclusively seawater land-based licencing, which is an essential requirement for full grow-out to market size of salmon. Licencing is not required under the EPA Act nor the Local Authority Act 1977 (1\(^{st}\) Schedule) Where the farm discharges any wastewater to the sea.

A discharge licence will be required where there is any regular or potential emergency discharge of water from the farm into the sea. An emergency discharge point is recommended to deal with the potential eventuality whereby the farm or part thereof needs to be drained for any reason (cleaning, fish health requirements, etc.

One problem highlighted many times by industry and brought forward by a number of speakers at IFA and BIM’s freshwater aquaculture conference held at the Marine Institute, Oranmore (Sept 2014) is the lack of consistency between local authorities on parameters for water quality from discharges. There are significant variations from county to county which bear no obvious relation to any national guidelines or regional/river basin Water Framework plans. There is a large variability in the extent of familiarity of engineering and environmental officials in various authorities with aquaculture requirements and

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\(^2\) [http://www.agriculture.gov.ie/media/migration/fisheries/aquacultureforeshoremanagement/aquaculturelicensing/aquacultureandforeshorelicencetemplates/AquacultureLandBasedFinfishFreshwaterTemplate021014.pdf](http://www.agriculture.gov.ie/media/migration/fisheries/aquacultureforeshoremanagement/aquaculturelicensing/aquacultureandforeshorelicencetemplates/AquacultureLandBasedFinfishFreshwaterTemplate021014.pdf)
processes. This uncertainty adds an additional amount of “guesswork” for the operator seeking to locate a site around the coast.

With Irish Water now in operation, it has been confirmed to IFA that waste water discharges using public utilities such as sewage treatment which were the responsibility of local authorities will now have their licences transferred to Irish Water. This raises the opportunity to achieve a consistency of parameters for land based finfish farm discharges and water quality. However, the sheer amount of discharge points both licenced and unlicensed which are now under the remit of the new organisation (estimated to be around 10,000 according to an IW representative at the June meeting of the Molluscan Shellfish Safety Committee www.FSAi.ie) would give rise to concern that applications to process new licences may be significantly delayed.
6. Siting of land based salmon grow-out systems

6.1 Siting criteria

One advantage with a land based containment system in the form of a RAS is that the need for external water is small compared to that of a land based flow-through system - approximately 0.5% of a flow-through system.

However small a flow though, as mentioned above only 0.5% of a flow-through system, a land based RAS grow-out will need a certain supply of high quality water to compensate for a certain loss of water in the system. In the case of land based salmon grow-out, one will need a salt water supply. This means one needs to be in the proximity of the sea and a need for a pipe line intake with a pumping station. The same amount will be discharged back to the sea. This entails that there is a limit to how far an otherwise suitable site can be from the sea. In the following assessment, a distance of maximum 1,000 meters from shoreline has been set in an attempt to identify potential sites in Ireland, bearing in mind that this pipe line may have to be extended further out to sea depending on tidal ranges and depth profiles in a given area.

The building size for a 5,000 tons per annum system will be around 22,000m². With foreshore access, parking, loading and turning area for commercial vehicles a total area of approximately 35,000 m² or say up to 4 hectares will be needed. A smaller production than the 5,000 tons is of course a possibility with a corresponding smaller area needed.

Figure 1. Example of a 5,000 tons salmon grow-out layout.
The geological criteria are normally specified as soil, clay or sand as preference. Fish tanks and parts of the water treatment plant need to be underground to some extent (2-3 m), otherwise with tank heights of 4.5 m, necessary working height above tanks of 3 m, a building height could easily be > 10 m exclusive of roof pitch.

### 6.2 Site availability in Ireland

Of the 26 counties in the Republic of Ireland, 15 have access to the sea. An assessment of potential sites in the largest of these counties has been carried out. As it always will be associated with uncertainty whether one will obtain the necessary permissions in a rural setting, focus has mainly been on sites within existing industrial areas or planned industrial development areas around main towns at coastal locations.
**Co. Wicklow:**

The Co. Wicklow coastline is mostly recreational with long stretches of cliffs or sandy beaches. It is not a very industrialized county with, apart from Bray, only two larger towns: Wicklow town and Arklow. There are however, two potential sites here:

1) North of Wicklow Harbour on redundant industrial 25,000 m² site – approximately a couple of hundred yards from shoreline. Problem: railway line between site and the sea.

2) In Arklow there is a site which in fact could have large potential at the Roadstone quarry. Roadstone has now explored a good bit into Arklow Rock that has left much redundant land: about 4 hectares. Taken into considerations the vast operations and buildings and machinery, a planned RAS would probably not meet objections and refused planning permission. Distance from sea including a large jetty is 2-300 meters.

**Co. Wexford:**

There have been no obvious sites identified here

**Co. Waterford:**

Not many if any. The largest site is in Tramore, Riverstown Business Park. Distance from sea 500 meters. Size: 15,000 m², which is on the small side.

**Co. Cork:**

Maybe Little Island Industrial Estate – 2-3 hectare site available.

Personal communications with Michael O’Neill from Abalone Ireland, Co. Cork who has identified two sites west of Clonakilty, both on farm land.

**Co. Kerry:**

None identified as yet.

**Co. Galway:**

Future Kilkieran Aqua Park, Udaras development. Size unknown.

**Co. Donegal:**

One potential site at Sallybrook. Area: 30,000 m².

**Conclusion:**

*There are only a handful of sites identified so far, but it can be concluded that there will be more sites suited for the purposes in question and to find the 7-12 sites needed to replace and/or for increased production up to 35,000 tons would be possible. Successful planning permission depends on the results of the planning process and the final determination of the local authority and/or An Bord Pleanála. It should be noted that in some coastal areas, industrial-type buildings or developments can meet strong local opposition.*
7. System design for 5,000 ton per annum unit

A stand alone land based salmon grow-out system has to be based on a design and production schedule that facilitates weekly harvesting and deliveries. In conventional practice, a salmon farming company would avail over many different sea sites, which are harvested in rotation. It is hence based on batch productions on the individual sites, but with continuity in supplies overall. This is neither possible nor practical in stand alone production as 1) batch production would entail tank water volumes 2-3 times larger than for sequenced production. With sequenced production, one would not start from smolt sized fish till harvest weight fish in same holding facility. Fish would be moved according to size to ensure tanks are as full as possible all the time, and 2) if cage production at sea production mode is copied, it would render use of much larger tanks that would be unpractical to operate.

With land based production in RAS it has to be anticipated that fish need to be purged before delivery to the market to clear any off flavour.

In the following is described a system that is based on weekly harvest, purging and deliveries. The proposed annual production size of 5,000 tons has been chosen to be as close as possible to other average sized salmon companies and to achieve a margin of scale to reach best economy.

7.1 RAS processes

There are many RAS concepts or technologies available on the market today. Basically, the processes in a RAS consist of following:

1. Solids removal
2. Biological treatment
3. Gas control – oxygen injection/CO₂ degassing
4. pH adjustment – alkalinity control
5. Pathogen control – UV/ozone dosing
6. Waste/sludge management

**Solids removal:** solids, mainly fish faeces, has to leave the fish tanks as quickly and as intact as possible so we get as large a proportion as possible removed before the bio filters. There are different concepts used but the most widely would be micro screening in the form of drum filters. These filters, depending on the application, would have filter mesh sizes from 20-100 microns.

There are other solids removal concepts, for instance settling chambers or solids entrapment filters. These filters are in line and can create problems with leaching and not least in a saltwater application, with Sulphite formation. Saltwater contains relatively high sulphate levels and with any sludge pockets one will experience lowered oxygen levels with good conditions for sulphate reducing bacteria. In other words. Sulphate is reduced to sulphite, which may inhibit fish growth.
The solids that are removed from the system will later need some form of treatment either in the form of dewatering or further mineralisation depending on disposal options at a given location.

**Biological treatment:** the main target compound for the bio filter in a RAS to deal with is the ammonia produced by the fish, which if not treated will accumulate and reach levels that are toxic to the fish. It is therefore essential to have bio filter concepts and conditions that optimise and favor the bacteria that are responsible for this, i.e. nitrifying bacteria.

Nitrifying bacteria consist of two groups of “Autotrophic” bacteria, Nitrosomonas that convert Ammonia to Nitrite, and Nitrobacter that convert Nitrite into the more harmless Nitrate after following equations:

1. \[2 \text{NH}_4^+ + 3 \text{O}_2 \rightarrow 2 \text{NO}_2^- + 2 \text{H}_2\text{O} + 4 \text{H}^+\text{ (Nitrosomonas)}
2. \[2 \text{NO}_2^- + \text{O}_2 \rightarrow 2 \text{NO}_3^-\text{ (Nitrobacter)}

As mentioned above, drum filters remove the solids fraction down to a certain particle size. The second task for the bio filter is to mineralise the remaining organic matter which will come from them. It is important that the drum filters remove as much organic matter as possible as otherwise the bacteria (heterotrophic) that mineralise the organic matter will compete with the nitrifying bacteria in the bioreactor for oxygen.
There are a number of different bio filter concepts:

- Stationary submerged filter, which partly carry out biological activity and partly act as particle filters.
- Trickling filters
- Fluidised sand filters
- Moving bed bioreactors – MBBR

Of these, MBBR technology has become the favored concept within RAS design due to its high capacity and ability to tolerate varying conditions. MBBR do neither have any sludge accumulation and potential risk for sulphite formation in saltwater systems.

Figure 4. Example of Moving Bed Bioreactor. The water flows into the pump sump.

**Gas control – oxygen injection, CO₂ degassing**: an advantage with a RAS compared to an ambient system, is that one has the possibility to maintain an optimum oxygen regime and hence a good growth. As one also can control temperature, one will achieve a significantly faster growth than in the sea at ambient temperatures and oxygen levels.

There are numerous oxygen injection systems for aquaculture systems. In RAS it will mainly be:

- Low head oxygenators (LHO’s) of various configurations
- Oxygen pressure cones

Oxygen pressure cones were once widely used in RAS, especially with high intensity production. However, energy consumption is very high and later, different versions of LHO’s have taken over. In some designs pressure cones are still included for intensive production at peak periods.
Figure 5. Example of low head oxygenator, Oxymat(left) and oxygen cones (right), Courtesy of Grieg Seafood.

With a respirational coefficient of 0.9 applied with the feeds used for salmon today, for every kg of oxygen used by the fish, 1.30 kg of CO₂ is produced. In RAS this will build up to unacceptable levels, even toxic levels, if CO₂ degassing doesn’t take place. High CO₂ levels will additionally lower pH, which will have an effect on bio filter performance.

With salmon at the smolt stage guideline figures are a maximum of 10-12 mg/l and with grow-out fish, 15-20 mg/l.

The CO₂ degassing takes place in a centralised facility, either by cascading the water flow over a 1-1.5 m high column with a counter air flow to remove the CO₂ or by a heavy aeration in the pump sump.

**pH adjustment – alkalinity control**: Nitrifying bacteria in a bio filter are only active, or perform, within a certain pH range:

- Nitrosomonas optimum pH range – 7.4-7.8
- Nitrobacter optimum pH range – 7.2-7.4

Outside these ranges, the Nitrobacter are less tolerant and it is normally best to adjust pH as close to their optimum range as possible, i.e. from pH 7.0-7.5.

For pH adjustment either Sodium Hydroxide or a bicarbonate can be used. The nitrifying bacteria need alkalinity and a content of > 80 mg/l Calcium Carbonate is recommended. What is used depends on the alkalinity in the make-up and on the contribution from the fish feed. In either instance, dosing is regulated automatically.
**Pathogen control – UV/ozone dosing:** Bio security is essential in any aquaculture facility. Provided that all intake water is sterilised, a RAS should in principal be pathogen free. There are however, always threats from introduced fish, from stress induced opportunistic organisms etc. In a RAS the following arrangements will apply:

**Inlet make-up water:** in a salmon grow-out situation, make-up water would be sea water. A seawater pumping station would be established with a pipeline up to the RAS. Before the water enters the RAS it will undergo fine particulate filtration followed by full sterilization by ozone.

**Within the RAS:** most RAS would have UV filtration on a sideloop of 10-25% of total water flow. This means total water volume in the system will go through the UV system several times per day. In freshwater systems ozone is sometimes also used internally but one has to be careful in saltwater with interactions between ozone and the bromide content in seawater.

**Waste/sludge management:** the drum filters in a RAS collect sludge which in some way has to be further treated and disposed of in a cost-effective way. Measured as dry content, the production of sludge is approximately 200 kg per ton of feed fed. However, it has a relatively low solids content (1.0-2.4%) when it comes from the drum filters so the first step will be concentrating it. This can be done by mixing with a polymer to flocculate the solids before dewatering on a belt filter.

![Figure 6. Polymere mixer tank and belt filter, Courtesy CM Aqua](image)

The dry matter content goes from the 1.0-2.4% before thickening to 8-12% dry matter after. Latest trials with centrifuge technology can thicken sludge to 32% dry matter.

Depending on location, this sludge may be disposed of or, if distance and transport costs are high, it can be further treated/digested on site.
7.2. System design

The production of 5,000 tons is based on 6 annual stockings of smolt into a plant complex consisting of the following plants and plant sections:

1 x post smolt RAS plant:

It is envisaged to have 6 annual inputs of 180,000 smolt @ 100 gram. This system is isolated from the pre-grow-out and grow-out systems. The smolt will here be grown up to 200 gram whereafter they will be transferred to the pre-grow-out system.

Apart from growing the incoming smolt from 100 to 200 gram, this unit will act as a quarantine facility so that any imported fish can be assessed and treated if necessary – maybe even be rejected.

MBBR based bio filtration technology, 40 micron drum filters and low head oxygenation. Centralised and decentralised CO2 de-gassing.

The post smolt RAS plant consists of 4 x tanks of 10 mØ x 2 m water depth with a water volume of 157 m³ each and a total production volume of 628 m³. The maximum stocking density will be 55 kg/m³ or a total stock of 34,540 kg.

The plant has a design feeding capacity 1.72% bodyweight or approximately 594 kg/day at a temperature of 12 °C. The system is based on MBBR biofilter technology, low pressure oxygen cones and 40 micron drum filters.

1 x pre-grow-out system:

One RAS plant for salmon pre-grow-out. The plant consists of 30 raceways with a volume of 120 m³ per raceway and a total volume of 3,600 m³. The plant has a design feeding capacity of 3,000 kg/day.

MBBR based biofiltration technology, 60 micron drum filters and low head oxygen boxes. Centralised CO2 de-gasssing over pump sump.

Smolt at 200 g will be transferred to the pre-grow-out system and grown to 1,000 g. In this unit grading will take place before distribution to final grow-out system where no grading will take place before harvest and delivery.

Fish are crowded to aid handling, for example prior to grading, counting, transport and slaughter.

Handling is stressful, particularly if it entails removal from the water. It can result in scale loss, injuries to eyes and fins and muscle bruising. Handling can also lead to injuries to the skin, which is fishes’ first line of defence against disease, and to damage to the mucous coating which secretes a protective layer over the skin and is a primary protection against pathogens and parasites.

A raceway system has been chosen as handling of fish, mainly for grading or maybe vaccination, in large round tanks is especially complicated and involves fish having to be netted and pumped with a large degree
of stress and/or damage on the fish. In a raceway, the fish can be handled more gently without using nets and movement of fish on fish elevators entail less stress on fish than pumping.

When the fish reach one kg in a raceway they will be transferred to the final grow-out system where no further grading will take place.

3 x grow-out systems:

There are three separate RAS plants for final grow-out. Each plant consists of two rows of 5 @ 16 mØ tanks x 4 m water level with a water volume of 800 m$^3$ or 8,000 m$^3$ altogether. Each plant has a feeding design capacity of 4,700 kg/day at a temperature of 12 °C.

The plants are based on MBBR technology, 60 micron drum filters, centralised and de-centralised CO$_2$ degassing and low head oxygen system.

In between the two rows of round tanks and in full length is situated a fish out channel. The fish can be sluiced directly into the channel without any netting or pumping. These channels will serve as off flavour purging and harvest facilities.

A detailed layout and description of technology is found in Appendix 1 and 2.

The design shown is for proven RAS technology. These systems have been successfully used for a number of other fish species where pristine water quality and low operational costs are essential. RAS has the perception of being capaital expensive, see chapter 7.1. There is of course some truth in that, but for many fish species, the gains one gets from optimum growth conditions outweighs this.

There is a new emerging design in RAS, the so-called Concentric Tank Concept (CTC). This concept is based on shared tank walls as well as bioreactor section. There are quite significant savings in construction costs for this new concept. A unit is erected on a flat concrete slab. There is no expensive underground pipework nor any expensive concrete constructions. The shared tank walls also saves costs for tanks.

7.3 Water environment and growth

The system design or concept is very important in a salmon RAS context. Salmon is a cold water fish and is a relatively slow grower. This means that one has to avoid other growth limiting factors such as poor water quality: high ammonia levels and high CO$_2$. It is also important to avoid the potential for H2S formation. Good oxygen levels and temperatures, two very important factors for growth, are in principle easy to maintain in a RAS.

In Table 1 is shown levels for the main water quality variables that one has to maintain in a RAS for land based salmon:
<table>
<thead>
<tr>
<th></th>
<th>Salmon smolt freshwater</th>
<th>Salmon grow-out 34 ppt saltwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>14-16</td>
<td>12-14</td>
</tr>
<tr>
<td>Total ammonia TAN</td>
<td>&lt;1.0</td>
<td>&lt;1.0</td>
</tr>
<tr>
<td>Nitrite NO₂-N mg/l</td>
<td>&lt;0.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Nitrate NO₃-N mg/l</td>
<td>&lt;75</td>
<td>75</td>
</tr>
<tr>
<td>BOD mg/l</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Alkalinity mg/l as CaCO₃</td>
<td>&gt;80</td>
<td>&gt;80</td>
</tr>
<tr>
<td>TSS mg/l</td>
<td>&lt;10</td>
<td>&lt;10</td>
</tr>
<tr>
<td>O₂ % saturation</td>
<td>&gt;80</td>
<td>&gt;90</td>
</tr>
<tr>
<td>CO₂ mg/l</td>
<td>&lt;12</td>
<td>&lt;20</td>
</tr>
<tr>
<td>pH</td>
<td>6.9 – 7.8</td>
<td>7.2-7.8</td>
</tr>
<tr>
<td>Fish stocking density kg/m³</td>
<td>&lt;55</td>
<td>&lt;80 mainly but occasionally peaks at 100</td>
</tr>
</tbody>
</table>

Table 1. Water quality variables for the proposed 5,000 tons salmon grow-out system.

Compliance with above water quality variables is today achieved in well functioning RAS.

**Fish growth:**

Salmon in Ireland are grown in oceanic water with temperatures ranging from 7°C in winter to 15°C in the summer (Malin Head). In the South of Ireland it can be up to 3 degrees warmer both in summer and winter. Apart from the southerly parts of the West coast of Ireland, Ireland probably avails of the best temperature range of the European salmon producing countries.

Under Irish conditions, to grow market size salmon of 3.0 to 5.5kg from 70-100 gram smolt takes approximately 15 to 22 months.

The optimum growth temperature for salmon is given at 12-14°C (NOFIMA). At this temperature it is possible to grow a salmon from 100 gram smolt to 4.5-5.0 kg in 12 months (Namgis). Namgis have achieved their predicted growth, except for times with bio filter mal functioning.

Langsand figures for expected growth is given in Table 2.
Table 2. Langsand anticipated growth figures under ideal conditions.

This growth has as yet not been achieved. Growth has been 25% less than anticipated. One reason given is due to an outbreak of Furunculosis.

NOFIMA in Norway have carried out growth trials from post smolt to 1 kg fish at different salinities: 12, 22 and 32 ppt. They found that salmon grew fastest at 12 ppt. This is obviously due to less energy demand for regulation of salt balance which the fish maintain at around 12 ppt.

There is nothing to indicate that it is not possible to produce salmon in RAS from 100 gram smolt to 5 kg in 12 months providing water quality is not compromised.

### 7.4 Day to day management of a 5,000 tons per annum unit

In all fish farm activities there are a number of daily routines (fish husbandry), the most important of which are:

- Feeding
- Grading
- Harvest and delivery
- Fish health monitoring and treatments
- Water quality checks
- Bio security
- Maintainence
- Production planning

Of these, feeding, grading and harvest and delivery are the main time consuming routines. Over the years there has been developed automated feeding systems for both sea cage as well as for land based systems, so in fact, daily feeding today is more or less carried out on a computer. There are many types of feeding systems, which all today are quite proven.
**Post-smolt system:**

Every two months the post-smolt system will receive 183,000 salmon smolt at 100 grams. This system, apart from being a part of the production cycle, will act as a quarantine system. Fish will be fed here for a two month period and transferred at around 200 grams to the pre-grow-out system. There will take no grading place in this system. However, there will be carried out frequent health monitoring and/or treatment of the fish. This system will be isolated from the pre-grow-out and grow-out system. The water temperature in this system will 14-16 °C.

For bio security reasons, the people working here will be in charge of the RAS water treatment system. The work load is very little in the post smolt system and one personnel is adequate timewise. However, with alarm duties and spread of husbandry and RAS technical knowledge, two personnel will be assigned.

**Pre-grow-out system:**

In a salmon farming situation, grading and delivery will be the main time consuming routines. In cages the fish are only graded once. This takes place when they are between 500 grams to 1 kg.

Handling of salmon has always been of concern as they loose their scales easily, which renders them as target for external pathogens or parasites. For this reason, there is incorporated in the system described in this report, a pre-grow-out system with raceways. Fish can be carefully crowded and moved around with minimum physical effort, graded and via gentle fish elevators (not fish pumps) be transported to the grow-out tanks. This system is essential, not just in reducing physical strain on the fish but also to minimise workload within the infrastructure to be able to have weekly supplies of fish.

The difference between a cage farm and and land based facility is that with cage farming, though same amount of fish are handled, there will be fewer but larger exercises with grading and deliveries, where the land based will be more continiously.

It is envisaged that, with the equipment include in a modern land based salmon grow out system, that there will be two men involved with grading. Feeding will be carried out automatically.

**Final grow-out systems:**

This system consists of three modular units with a total output of 5,000 tons per annum or 100 tons per week.

Feeding in all units will be automated. The main work routines will be purging and harvest. A tank at the time with 72-80 tons will be emptied out into the purging and harvest channels. When fish are in the channels, movement is relatively simple as fish can be crowded to the fish elevator for harvest and can in principal be done by two to three people.

**Fish health and bio security:**

There will be one assigned personnel who will be in charge of overall fish health and disease prevention. This person will also be responsible for bio security protocols and compliance.
**Water quality checks:**

The big difference between a RAS and any other fish farm concept is that we do not rely on an external source of water, except a very small amount of make-up water which would equal 0.3% of the water we would need to operate a non-RAS. In other words we have to “supply” ourselves with good quality water via re-use. We therefore have to treat the water in the water treatment part of a RAS. The processes in this water treatment system is described in Chapter 5.1.

The treatment system in a RAS will be what ensures that the fish are supplied with a sustainable water quality. The bio filter has to be a concept that is stable and safe to operate. All mechanical components and equipment has to be of high quality. A RAS also needs a sophisticated alarm and control system that is proven. Finally, and obviously vital, a RAS needs stand-by components, for example pumps, blowers etc. Oxygen is the life line and extra capacity for oxygen generators is essential. It is likewise essential to have back-up generators in case of power failures. If water pumps fail excessively, i.e. there will not be an oxygen supply to the fish even if oxygen generators are fully functioning, there are oxygen emergency diffusors in each tank coupled on the the oxygen generators.

As can be seen, the treatment and emergency systems are complex, but relatively safe with the back-ups in place. The safety aspect is enhanced if people operating the RAS have sufficient education and training. In the case of the treatment system with all it’s technical build up, one needs technical trained personnel that than can oversee the plant and that can predict what can go wrong and that can carry out maintenance.

The treatment system also consists of a biological filter. Knowledge of the processes, i.e. nitrification, is essential. In essence, one can say that in a land based RAS, one is producing two organisms: fish in the tanks and bacteria in the bio filter – and none is more important than the other. A person is needed with relevant experience to run the bio filters optimal to check water quality.

All in all, though timewise not always full time, it is envisaged that a personnel of two people are necessary for the running of the treatment plant bearing in mind off hours calls/duty.

**Production planning:**

As mentioned, feeding is a relatively easy task having fully automated feeding systems. However, feeding in itself is the major cost in aquaculture operations: > 50% of total costs. Feeding can either make or break an aquaculture business. Careful planning and monitoring of fish stocks and growth performance are essential tasks. This would be under the responsibility of a production planner and biological performance personnel.
7.5 Issues and/or risks related to RAS, biological or technical

As seen from previous chapter, a RAS is a sophisticated system with numerous processes beyond just growing the fish, the whole water treatment complex and it’s management. This makes it relatively expensive in terms of capital expenditure, an investment that has to be safeguarded. A RAS is/should be equipped with efficient alarm systems and emergency back-ups. However, accidents happen and fish losses can not be excluded neither from technical nor biological causes.

**Biological:**

The biology of the Atlantic salmon is exceptionally well known both as wild and as domesticated fish. In a fish farm situation, one wants as fast a growth as possible and produced as intensively as possible. It is a fine balance to get that right, but it can be done. The achieved growth in some of the newly established land based farms has shown to be satisfactory and in accordance with projections. In other cases, growth has not been satisfactory, which probably is down to system design, i.e. mainly bio filter concept and performance, giving poor water quality. Even in some RAS concepts, biofilters is designed to include sludge entrapment in line – a recipe for disaster, especially in a saltwater environment with its content of sulphite and potential sulphite reducing bacteria, which favor sludge and anoxic conditions. Despite these filters being back washed on a regular basis, does not exclude the potential of Sulphite (H₂S) production with immediate effect on fish growth.

With new species, or with new technologies, one can run into a number of unexpected problems. With regards to land based salmon grow-out, the main biological problem to date has been high incidences of precocious males, i.e. early maturing male fish. These fish stop growing at around 1.5-2 kg and acquire the typical features of mature fish with loss of pigment, dark skin color etc. and are not marketable.

There is suspicion, though not conclusively, that the reason for the phenomena or for the triggering of early maturity in the male population is the presence of female pheromones. Unlike in a cage situation or in a land based flow-through system where pheromones will be flushed out, in a RAS situation pheromone levels may well be accumulated.

The incident rate of precocious males have been reported to be up to 25-30%. Temperature and salinity seem to have an influence in that higher temperatures promote early maturing as does lower salinity. From a general growth aspect, this is unfortunate as one then has to compromise a good growth potential. For instance, a salinity of 12 ppt gives the best growth but then also promotes early maturation.

A solution is to look at/develop strains of salmon suited for RAS or all female fish.

In all fish farm situations, bio-security protocols and adherence to them are imperative. Most diseases are introduced/transfered into the fish farm somehow and it is important to minimise this risk. In an ambient system, one is however, left at nature’s will – all diseases are in or originate from nature. When a fish disease outbreak occurs, one’s only option is to treat the fish therapeutically.

In a RAS situation, one has larger degree of control over introduction of pathogens from external sources. Make-up water is the only external waterborne pathway. Make-up water however, can/should be sterilised
and it has been claimed that RAS for salmon grow-out can be kept disease free. Nevertheless, one cannot exclude diseases in a RAS, there can be accidents or inadequacies in system design which entails stress on fish and suppresses the fish’s immune system. This can easily trigger outbreaks of fungal disease or other dormant opportunistic diseases.

Langsand Salmon had an outbreak of Furunculosis, which was introduced via the make-up water. The inlet water treatment did not have adequate sterilisation capacity. This had severe consequences as the plant had to be closed down for a subsequent complete sterilisation and rectifying a number of other issues in the design.

- Diseases can also be introduced with the eggs or juvenile fish going into a RAS.
- Diseases can be introduced from visitors, equipment suppliers, fish feed trucks etc.
- Despite the potential to keep RAS disease free, there are no guarantees.

**Technical:**

As mentioned, a RAS is complex technically and there would always be potential worry for component failure - and this happens. From the initial design considerations, it is imperative that a component failure doesn’t lead to fish loss. Everything is a cost, but it is important to include a number of back-up procedures or back-up components. One obvious item, as first line of defence, is emergency generators in case of power failure. All components run on electricity. One need spare pumping capacity as second line of defence as it supplies the fish with oxygen. If for instance this still fails, one must incorporate other means of oxygen supplementation, for instance having emergency diffusers in each tank, which can get a supply of oxygen.

The oxygen supply system is critical. For a RAS this would normally either be by oxygen generation on site or a liquid oxygen supply, or a combination. Own oxygen generation is the cheapest, however, liquid oxygen is the safest as it without the need for electrical power can drive the oxygen out to the emergency diffusers in case there was a power failure and even an emergency generator failure – most unlikely of course. But it shows even in it’s extremities, there can be a solution. However, in an Irish context, liquid oxygen is not available at prices that render it economically viable for fish farming. This means that a considerable amount of back-up oxygen generation will be necessary.

As mentioned, component failure will occur but shouldn’t lead to fish loss. There can however, due to component failure be other problems – loss of production or growth. Danish salmon, a 2,000 tons per annum facility, had problems with their water cooling system. This was unfortunately in the summer months and water temperatures rose drastically in the plant – to 20 °C. Luckily, nothing happened to the fish, but feeding had to be dropped to a minimum with basically three months lost production and with dramatic consequences for the years results. Had the water risen a few degrees more, it might have been another picture completely.

Component failure can in certain circumstances effect water quality – for instance if drum filters fall out.

Emphasis on bio filter performance or concept has not always drawn adequate attention. There are some concepts that are not the ideal for saltwater RAS. Not just in nitrification performance, but also with risk of Sulphite formation. These would be submerged stationary filters. These have to be backwashed at intervals, but inbetween backwashes, sludge will accumulate and if oxygen levels drop there is risk of Sulphite and
other aneroic gas formation. Minute concentrations can have growth inhibiting effects on the fish. After backwashing, filter capacity has to build up again and one will get fluctuating performances. This is moreso in saltwater systems as nitrifying bacteria are slower to build back up to peak performance again compared to freshwater systems for example. Finally, any bio filter concept that accumulates even the slightest amount of sludge will encourage organisms that produce geosmins.

All in all with regards to what can go wrong in a RAS, there have been incidents but mainly due to poor design and cutting short corners. It is very important to choose an acknowledged RAS supplier with experience and a good track record. In the salmon smolt systems built to date there have been few technical problems.

**Conclusion:**

*There are RAS concepts that technically will be able to produce quality salmon. Due to being able to operate at the optimum growth temperatures, 12-14°C year round, growth rates, i.e. production time to market size will be faster compared with conventional rearing in sea cages.*

*There are some unsolved biological issues with early maturing males. This may be attributed to sex pheromones from female fish accumulating in the systems. It seems that the higher average temperatures and faster growth in a RAS compared to sea rearing may further exacerbate this.*

*Due to the fact that a RAS is not being exposed to open waters, there are less chances of introduction of diseases into a RAS. However, diseases outbreaks can not be excluded and have happened.*
8. Supply of smolts

In the example of land based salmon grow-out system in this report, supply of the approximately 1.1 million smolt is based on purchase. A salmon smolt system could have been included but would have entailed an additional capital expenditure of probably in the region of €1.5-20 million on top of an already large capital sum.

With own production one would save money, being able to produce them at roughly half price. It would make sense from a bio security point of view to have own production and should be an add on at a later stage. With the situation as described with purchase, one has to ensure that supply comes from disease free hatchery, and that may not be easy as in Ireland as these would be from flow-through systems.

Smolt are normally supplied in size ranges from 80-120 grams. There is though more and more preferences for larger smolt, especially in Norway where 200 gram smolt or even up to 500 gram are the norm. These smolt are all reared in RAS.

These larger smolt shortens the production cycle in the sea with higher productivity gained. At the same time, the shorter sea cycle addresses indirectly some of the issues the salmon farming industry often are accused off, for instance excessive sea lice occurrences.
9. Economic aspects under Irish conditions

Finfish aquaculture businesses require substantial amounts of both operating and investment capital. One of the largest challenges starting an aquaculture business is to acquire sufficient capital. Undercapitalized farms rarely survive. Careful thought and planning need to go into determining the amount of capital needed to operate at an efficient level and to identifying sources for the needed capital.

Capital requirements begin with the investment capital needed to purchase land, build in this case a RAS and purchase quite a lot of equipment beyond the RAS itself. Depending on the specific location, new roads may need to be constructed, electric power lines may need to be installed, or there may be additional infrastructure required that will increase the total amount of investment capital needed.

The best way to reduce the fixed cost portion of the cost of producing fish is to produce at an intensive level with high yields. High yields spread the annual fixed costs over a greater level of production and lower the cost per kg of production.

Operating capital requirements can often be up to half of investment capital requirements for aquaculture businesses. Frequently, this is because high yields are needed to lower the per-kg annual fixed costs and keep production costs at a competitive level. Achieving high yields requires high numbers of fingerlings, large amounts of feed, greater power consumption, and corresponding amounts of other inputs such as labor, repairs and maintenance etc.

Operating cost requirements are compounded by the fact that some types of farmed fish do not reach market size for a year or more. Thus, the investor must prepare to support the business for more than a year without revenue from the business. Careful financial planning and controls are keys to having access to sufficient amounts of capital with which to build the business until it reaches its full production capacity.

The high levels of capital required for many aquaculture businesses result in substantial amounts of financial risk. The profit potential is often accompanied by a variety of risks, and the best method to prevent potential losses is adequate and thorough planning, monitoring, and assessment of the economics and finances of the aquaculture business throughout its life.

Adequate financial resources are essential and the ability to acquire sufficient capital is crucial. One of the first steps is to identify the sources of available capital. Venture capital can be difficult for aquaculture and often follows certain patterns and trends that may not always favor financing aquaculture businesses. Private capital from partners, whether active or silent, can be considered in establishing the business. Many lenders may be skeptical about aquaculture and view it as a risky business. Perceptions of high risk or lack of a viable official licensing system leads to less favorable terms of lending, requirements for greater owner equity in the business, higher interest rates, or refusal to consider loans for aquaculture ventures.

It may be necessary to spend a great deal of time working with a lender to help them understand the basics of aquaculture, introduce them to people who are knowledgeable about successful aquaculture businesses and the keys to their success, and to keep them informed of the most recent trends in aquaculture.
9.1 Capital costs

The capital costs include a full turn-key project and all ancillary equipment. Included is also inlet make-up water pumping station and water treatment system. Finally, there are included feed storage, staff facilities, waste management system and truck and staff pick-ups.

Capital costs will depend a little on site and/or locality. Capital costs can depend a little on whether or not there is apart from saltwater, also a freshwater supply available. This last thing can have an influence on smolt size supply and smolt strategy. A capital expenditure has been found to lie between €33-35 million. In the following financial assessments, the lower value, i.e. € 33 million CAPEX has been used. The headings can be seen below and full detailed capital budget is shown in Appendix 3.

Capital cost headings:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparations and licenses</td>
<td>€ 520,000</td>
</tr>
<tr>
<td>Pre-grow-out system</td>
<td>€ 7,201,479</td>
</tr>
<tr>
<td>3 x grow-out</td>
<td>€ 23,162,390</td>
</tr>
<tr>
<td>Inlet pumping station, water treatment</td>
<td>€ 250,000</td>
</tr>
<tr>
<td>Waste management</td>
<td>€ 1,200,000</td>
</tr>
<tr>
<td>Vehicles</td>
<td>€ 298,900</td>
</tr>
<tr>
<td>Fencing infrastructure, staff facilities</td>
<td>€ 480,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>€ 33,112,769</strong></td>
</tr>
</tbody>
</table>

This capital cost matches quite well per given production volume the systems that have been built so far:

Langsand: 1,000 tons operation € 6,039,000 equals € 30,195,000 for 5,000 tons
Danish Salmon: 2,000 tons € 13,400,000 equals € 33,500,000 for 5,000 tons

It shows that there is little disparity in capital costs from other RAS projects and the cost for the plant described in this report. It has to be noted that the plant in question in this report has an additional feature with a grading facility and purging and harvest channels enabling it to do weekly harvest and deliveries. This would not be included in systems built so far – so if anything, the plant described here is maybe in relative terms slightly cheaper than seen before.

The capital cost for land based salmon grow-out is, according to NOFIMA report 32/2013, approximately 2.5 times that of cage systems.

There are emerging new ideas for Concentric Tank Concept RAS (CTC) for large scale production. These systems are based on shared tank walls and shared walls with water treatment system.
There is no expensive underground pipework. Nor are large concrete structures as in today’s design. See Appendix 6. The systems will reduce capital expenditure. There are still some challenges construction and design wise, but there is no reason to believe they can’t be used for salmon grow-out.
9.2 Operational costs

Two key financial ratios that are normally used in an analysis of a new venture are return on investment (ROI) and return on equity (ROE). A financial analysis normally assumes that the entrepreneur will obtain a certain loan for the total investment required, making up the additional amount with equity investment. A loan could be obtained at standard business rates, or possibly at higher rates due to the risks inherent in new technology ventures. It is difficult to predict which terms of repayment will be accepted by a bank or other venture lender. It could be repayment of 15 years or it could be 7 or something else. It means there are many scenarios, and many speculative ways one can approach financial costs.

The operational costs for a 5,000 tons per annum land based salmon grow-out system are itemized below. Full breakdown of costs can be seen in the attached financial spreadsheet.

<table>
<thead>
<tr>
<th>Costs</th>
<th>€</th>
<th>€/kg</th>
<th>%</th>
<th>NOFIMA €/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smolt purchase</td>
<td>1,320,000</td>
<td>(0.26)</td>
<td>10.3</td>
<td>(0.21)*</td>
</tr>
<tr>
<td>Fish feed</td>
<td>7,609,840</td>
<td>(1.52)</td>
<td>59.4</td>
<td>(1.06)*</td>
</tr>
<tr>
<td>Salaries</td>
<td>640,000</td>
<td>(0.13)</td>
<td>5.0</td>
<td>(0.21)*</td>
</tr>
<tr>
<td>Oxygen supply</td>
<td>419,184</td>
<td>(0.08)</td>
<td>3.3</td>
<td>(0.084)*</td>
</tr>
<tr>
<td>Power</td>
<td>1,181,549</td>
<td>(0.24)</td>
<td>9.2</td>
<td>(0.18)*</td>
</tr>
<tr>
<td>Fish health</td>
<td>150,000</td>
<td>(0.03)</td>
<td>1.2</td>
<td>(0.03)</td>
</tr>
<tr>
<td>Chemicals</td>
<td>500,000</td>
<td>(0.10)</td>
<td>3.9</td>
<td>(0.008)</td>
</tr>
<tr>
<td>Insurances</td>
<td>371,200</td>
<td>(0.07)</td>
<td>2.9</td>
<td>(0.007)*</td>
</tr>
<tr>
<td>Maintenance</td>
<td>120,000</td>
<td>(0.02)</td>
<td>1.0</td>
<td>-</td>
</tr>
<tr>
<td>Misc. waste management, office</td>
<td>500,000</td>
<td>(0.10)</td>
<td>3.9</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total costs before financial costs</strong></td>
<td><strong>12,811,773</strong></td>
<td><strong>(2.56)</strong></td>
<td><strong>(100)</strong></td>
<td></td>
</tr>
</tbody>
</table>


From table 3 it can be seen that primary operational cost is € 2.56 per kg of whole fish. This in itself is production cost that can compare with sea cage farming.

Capital needs will consist of capital costs plus the first years operational needs as follows:

- **Capital costs:** € 33,112,769
- **First year’s operational needs:** € 12,811,773
- **Total:** € 45,924,769
Such finance will be a combination of private equity and loan capital, either bank or venture capital etc. If for arguments sake one says that the first years operational needs is covered by private equity, then there is need for financing of € 33,112,769 or in round figures € 33 million. As mentioned above, it will be very difficult to assess which financial package would be available. It is up to a bank (or other assessor) to assess the risk involved and offer an interest rate and payback time. Interest rates can vary probably between 5 – 6%. If we for example assume an interest of 5.5% and a 15 year term and depreciation, which coincidently also is 15 years, depreciation and financial costs will be as follows:

<table>
<thead>
<tr>
<th></th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation: 15 years</td>
<td>€ 2,200,000</td>
</tr>
<tr>
<td>Financial costs: 5.5% over 15 years</td>
<td>€ 3,098,186</td>
</tr>
<tr>
<td>Total costs for 1 year</td>
<td>€ 5,298,186</td>
</tr>
</tbody>
</table>

This means that depreciation and total financial costs for a 5,000 ton production amount to € 1.06/kg whole weight and a total production cost of € 2.56 + € 1.06 or € 3.62/kg whole weight.

Salmon are sold into the European market Head on Gutted (HOG), iced and boxed. There will be given weekly prices delivered to market – often referenced to as the delivered price to Brussels, in FIS (Fish Info and Services) Market Monitor, NASDAQ, Oslo Food index, etc. The prices are given in Norwegian Kroner (NOK).

The total cost into the European market HOG will with costs of processing and freight from Ireland of € 720 per ton, be as follows:

| Cost per kg whole weight before depreciation and financial costs: | € 2.56 |
| Depreciation, 15 years: | € 0.44 |
| Financial costs, 5.5% interest – 15 years: | € 0.62 |
| Total production costs per kg whole weight: | € 3.62 |

| Total cost for Head on Gutted (HOG) with 88% yield: | € 4.12 |
| Cost of processing, freight: | € 0.72 |
| Total Cost to market HOG (volume of 4,400 kg): | € 4.84 |

According to FIS price indices for 2014, the prices were very fluctuating with a maximum price for salmon of NOK 52.00/kg HOG. Minimum price was 32.00/kg HOG and an average price for the year of NOK 40.81/kg HOG, respectively € 6.17, € 3.85 and € 4.84/kg HOG.

To break even for land based production in 2014, a price of € 4.84 need to be obtained. It can be seen that in this case with a market price of € 4.84/kg HOG, there is no profit. If for arguments sake a sales price was € 5.50/kg HOG can be achieved, ROI would be 18.2%. That would be closer to acceptable ROI levels and probably can be set as a theoretical minimum price. In reality a minimum price would need to be higher as things don’t always go according to plan.
One can also look at cash flows for given sales prices over time. These considerations have been done for sales prices of € 4.84 and € 5.50 respectively. See Appendix 4. It basically shows that in both cases it takes a long time to generate positive cash flows, 9 and 8 years respectively from time of construction start. This is attributed to the relatively high capital cost/financial costs versus profit margin. The capital requirements/costs are approximately 2.5 times higher than for conventional salmon farming. With the relatively high financial costs associated with the high capital costs, salmon farming in RAS would be vulnerable if salmon prices were to slump. It must be noted that some planned land based projects base their financial projections on a premium price, often 10-20% higher than salmon from conventional production in the sea.

The operational costs showed in this report are based on trouble-free production. There is for instance not taken into consideration, the incidence of early maturing males occurring at present in recent constructed land based facilities.

**Conclusion:**

A 5,000 tons per annum RAS for land based salmon grow-out will cost in the region of € 33 million. This is approximately 2.5 times more for the long term capital requirements of conventional sea cage rearing systems, i.e. when the shorter depreciation time of cage structures are taken into consideration.

High capital costs entail high relatively high financial costs both with regards to depreciation and capital funding. The total production cost including depreciation and financial costs is € 4.84 per kg HOG delivered to market. The average cost for salmon in 2014 was € 4.84 per kg HOG.

Emerging new CTC RAS design will be an important step in reducing capital expenditure.
10. Market aspects

Knowing that a market exists is the starting point for any aquaculture venture. Gaining access to that market may however, not always be that easy and in any case, market planning is not to “predict” but to “interpret” that market. In all cases, the distinctiveness of one’s product – and in this case a salmon produced in a RAS, is the focal point.

10.1 Fish quality

Needless to say, when you are launching a new product or a new production concept on a market, it has to be of high quality – even higher than existing produce. Salmon is in principle considered a generic product. However, there is a general bigger awareness of issues such as traceability and sustainability with food production today. Beyond quality, salmon has to be marketed on distinctiveness. An example is Irish farmed salmon.

There is in principle no reason that salmon produced in a RAS could not be of good quality. Flesh quality and texture could be equal to that of conventional farmed salmon. The fish are in round tanks and are swimming in a relatively high water flow, around one body length per second.

It is expected that growth rates are much higher than in the sea, an aspects that is essential for a RAS to be economic viable. However, flesh quality can be compromised if growth is too fast – it can lead to soft flesh and flesh gapping when product is being cooked. There is a need to define/research not just optimums for growth, but also optimums for fish quality for fish produced in RAS.

An issue in all fish produced in RAS is off flavor caused by Geosmins and MIB’s (Methylisoborneol). These are off flavor compounds produced by organisms (often Cyanobacteria) which would live/develop in a RAS. The fish can though be depurated by purging them in external water for a period of time, often 7-10 days.

In principle, fish from a RAS can be of equal quality to conventional farmed salmon which is documented by the trials undertaken by Namgis, Vancouver Island, Canada and this with stocking density of 80 kg/m3.

10.2 Acceptance and image

Sustainability and traceability are terms associated with all food production today. Of these, traceability is automatically included in all modern fish farm protocols. The same would obviously apply to land based salmon farming in RAS.
There are many definitions of sustainability, from the original Brundtland definition, UN 1987 (which since has been considered flawed), to the more modern “Three Pillars of Sustainability” definition: environmental sustainability, social sustainability and economic sustainability, where all three are linked, contrary to the Brundtland’s definition.

There are a number of indicators of environmental sustainability, the most important being:

- Bio diversity interactions – direct
- Bio diversity interactions – in-direct
- Carbon footprint

### 10.3 Bio diversity interactions

**Direct:**

What is meant here are risks of having a direct negative effect on surrounding water environments and/or biota. Potential risks quoted are nutrient enrichment, fish escapees and effects on wild salmon and sea trout in relation to sea lice impact. With a RAS production of salmon with full waste management included, there are none of the above mentioned risks associated. This would be the main arguments/incentive to develop land based salmon production.

**Bio diversity – in-direct:**

What is meant here is sustainable sourcing/usage feed ingredients. There is pressure on wild fisheries and more and more vegetable oils and proteins are incorporated in fish feeds. This issue would be the same regardless of production type, being it in the sea or in RAS.

**Carbon footprint:**

Carbon emission and carbon footprint are important indicators of sustainability. A study conducted by Trond Rosten, NOFIMA, Norway and Brian Vinci, the Freshwater Institute, West Virginia, USA found that production of salmon in RAS had a higher CO₂ footprint compared to cage farming, see Appendix 6:

- Model net pen: 2.72 kg CO₂ per kg of whole salmon
- Model RAS: 6.08 kg CO₂ per kg of whole salmon
Most of the CO₂ emission from the Model net pen situation is related to fish feed production. However, it shows that Norwegian fresh salmon transported to the US had a total CO₂ production of 8.24 kg per kg of HOG salmon. So transport alone to the US is more than the production footprint.

It can be seen that the production footprint for RAS is 6.08 kg per kg whole weight salmon. This is more than double that of cage reared. In this connection, the energy consumption for the RAS described in the Carbon emission study was 4.6 kW per kg of salmon produced. That is more than double of the RAS system designed for this study. The reason being that it is two different RAS concepts. If the figures for the system described in this report were put into the model, then the CO₂ footprint would be 4.36 kg CO₂ or 38% higher than for cage rearing. It has in this context to be mentioned that in the mentioned model for carbon footprint, which is indicative, for the sea cage situation, footprint from well boats, feed barges and certain work vehicles only include fuel consumption. But all in all production in RAS will have a higher carbon footprint than rearing in sea cages.

Salmon produced in RAS will with regards to sustainability be able to be marketed as environmentally sustainable with zero or near zero effect on pollution and surrounding biota, including wild salmon stocks. However, production from RAS will not be able to achieve organic status.

Conclusions:

- **An RAS using saltwater can produce a market size salmon.**
- **A RAS with full waste management included, will have no or insignificant measurable direct negative effects on the environment.**
- **Production in RAS will have a carbon footprint higher than conventional sea cage rearing.**
- **Production from RAS will probably be able to be accredited for certain environmental merits in private accreditation schemes. However, the production in RAS will not merit organic status under EU law.**
11. Success/failures of existing trial or commercial land based salmon farming in RAS

In the following is a list of existing land based salmon grow-out systems built:

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Production</th>
<th>Known costs</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langsand</td>
<td>Denmark</td>
<td>1,000 tons/annum</td>
<td>Production price €4.35/kg</td>
<td>Only 755 of production target achieved. Problems with disease due to inadequate water in-take sterilization. System closed down for re-construction.</td>
</tr>
<tr>
<td>Danish Salmon</td>
<td>Denmark</td>
<td>2,000 tons/annum</td>
<td></td>
<td>Production commenced April and no conclusion on performance yet.</td>
</tr>
<tr>
<td>Namgis</td>
<td>Canada</td>
<td>300 tons/annum</td>
<td></td>
<td>The Namgis project is a pilot project commissioned by First Nation. Biological performance has met expectations.</td>
</tr>
<tr>
<td>BDV</td>
<td>France</td>
<td>100 tons</td>
<td>Production price €3.90/kg</td>
<td>This system has been in operation for 3 years. It is very simplistic consisting of 2 tanks. The design would not be suitable for up-scaling. Fish growth good. Fish quality is good. Fish produced in 20 ppt salinity</td>
</tr>
<tr>
<td>Freshwater Institute</td>
<td>USA</td>
<td>Coherts @ 5.4 tons</td>
<td></td>
<td>Research facility. Established good growth. Intensive analysis on fish quality, which is deemed good. Fish are regularly sold on local markets. System water freshwater. Identiﬁcations on production problems on precocious males.</td>
</tr>
<tr>
<td>Yantai</td>
<td>China</td>
<td>100 tons</td>
<td></td>
<td>No information available</td>
</tr>
</tbody>
</table>
Planned or under construction Atlantic salmon systems:

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Production</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinese Government</td>
<td>China</td>
<td>1,000 tons/annum</td>
<td>Under construction</td>
</tr>
<tr>
<td>Salmo Scania</td>
<td>Sweden</td>
<td>6,000 tons</td>
<td>Planned construction end of 2015</td>
</tr>
<tr>
<td>Swiss Alpine Salmon</td>
<td>Switzerland</td>
<td>600 tons</td>
<td>Planned for 2015</td>
</tr>
<tr>
<td>Hanstholm</td>
<td>Denmark</td>
<td>2,500 tons/annum</td>
<td>Planned for 2015</td>
</tr>
<tr>
<td>Namgis</td>
<td>Canada</td>
<td>2,000 tons/annum</td>
<td>Planned for 2016</td>
</tr>
</tbody>
</table>

Other salmon species:

<table>
<thead>
<tr>
<th>Company</th>
<th>Country</th>
<th>Production</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell Aquaculture</td>
<td>USA</td>
<td>100 tons COHO</td>
<td></td>
</tr>
<tr>
<td>Sweet Springs</td>
<td>USA</td>
<td>100 tons COHO</td>
<td>Growth under expected, but based on RAS system. Closed down</td>
</tr>
<tr>
<td>Teton and Hutterite</td>
<td>USA</td>
<td>2 @ 100 tons COHO</td>
<td>Both closed down</td>
</tr>
<tr>
<td>Sustainable Blue</td>
<td>Canada</td>
<td>100 tons COHO</td>
<td>Electricity failure. Closed down</td>
</tr>
</tbody>
</table>

Conclusions:

Atlantic salmon:

There are 4 systems that have produced fish for the markets where we have information of performance:

- Namgis
- Freshwater Institute
- Danish Salmon
- Langsand

Of these, only two are of commercial size; Langsand and Danish Salmon.

Langsand has experienced disease problems and a lower growth performance than planned – 25% less growth. However, the disease issue has been due to poor design of the make-up water inlet system. Inlet water has of course to be of good quality with regards to standard water quality criteria. However, the make-up water has also additional to be sterilized. The sterilization process in this case was not adequate resulting in an outbreak of Furunculosis. This subsequently meant that the system had to be closed down.
and be sterilized. The company is in autumn 2014 making necessary changes to the inlet system and making other changes to the RAS.

Growth limitations would be expected of the RAS concepts where sludge entrapment takes place as a means of solids control. In saltwater with its relatively high content of sulphates, one may risk in a sludge environment, H$_2$S formation from sulphate reducing bacteria. Even in minute concentrations there will be growth inhibitions.

Danish Salmon A/S which is a 2,000 tons production facility have had some “teething” problems, partly with under estimating waste management issues, but also with water temperature control. This has meant that they have lost several months growth due to excessive high water temperatures.

As can be seen from above, there are no conclusive results as to whether land based grow-out has been successful at meeting financial expectations from the two commercial Atlantic salmon production sites in operation in Denmark.

The research grow-out facility at the Freshwater Institute has successfully grown market size salmon. Growth has been good and likewise for Namgis in Canada and in both cases grown market size fish within 12 months of smolt input.

In all cases of Atlantic salmon grow-out in RAS, it has been established that there is a high degree, up to 25%, of early maturation in males. Speculation is that this is caused by accumulation or high levels of sex pheromones in a RAS. The highest levels of early maturation seem to occur in systems with lowest salinity and/or highest temperature. This is unfortunate in that comprises growth potential.

The problem with early maturation can maybe be reduced by day light length manipulations. Langsand have been to reduce the occurrence to 5%. A drastic improvement, but still a loss factor production wise.

Other salmon species:

With regards to other species of salmon, it seems that nearly all systems of the 100 tons Coho size units in the US have failed. Growth has not been as anticipated and this together with margin of scale is attributed to this.
Appendix 1. Layout for 5,000 tons per annum land based salmon grow-out
Appendix 2. Description of technology

Two types of plants are included in the proposal for RAS production of a 5,000 tons salmon grow-salmon, one including round tanks, and one built from concrete raceways.

The core water treatment processes are identical in the two plants.

Water supply for the fish tanks are provided low head axial propeller pumps, pumping water from the pump sump into the inlet channels (raceways plant) or closed supply pipe network (round tank plant). From the inlet channels/pipes water flows into Low Head Oxygenation (LHO) boxes, where oxygen is added by the counter current principle.

Oxygen is dosed automatically in accordance with the oxygen demand in each tank/raceway individually by feedback from an oxygen probe at the outlet of the tank.

In peak load situations in round tanks supplementary oxygen can be provided by pressure oxygenation of water in oxygen cones, mixed into the tank water inflow.

The total water circulation is approximately 4 times per hour in raceways and 1.5-2 times per hour in round tanks, which ensures efficient supply of clean water and removal of metabolites from the tanks. The pump capacity and reservoir configurations are designed in order to operate at the lowest possible pumping head.

Mechanical filtration.
From the outlet ends of the raceways/center- and side drains from round tanks all system water drains through special outlet screens by gravity via the back channels through a number of 40-60 micron drum filters, arranged in parallel, for mechanical filtration into 2-3 bio-reactors, also arranged in parallel, and finally back into the pump reservoir, where temperature - and pH-control is performed. Backwashing of the drum filters is done automatically. Wastewater from the backwashing process is lead to waste management plant.

Biological treatment.
Two to more blowers (including one stand-by) provide aeration for the bio-reactors, serving several purposes:

- Operation of the airlifts and turbo mixing systems, ensuring efficient self-cleaning of the bio-medium and removal of exhaust bacteria film.
- Optimal distribution of substrate and oxygen for the bacteria.
- Provision of up to 75% of the maximum oxygen requirement of the bacteria.
- De-gassing of up to 60% of the carbon dioxide generated by the fish respiration.

The balance amount of oxygen for bacterial respiration at maximum feeding is supplied as pure oxygen by automatic control. Oxygen is dosed individually for each bio-reactor via oxygen turbo mixers, receiving side streams of water from the pumps.
Salinity impact.
There is no in principle difference between nitrification processes in fresh- and seawater, but by reference to literature it is often concluded that nitrification in seawater requires significantly larger bio-filters than in fresh water. Such articles are referring to measurements in stationary bio-filters, which are extremely prone to accumulate organic sludge and not allowing optimal distribution of oxygen and metabolites in the filters due to constrained water flow through the filters. This results in reduced nitrification efficiency due to oxygen depletion in a majority of microenvironments of the filters.

In seawater the nitrification inhibiting effect in stationary filters becomes more prominent due to:

- increased disintegration of suspended solids, causing more accumulation in the filters,
- reduced oxygen carrying capacity in seawater
- increased activity of sulphate reducing microorganisms, working in anaerobic environments of the filters, and inhibiting the efficiency of fish to utilize ingested feed optimally.

In the MBBR the conditions for the nitrification bacteria are kept optimal due to the bio-film control mechanism described. This means that no sludge accumulation will take place, and distribution of oxygen and metabolites is hydraulically optimized.

CO₂ degassing.
Central degassing is taking place in the bio-reactor airlifts, where all CO₂, generated by the mineralization processes, plus part of the incoming CO₂ from the fish respiration is degassed. In RAS with low feeding loads the bio-reactors will be sufficient degassing in the plant, but in more intensive plants like the plants proposed, supplementary degassing is necessary in order to maintain the CO₂ concentration in the plants below acceptable maximum limits.
In raceway plants with the fast turnover (i.e. short retention time) in the raceways, additional centralized degassing by diffusion in the pump sump or through cascade, either between the bio-reactors and the pump sump or in front of the raceway inlets, will suffice for maintaining the CO₂ concentration low.
In round tank plants supplementary centralized degassing by diffusion in the pump sump or in cascade between the bio-reactors will reduce the CO₂ concentration to an acceptable inlet level in the tanks, but due to the long retention time in the tanks, supplementary decentralized degassing at the tank level is required. This is performed in diffusion airlifts, placed on the outside of the tanks, airlifting tank water through the degasser and in this process expelling CO₂ out of the water.
With respect to de-gassing of carbon dioxide it is essential to perform efficient removal from the building of the carbon dioxide eliminated by de-gassing.

UV-treatment.
UV-treatment of 5-10% of the recirculation water flow, depending on the water turnover rate, is included as a side treatment in plants for start feeding and juvenile production. Treated water is pumped from the pump sump, through fine mechanical filtration in a bead filter, and through the UV-treatment plant, providing a treatment dose of 60 mJ/cm².
De-nitrification.
De-nitrification may be included in the plants as a side treatment:

- Either as an integrated part of the plant operation for optimization of the plant heat balance and saving of make-up water,
- Or for treatment of discharge water in order to meet legislative discharge water
Appendix 3. Feed composition and resource management.

Commercial salmon feed types, preferably optimised for RAS operations, will used in the production. Feed manufacturers have over the last decade been striving at composing diets with reduced content of marine fish based fish meal and oils, which are highly spoken for by many feed industries, and as a consequence becoming more and more expensive and limiting, as wild catches are exploited to their limits.

By replacing fish meal with preferably vegetable resources, feed manufacturers are compromising on the digestibility of the commercial diets, which leads to higher feed conversion rates (FCR) in the production and more waste products in RAS plants, challenging the manufacturers of such plants. Recently some of the commercial feed manufacturers have entered into development programs with RAS plant manufacturers in order to optimise on feed digestibility as well as on incorporation of vegetable raw materials.

By using the best feed products available it is possible to maintain the FCR at 0.6-1.0, increasing from small sizes up to 1.2kg+. Above that size the FCR will increase slightly with fish size due to increasingly lower exploitation efficiency by the fish. Even as important for obtaining low FCR’s in fish production, is maintaining high oxygen concentrations >80% saturation in the fish tanks, as reduced oxygen levels immediately affects the FCR towards a significant increase, in bad cases up to 50-70%.

De-nitrification is performed in closed reactors in order to secure complete reduction of the nitrogen components into atmospheric N\textsubscript{2}-gas. Substrate for the process is used from intrinsic organic waste material from the mechanical treatment section (re. above), possibly supplemented with external carbon substrate like molasses or another waste product from industrial production.

Ozone treatment.

Ozone (optional) treatment may be performed on a side stream of water, pumped from the reservoir after the bio-reactors, either as a supplement before the UV-treatment or as an alternative to that. Ozone treatment is included in the fish purging system for elimination of geosmine in order to eliminate off taste in the salmon before harvesting for marketing.

In seawater the nitrification inhibiting effect in stationary filters becomes more prominent due to:
- increased disintegration of suspended solids, causing more accumulation in the filters,
- reduced oxygen carrying capacity in seawater
- increased activity of sulphate reducing microorganisms, working in anaerobic environments of the filters, and inhibiting the efficiency of fish to utilize ingested feed optimally.
Appendix 4. Capital costs

Land based salmon grow-out CAPEX
5,000 tonnes per annum production

<table>
<thead>
<tr>
<th></th>
<th>m³ vol</th>
<th>m³ cost</th>
<th>Area</th>
<th>m² cost</th>
<th>total</th>
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</thead>
<tbody>
<tr>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60000</td>
</tr>
<tr>
<td>Land purchase</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250000</td>
</tr>
<tr>
<td>Planning permission, discharge consents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60000</td>
</tr>
<tr>
<td>Fish culture licences, foreshore licence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50000</td>
</tr>
<tr>
<td>Site preperations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>520000</td>
</tr>
</tbody>
</table>

### Pre-grow-out 100 gr - 1,000 gr

<table>
<thead>
<tr>
<th></th>
<th>m³</th>
<th>€</th>
<th>m²</th>
<th>€</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>1800</td>
<td>500</td>
<td></td>
<td>90000</td>
<td></td>
</tr>
<tr>
<td>Building</td>
<td>4480</td>
<td>300</td>
<td></td>
<td>134400</td>
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### Pre-growout equipment

<table>
<thead>
<tr>
<th></th>
<th>Plant incl. Install</th>
<th>4062924</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x PCI Oxygen Generator, DOCS500</td>
<td></td>
<td>207185</td>
</tr>
<tr>
<td>Automated Pneumatic Feed and Control system</td>
<td></td>
<td>142187</td>
</tr>
<tr>
<td>1 x Fish Grader 3-500g g, plus 1 x 500 - 3000g</td>
<td></td>
<td>86827</td>
</tr>
<tr>
<td>plus 1 fish elevator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walkway system, seawater aluminium app 550m</td>
<td></td>
<td>170356</td>
</tr>
<tr>
<td>Electric contractor</td>
<td></td>
<td>240000</td>
</tr>
<tr>
<td>Back-up generator</td>
<td>Broadcrown</td>
<td>48000</td>
</tr>
<tr>
<td><strong>Total Pre-growout</strong></td>
<td></td>
<td>7201479</td>
</tr>
</tbody>
</table>

### 3 x Growout 1000-5500 1000g => 5000g

<table>
<thead>
<tr>
<th></th>
<th>m³</th>
<th>€</th>
<th>m²</th>
<th>€</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>x 3</td>
<td></td>
<td>2343</td>
<td>500</td>
<td>1171500</td>
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<tr>
<td>Building x 3</td>
<td></td>
<td></td>
<td>16128</td>
<td>300</td>
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### Growout equipment

<table>
<thead>
<tr>
<th></th>
<th>Plant incl install</th>
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</tr>
</thead>
<tbody>
<tr>
<td>3 x PCI Oxygen generator DOCS500</td>
<td></td>
<td>310777</td>
</tr>
<tr>
<td>Description</td>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>3 x Automated Pneumatic feed and control system</td>
<td>284370</td>
<td></td>
</tr>
<tr>
<td>3 x Fish Elevator</td>
<td>134040</td>
<td></td>
</tr>
<tr>
<td>3 x 10 fish tanks 16 mØ x 4m WL</td>
<td>2297970</td>
<td></td>
</tr>
<tr>
<td>3 x walkway system seawater alu, 445 m</td>
<td>409038</td>
<td></td>
</tr>
<tr>
<td>3 x Electrical contractor</td>
<td>760000</td>
<td></td>
</tr>
<tr>
<td>Back-up genrator</td>
<td>Broadcrown No 3 39000 117000</td>
<td></td>
</tr>
<tr>
<td><strong>Total Growout</strong></td>
<td><strong>23162390</strong></td>
<td></td>
</tr>
<tr>
<td>Feed storage silos, chemical room</td>
<td>60000</td>
<td></td>
</tr>
<tr>
<td>Outdoor infrastructure Fence, gates, tarmac, loading areas, lighting</td>
<td>300000</td>
<td></td>
</tr>
<tr>
<td>Staff facilities</td>
<td>120000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>480000</td>
<td></td>
</tr>
<tr>
<td>Inlet make-up water treatment and operations</td>
<td>250000</td>
<td></td>
</tr>
<tr>
<td>Waste management system</td>
<td>1200000</td>
<td></td>
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<tr>
<td></td>
<td>1450000</td>
<td></td>
</tr>
<tr>
<td>Misc Vehicles (1 truck + 2 staff pick-ups)</td>
<td>298900</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td><strong>33112769</strong></td>
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</table>
## Appendix 5. Operational costs

### Operational costs for a 5,000 tons per annum land based salmon grow-out system

<table>
<thead>
<tr>
<th>Unit</th>
<th>No. unit cost</th>
<th>€ per kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CAPEX</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smelt purchase</td>
<td>100g</td>
<td>1,100,000</td>
<td>1.2</td>
</tr>
<tr>
<td>Feed from 100 - 1,000g</td>
<td>1,118</td>
<td>1,400</td>
<td>1,955,200</td>
</tr>
<tr>
<td>Feed from 1,000-5,000g</td>
<td>4,204</td>
<td>1,285</td>
<td>6,044,640</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5,822</td>
<td></td>
<td>1,521,986</td>
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<tr>
<td><strong>Salaries - operational</strong></td>
<td>10</td>
<td>400,000</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Salaries - administrative</strong></td>
<td>4</td>
<td>600,000</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Power for O2 production</strong></td>
<td>582,000</td>
<td>0.6</td>
<td>419,184</td>
</tr>
<tr>
<td><strong>Power up to 200g</strong></td>
<td>84</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power up to 1,000g</strong></td>
<td>340</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power up to 5,000g</strong></td>
<td>750</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power misc</strong></td>
<td>50</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td>52560</td>
</tr>
<tr>
<td><strong>Fish health - medication</strong></td>
<td>500,000</td>
<td>0.03</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Chemical pH regulation</strong></td>
<td></td>
<td>0.1</td>
<td>500,000</td>
</tr>
<tr>
<td><strong>Insurance</strong></td>
<td>2500</td>
<td>3712</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
<td></td>
<td>1,181,549</td>
</tr>
<tr>
<td><strong>Chemical pH regulation</strong></td>
<td>500,000</td>
<td>0.03</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Insurance</strong></td>
<td>2500</td>
<td>3712</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Power for O2 production</strong></td>
<td>582,000</td>
<td>0.6</td>
<td>419,184</td>
</tr>
<tr>
<td><strong>Power up to 200g</strong></td>
<td>84</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power up to 1,000g</strong></td>
<td>340</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power up to 5,000g</strong></td>
<td>750</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Power misc</strong></td>
<td>50</td>
<td>8760</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Energy</strong></td>
<td></td>
<td></td>
<td>52560</td>
</tr>
<tr>
<td><strong>Fish health - medication</strong></td>
<td>500,000</td>
<td>0.03</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Chemical pH regulation</strong></td>
<td>500,000</td>
<td>0.03</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Insurance</strong></td>
<td>2500</td>
<td>3712</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td></td>
<td></td>
<td>1,181,549</td>
</tr>
<tr>
<td><strong>Chemical pH regulation</strong></td>
<td>500,000</td>
<td>0.03</td>
<td>150,000</td>
</tr>
<tr>
<td><strong>Insurance</strong></td>
<td>2500</td>
<td>3712</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Capital costs</strong></td>
<td>€ 33000000</td>
<td>5.5%</td>
<td>15-years</td>
</tr>
<tr>
<td><strong>Total production cost whole weight</strong></td>
<td>€18,109,959</td>
<td>3.622</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unit</th>
<th>No. unit cost</th>
<th>€ per kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production achieved in Year 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilo Weight - Whole Salmon HOD</td>
<td>5,000,000</td>
<td>5,000,000</td>
<td>88%</td>
</tr>
<tr>
<td>Actual Output</td>
<td>4,400,000</td>
<td>4,400,000</td>
<td>88%</td>
</tr>
<tr>
<td>Sales Price per Kilo</td>
<td>€4.84</td>
<td>€5.50</td>
<td></td>
</tr>
<tr>
<td>Sales Value</td>
<td>€21,296,000</td>
<td>€24,200,000</td>
<td></td>
</tr>
<tr>
<td>Final Processing Costs per Kilo</td>
<td>€0.00</td>
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<tr>
<td>Net Sales Value</td>
<td>€21,296,000</td>
<td>€24,200,000</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 6. Carbon footprint

Facilities

Model Land-based RAS farm (32 million US $)

**Site production site**

- **Invested equipment:**
  - 40,000 m³ of rearing tank volume
  - 25,500 m² of building area
  - 2,500 m² processing facility
  - 885 m³/min of pumped RAS flow
    - Pumps and piping
    - Screen filters
    - Biofilters
    - Gas Conditioning Filters
  - 1.08 – 1.36 kg feed per m² supply water
  - Feeding Systems
  - Backup Generators

- **Investments in total: 32 M US $ – approximately 192 MNOK**

- **Maintenance and reinvestments set equal to the depreciations**

Model Net Pen farm (12.3 million US $):

- **Two production sites, each with six net pen cages:**
  - 658,000 m³ net volume
  - 120,000 m³ area footprint visible at sea
  - 379,000 m³ area footprint incl. no thoroughfare zone
  - 603,000 m³ area footprint incl. no fishing zone

- **Invested equipment:**
  - 3 licences
  - 12 Floating rings (157 m Ø)
  - 100 nets (25 m deep)
  - 2 mooring systems
  - 2 boats
  - 2 feed barges (150 Mtons)
  - 12 camera systems
  - 12 feed distributors
  - 12 power systems

- **Investments in total: 72.9 MNOK – approximately 12.3 M US $**

- **Maintenance and reinvestments set equal to the depreciations**

---

**Technology for a better society**

---

**Conservation Fund**

<table>
<thead>
<tr>
<th></th>
<th>Construction of facility and equipment</th>
<th>Small production</th>
<th>Feed production</th>
<th>Grow out (fuel and elec.)</th>
<th>Oxygen and lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Model RAS (90% hydro)</td>
<td>2.69</td>
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<td></td>
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</tr>
<tr>
<td>2) Model RAS (US mix)</td>
<td>6.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Model PEN: Base</td>
<td>2.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Model PEN: High Perf.</td>
<td>2.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**kg CO2e / kg salmon in live weight**

**Sum of GHG emissions caused by the production of one kilo of salmon in live weight from production of feed ingredients up through salmon being ready for slaughter.**

**Cases:**

1. Model RAS system using a 90% hydropower / 10% fossil fuel electric mix with a GWP of: 0.04 kg CO2e/kWh*
2. Model RAS system using an average electric mix for the US with a GWP of 0.77 kg CO2e/kWh*
3. Model Net Pen system with average FCR: 1.27
4. Model Net Pen system with best practice FCR: 1.14

* Modelled with data from the ecoinvent v2.2 database
13. References


