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Comparison of Atlantic salmon net pen and recirculating aquaculture systems: economical, technological and environmental issues

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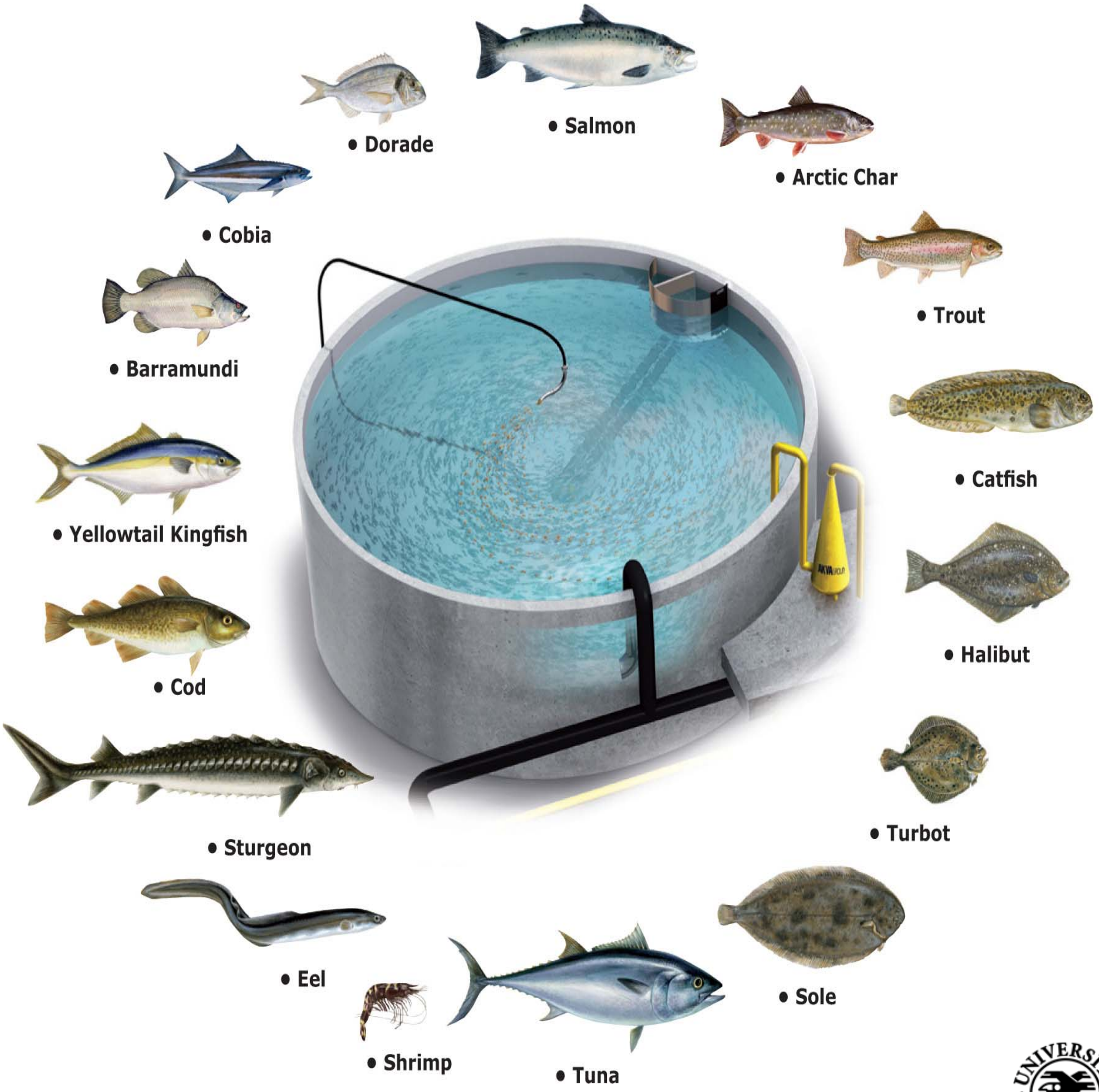

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Abstract

The modern aquaculture industry is a rapidly developing sector of the fisheries industry. Among the fish species reared in marine waters Atlantic salmon (*Salmo salar*) shares a significant part. Nowadays, the largest salmon producing countries are Norway, Chile and Scotland. The common technology used in the salmon production is a sea cage, which is presented in a form of floating plastic rings or robust metal installations fastened to a barge. In both cases, the fish is placed in the net in the open sea, and therefore, production is highly dependent on the external factors, such as environmental conditions, disease and parasites presence.

Recirculating aquaculture systems (RAS) have been used to supply smolts for further production of market-size salmon at sea. Nowadays, this system is suggested to provide the whole production cycle from smolt- to market-size in the closed environment with optimal biological conditions. Nonetheless, the existing projects require higher initial investment costs than the conventional net pen farm.

In the present work, comparison analysis of net pen system and RAS has been performed on the basis of the economic analysis of salmon aquaculture farm suggested by Trond Bjørndal and Frank Asche in "The Economics of Salmon Aquaculture", 2nd edition (2011) and report "Profitability analysis of the NIRI technology for land-based salmon farming" (2008) by Krisin Roll, Arve Gravdal and Asbjørn Bergheim. The analysis includes compilation of biological and bio-economical models for the both systems. Missing or out-of-date information has been replaced by new data from additional sources such as research articles, industrial reports and expert opinions. The net present value (NPV) and internal rate of return (IRR) are the main measures that have been used in analysis.

The overall conclusion from the comparison has shown that RAS is around 12 mil NOK less profitable than net pen farm in ten years time horizon, while NPV in both cases is positive. However, other findings from the research revealed an unreliability of the scaling method in respect to RAS, without detailed description of the farm production capacity and equipment. Besides, investment costs estimation is dependent on many factors that are complex and require a thorough investigation.

At the same time, in spite of scientific and industrial analyses show lower impact on the environment from RAS in comparison to the net pen aquaculture system, it may be questioned in terms of RAS location and power source use.

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1. Introduction

1.1. Aquaculture industry overview

Fish farming is a fast growing industry that has developed significantly over the last decades and is expected to continue to increase in the coming years (FAO, 2014). As a part of fish production aquaculture has shown a very rapid increase in production and doubled the quantity over the last decade from 32.4 million tonnes in 2000 to 66.6 million tonnes in 2012. That was around 40% of the total global fish production, which in 2012 was 158 million tonnes (Figure 1) (FAO, 2014).

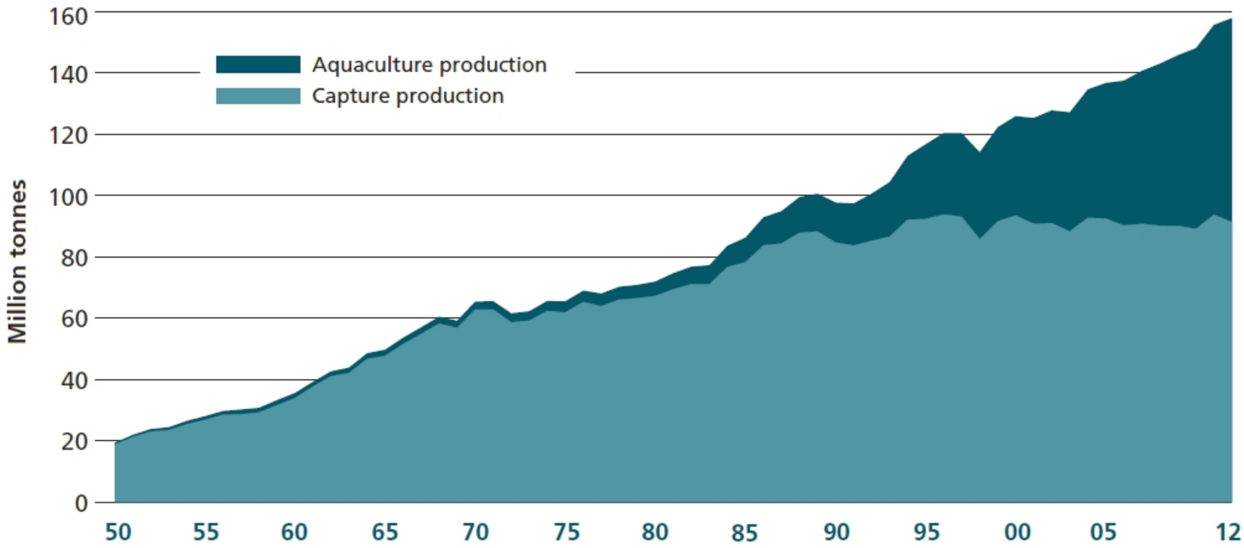

Figure 1. Total World fish production 1950-2012, million tons (FAO, 2014).

At the end of 2012, the most common farmed species are finfishes that form 57.9% (38.5 million tonnes) of the total aquaculture production, then follow molluscs – 22.8% (15.2 million tonnes), crustaceans – 9.7% (6.4 million tonnes), marine finfishes – 8.33% (5.5 million tonnes) and other aquatic animals which total share is 1.3% (FAO, 2014).

Atlantic salmon takes a significant place among the farmed diadromous fishes (Figure 2) and together with other salmonids it forms more than a half of the total diadromous fishes production since 1990s. However, maximum share of salmonids in the total production has been registered in 2001 (70.4%) and started declining afterwards (FAO, 2012).

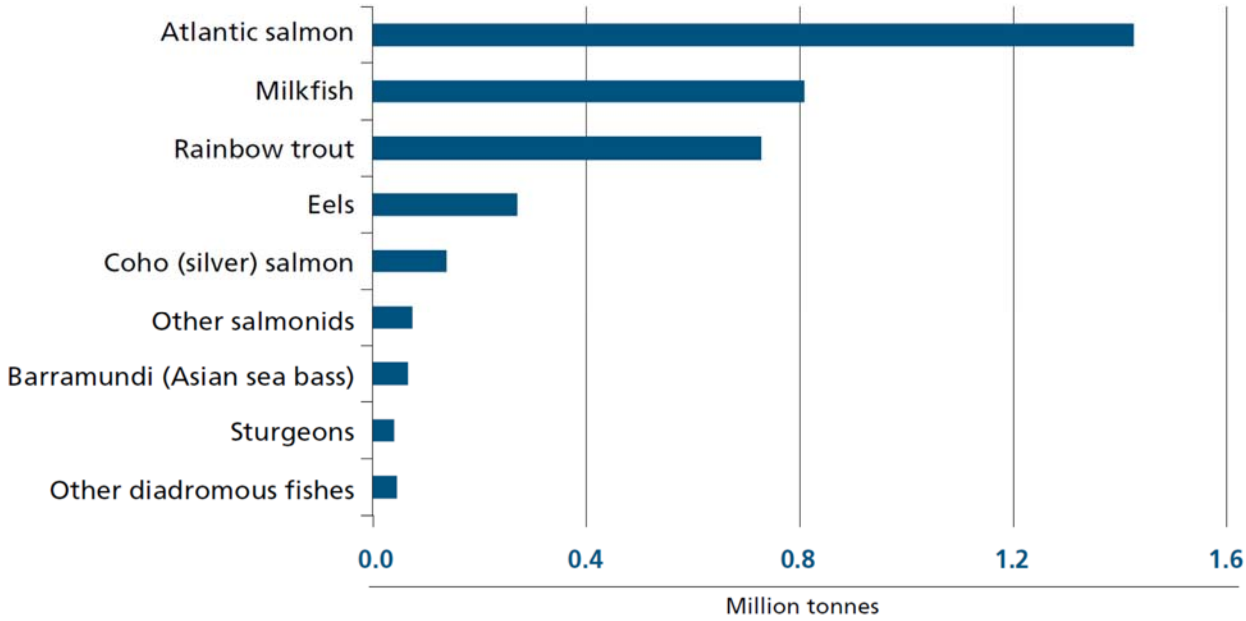

Figure 2. Production volume distribution among farmed diadromous fishes (FAO, 2012).

Technologies and systems for farming fish have evolved over time. Established as a changing of fish natural habitats, then activity turned into installation of ponds along coastline and in lakes. Farming in made of earth ponds implies use of impervious materials and barriers as a measure limiting inner and outer water exchange, fish movement and excluding escapes. This system has been used for centuries in Asia and Europe. Individual households often use this technique because of its constructing simplicity for; as it only requires digging a pool and carrying out the production process. The young fish in such facility are bought from breeders or occur naturally. Feeding may be performed by using households by-products (Subasinghe and Currie, 2005a).

From the knowledge assembled by fishermen and seafarers, engineers in aquaculture has developed techniques allowing to benefit from allocation of fish sea cages in offshore areas (Subasinghe and Currie, 2005b). The most common technique today is a sea pen that was developed in the 1980s. Since then, industrial production has increased, and instead of using a single pens, up to 14 pens are in operation. They are produced in form of steel cages, that can better sustain predator attacks, and plastic cages. The latter are relatively not costly and therefore more common. The size of modern plastic pen has increased significantly in diameter and depth comparing to first farms, from 5 m and 4 m to 50 m and 40 m, respectively. The cages are fastened to a barge where equipment and personnel is placed. The barges are movable with pens, besides it allows in some systems to submerge the pens in order to protect from stormy weather. The fish rearing process starts when the water temperature is suitable, usually from March to October in Norway and from September to March in Chile. As the water temperature is a significant factor for fish growth, biological development of the same species differs because of site-related factors (Asche and Bjørndal, 2011).

Environment and existing aquaculture industry are highly interacted, what makes the latter very vulnerable to any changes in water chemistry, temperature condition and biological organisms spreading, such as diseases and parasites. The sites are located in areas where the marine currents and tidal waters provide the required aeration and water exchange for optimal production (Paisley et al., 2010).

Among the most significant factors negatively influencing salmonids marine farms are vibrosis, furunculosis, Infectious Pancreatic Necrosis (IPN), Heart and Skeletal Muscle Inflammation (HSMI), Infectious Salmon Anaemia (ISA) and Sea lice (Asche et al., 2009; Marine Harvest, 2012).

In addition to diseases, the existing coastal aquaculture facilities may suffer from natural predators, such as seals and birds, and weather conditions, for example, storms or floods may damage floating cages with fish of other parts of the farm (FAO, 2012; Marine Harvest, 2014). Beside these natural factors, the changes of legal regulations and restrictions toward protection of wild stocks and habitats may substantially reduce the number of available sites for fish farming and increase costs of environmental impacts (Paisley et al., 2010).

However, technological innovation has allowed development of a new type of aquaculture system where the farming process can be carried out in an isolated environment (Subasinghe and Currie, 2005b). Rearing fish in man-controlled and regulated condition has become a basis for the hatcheries industry, as we know it today. In such systems, the fish may also be reared for food or ornamental purposes, due to improved knowledge on water chemistry and bacteria, the water may be recirculated and used over again and nutrients utilised effectively (Subasinghe and Currie, 2005a).

According to the elements stated above, it may become more challenging to use traditional net pen system to farm food fish in Nordic countries. In this light, alternative technologies may have advantages conforming to both changing law and environment. In terms of increasing demand for fish products and lack of available sites to raise production level, land-based recirculating aquaculture system (RAS) with closed environment could be a feasible substitution to existing farms. This complex system allows to rear fish in isolated from the surrounding environment water tanks, installation of modern technological equipment and sensors makes it possible to keep water condition in RAS suitable for any kind of species the whole year round. In addition, according to designers of the system, RAS shortens a grow-out period and excludes the necessity for farmers to wait for a proper season for fish release after harvesting the previous batch. Nevertheless, equipment, construction works and qualified employees are capital-intensive what makes it questionable that the system may compete to the developed conventional net pen system.

1.2. Objectives

This study is aiming to analyse profitability of existing Norwegian aquaculture companies and compare this with corresponding on-land facility in form of RAS in Nordic countries, *e.g.* Norway. Investigate which alternative is more preferable to an investor, net pen or land-based facility, taking into account only grow-out phase and not processing, and therefore to estimate how existing economic conditions may influence the development of the new technology.

The research questions could be expressed in this way:

1. What is the additional investment and operational costs of RAS compared with today`s aquaculture?
2. Can expected advantages of RAS, *e.g.* shorter fish growth period, and disadvantages, *e.g.* high start investment level, make it competitive to the existing net pen system?

For achieving the aim of the thesis, the following methods have been implemented:

- Analysis of existing RAS technologies provided by private companies;
- Production cycle modelling for net pen and RAS for production of Atlantic salmon;
- Comparison of the key economic parameters of the systems, such as operational costs, net present value (NPV), internal rate of return (IRR);
- Assessment of environmental impact magnitude from RAS and net-pen technology;

1.3. Constraints

Due to a limited number of RAS in operation and their technological differences it is problematic to make a universal economic analysis for such facilities. Therefore, it is considered to estimate feasibility of a farming system suggested by Niri AS and presented in the report “Profitability analysis of land-based salmon farming” (Roll et al., 2008), in terms of today`s fish and materials prices.

1.4. Hypotheses

1. Recirculating aquaculture system has higher cost per production than the conventional net pen system;
2. Recirculating aquaculture system is less profitable than the conventional net pen system.

2. Aquaculture systems

2.1. Issues related to net pen aquaculture technology

Considering the issues met by modern net pen aquaculture, spread of diseases and parasites is heavily influencing the industry. While there is development of medical treatment in form of vaccination and antibiotics use, this issue occurs worldwide and is difficult to forecast.

Despite active implementation of measures to control disease in 2003 and 2007, Chile experienced an outbreak in 2007 caused by ISA virus which led to a substantial production decrease (Asche et al., 2009). As the production cycle for Atlantic salmon takes from 1.5 to 2.5 years, the consequences of the event appeared later as a dramatic fall of production level from the peak volume of 388 048 tonnes in 2008 to 122 000 tonnes in 2010 (Figure 3) (Asche et al. 2009; FAO 2014).

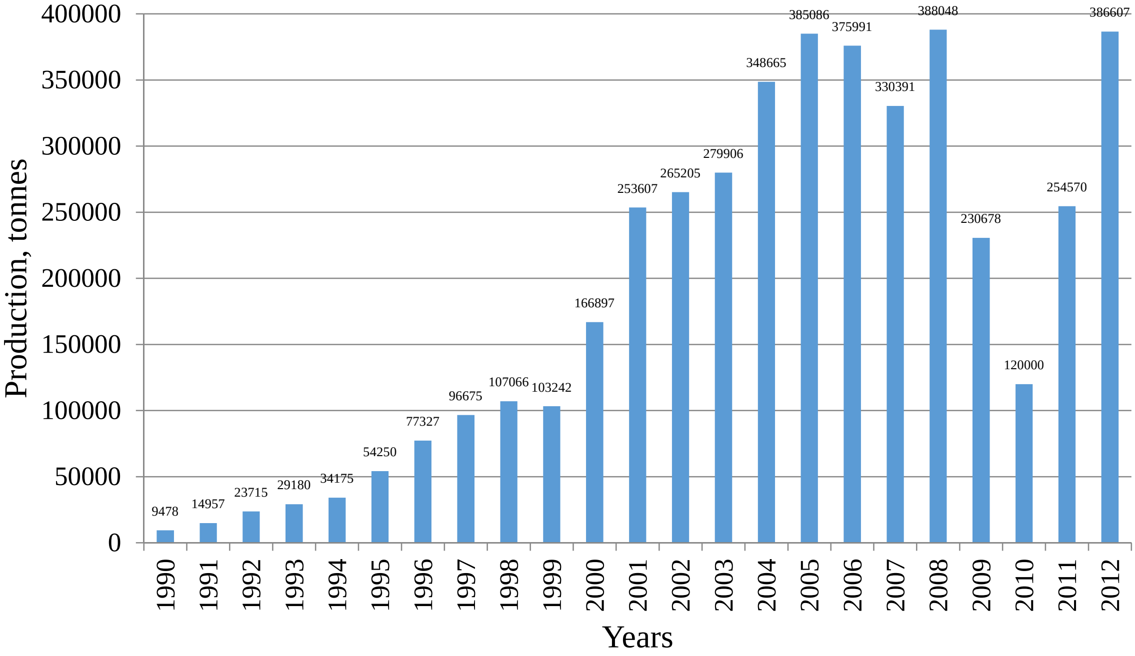

Figure 3. Atlantic salmon production in marine waters in Chile (FAO 2014).

Outbreaks were also registered during 2008, and government eventually introduced measures to stop the spread of ISAV. But the industry revealed that the measures were not effective to cope with the problem (Asche et al., 2009).

In Norway over the period from 1984 to 2005, 437 outbreaks have been registered. Thanks to the regulations implemented by the Norwegian veterinary authority in the end of 1980s the last peak of 80 occurrences was registered in 1990 (Lyngstad et al., 2008). However, investigation of 32 outbreaks registered between 2003 and 2005 showed that there is high risk of ISAV transmittance with water currents between adjusted marine aquaculture sites. Besides, all farms located along the coast of Norway use well-boats for various operations including transportation of smolts from breeding facilities. Therefore, by passing farming areas the boats are also considered as a significant factor for disease spread. While there are no reports interrelated with the boats in Norway, outbreaks in Scotland are strongly correlated with number of well-boats visits (Lyngstad et al., 2008).

Another occurrence of such kind happened in the Faroe Island in 2003 that caused a sharp fall in production level almost four times from 47 000 tonnes in 2004 to 12 000 tonnes in 2006 (Asche et al., 2009).

From the beginning of 2000 pancreas disease (PD) has become a substantial threat to aquaculture industry in Norway. PD is an atypical alphavirus, has been first reported in 1976 in Scotland (Taksdal et al., 2007), while the first report on the disease in Norway is registered in 1989 (Aunsmo et al., 2010), the significant outbreak on Atlantic salmon and rainbow trout sea farms took place in 1995 (Taksdal et al., 2007).

Relatively low number of outbreaks in period from 1998 to 2002 (Kristoffersen et al., 2009) turned into a rapid increase starting from 2003. Most of the affected sites located in the western part of Norway, but further, the disease has spread towards northern regions (Figure 4) comprising total quantity of 98 outbreaks in 2007 (Aunsmo et al., 2010).

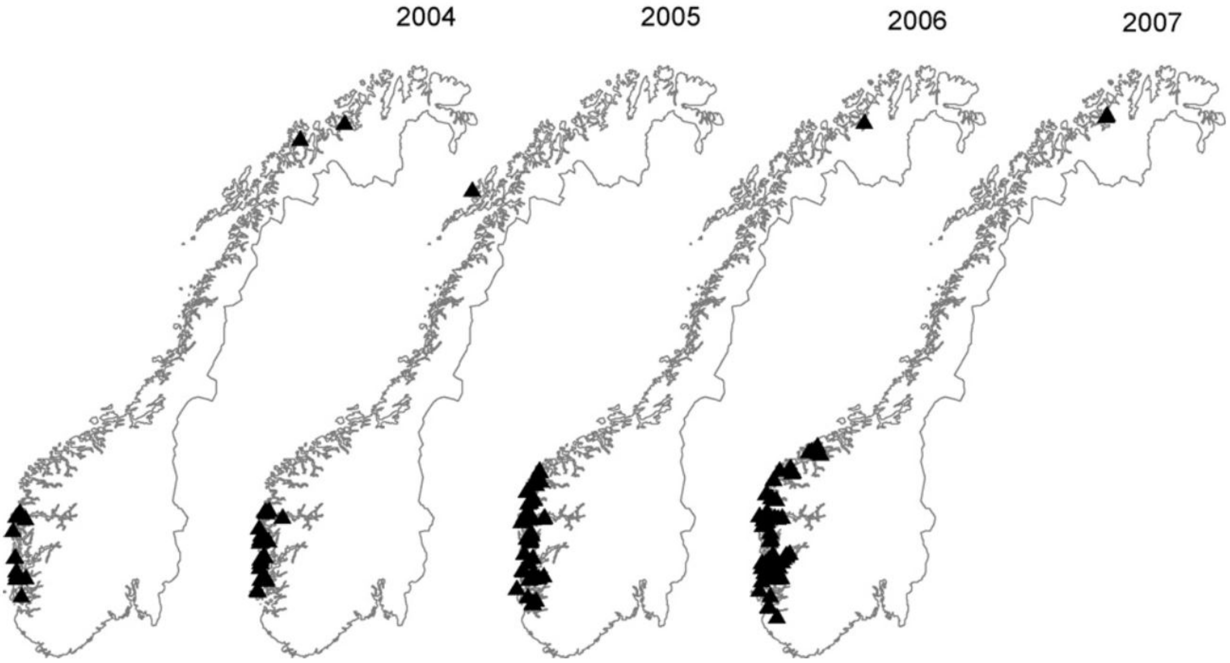

Figure 4. Pancreas disease spread in Norway from 2004 to 2007 (Kristoffersen et al., 2009)

The quantitative analysis of the disease development is presented in Figure 5.

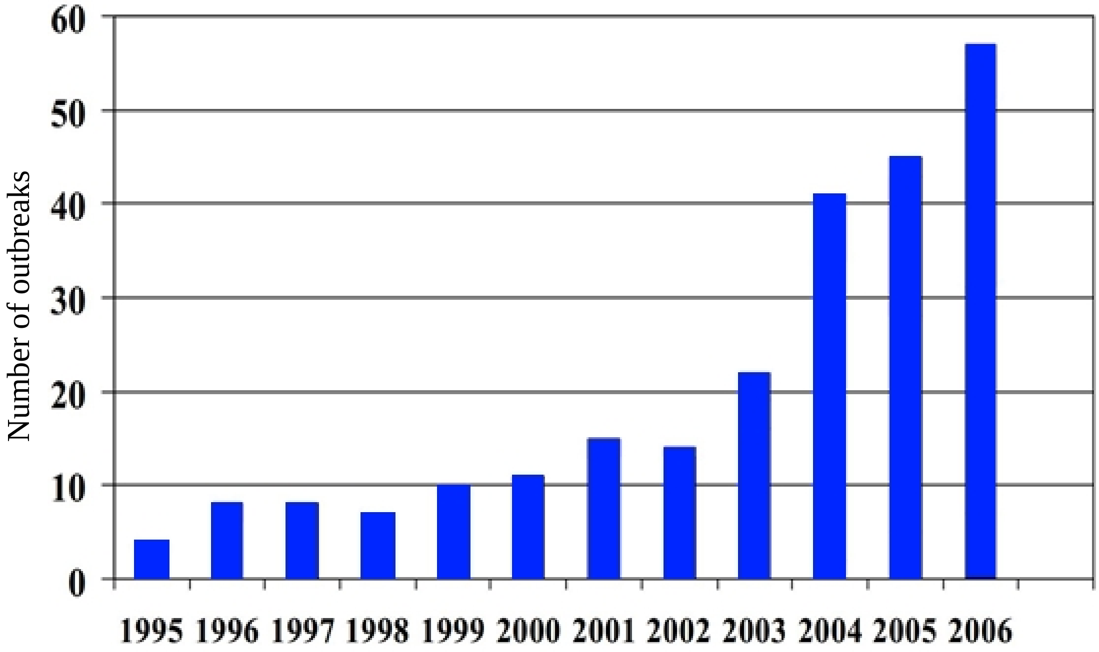

Figure 5. Quantitative growth of pancreas disease outbreaks (Hoel et al., 2007).

In the same year PD has been input in B list disease by the Norwegian Food Safety Authority (NFSA), because of significant negative influence on the industry (Kristoffersen et al., 2009).

The outbreaks may last in the range from 3 to 4 months (Taksdal et al., 2007), and the mortality level varies significantly. In Ireland the rate has been shown in between 0.1-63% (Kristoffersen et al., 2009), in the period from 1988 to 1992 on eleven seawater salmon farms total mortality was 50%, from 1990 to 1994 annual level was approximately 12.1% and form 2003 to 2004 – 9-15% (Aunsmo et al., 2010). In Norway the level varies from 3% to 20%, in the period from 1999 to 2002, 80% of infected sites experienced 5% and in 33% – 15% of PD-related mortality, with the highest level at 80% during transferring of smolts (Aunsmo et al., 2010; Taksdal et al., 2007). It is also suggested that smolts released in autumn are more exposed to PD infection than any other, because of seasonal changes of the environmental condition (Kristoffersen et al., 2009).

The virus is considered to spread passively in marine currents, with no necessity of an agent as human or animal, and hence, the farms located close to each other are at high risk, especially if neighbouring farms have experienced an outbreak. However, the farms that share a concession may obtain the virus through common facilities and personnel (Kristoffersen et al., 2009).

The fish that suffered from PD but survived, however loses its value as white muscle, the most valuable part of fillet, degenerates and has poor pigmentation, what in result affects the quality, particularly if the fillet is smoked (Taksdal et al., 2007). Moreover, production may be affected in a way to necessary shift from premium to ordinary class salmon, what has been estimated to reduce the price by about 2.2 NOK per kg (Aunsmo et al., 2010).

In terms of PD-related costs, decrease of production level does not lead to reduction of labour involved in the process, in opposite there is a necessity for extra force. In case the farm try to compensate the fish losses by prolongation of grow-out phase, this, however, causes increase in labour costs as well. Besides, the remaining biomass will affect the total biomass quota of the company and reduce potential production of other sites. Furthermore, this ability is limited by environmental and physical constraints in addition to legal (Aunsmo et al., 2010).

Total amount of direct costs a company may suffer from pancreas disease outbreak, if rear 500 000 smolts at one site, has been estimated at 15.6 mil NOK, in case of implementation of compensatory measures this amount would decrease by 1.2 mil NOK. However, while the disease may significantly influence market through fish quality and price and cause an economic growth slowdown, until present time the effect on the country's economy is limited. Besides, big companies are flexible to move their stocks from infected sites. Consequently, local small companies are mostly exposed to the losses from PD. Together with economic expenditures it causes reduction in employment what is crucial for costal societies (Aunsmo et al., 2010)

Independently of companies' flexibility, number of infected sites is increasing. For the period from 2012 to 2014, total amount of confirmed outbreaks is 120.

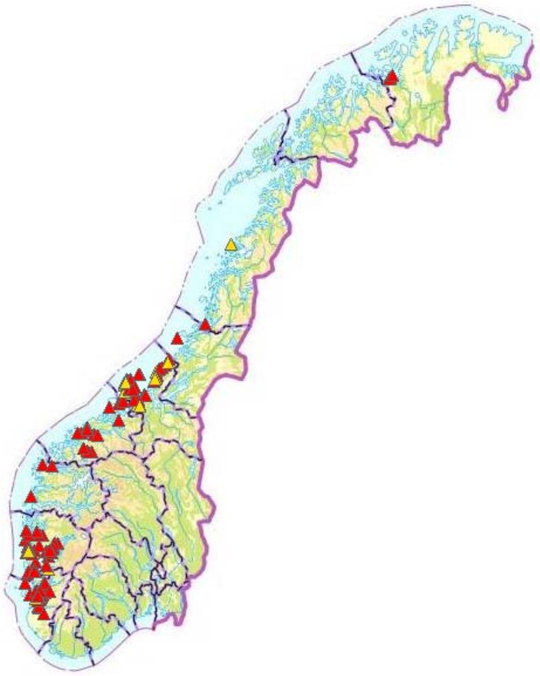

Figure 6. PD infected sites from 2012 to 2014. Red triangles – confirmed incidents, yellow – not confirmed (kart.fiskeridir.no).

Besides, the spread of PD has changed from year 2007 significantly (Figure 6), and now it covers partly middle Norway as well.

Together with disease, salmon lice *Lepeophtheirus salmonis* is still a threat to the industry. In Canada losses were estimated to 20 million CAD in 1995, in Norway – 500 million NOK in 1997 and from 15 to 30 million pounds in Scotland in 1998 (Heuch et al., 2005). Investigation on sea lice population and distribution showed that this parasite's larvae are mostly concentrated in the waters where salmon farming is actively performed. It has also been estimated that infected farmed salmon carries much more lice eggs, about 15 billion, when the wild one just 2.6 billion (Heuch et al., 2005). Thus, rearing of salmon in marine environment in open net pens can cause negative effects not on the farmed fish and farmers prosperity solely, but on wild nature as well. The parasite cannot survive on sea trout and Arctic charr when they migrate from salted ocean water to rivers. However, sea lice larvae infect fish when one passing areas with high farms concentration. In addition, escaped fish may transmit the parasite to longer distances than currents. Despite rapid decrease of escapees level (Figure 7) there is a presumption, based on previous estimations, that the real figures are much higher (Heuch et al., 2005).

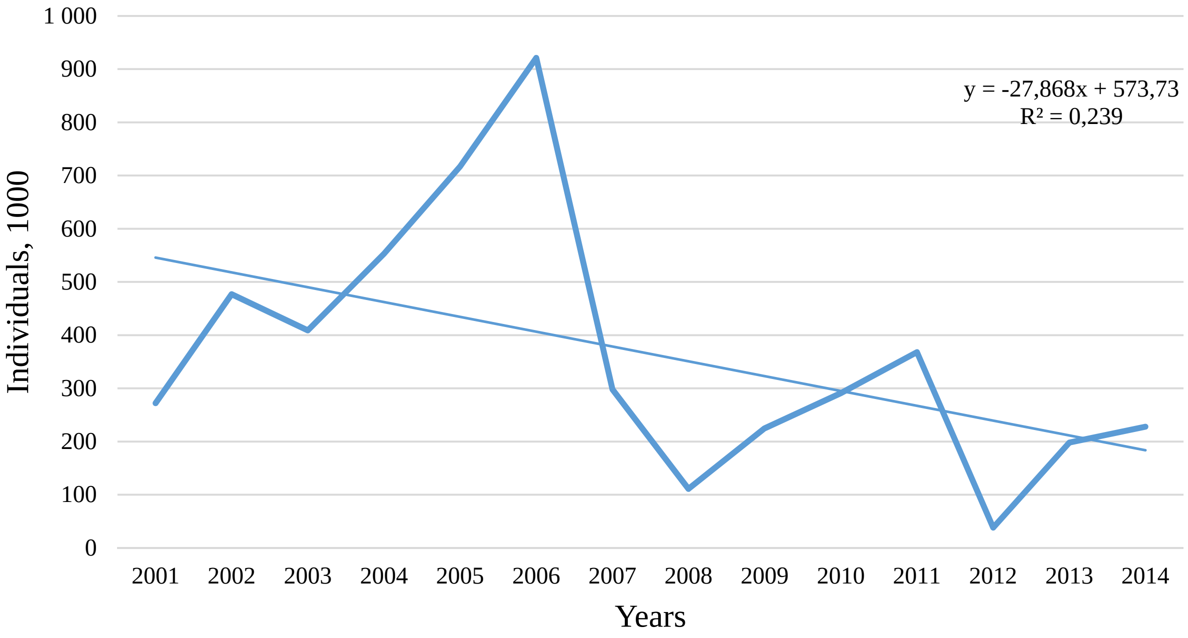

Figure 7. Escapes of Atlantic salmon in Norway (information for 2014 is estimated on 30.09) (Fiskeridirektoratet, 2014)

Heuch et al. (2005) suggested that in 2001 there were 3 times more escapees then it was reported, considering continues catches of farmed salmon within period when there were no reports on escapes.

Aquaculture of other species has suffered from disease and environmental disasters around the world as well. Among them are oyster farming in Europe, shrimp farming in Asia, South America and Africa (Mozambique in 2011). China met a dramatic loss of production of 1.7 million tonnes in 2010 because of natural and anthropogenic reasons (FAO, 2012).

Since the last decades of the XX century the World has met a new phenomenon that is called Global climate change. Because it influences all spheres of human activity and life as a whole, aquaculture industry must take the total uncertainty of this process into account. Climate change implies changes in weather patterns that may lead to drought and floods lasting for longer periods in different parts of the planet. Another effect is highly increased number of reported disasters (Figure 8) (FAO, 2012).

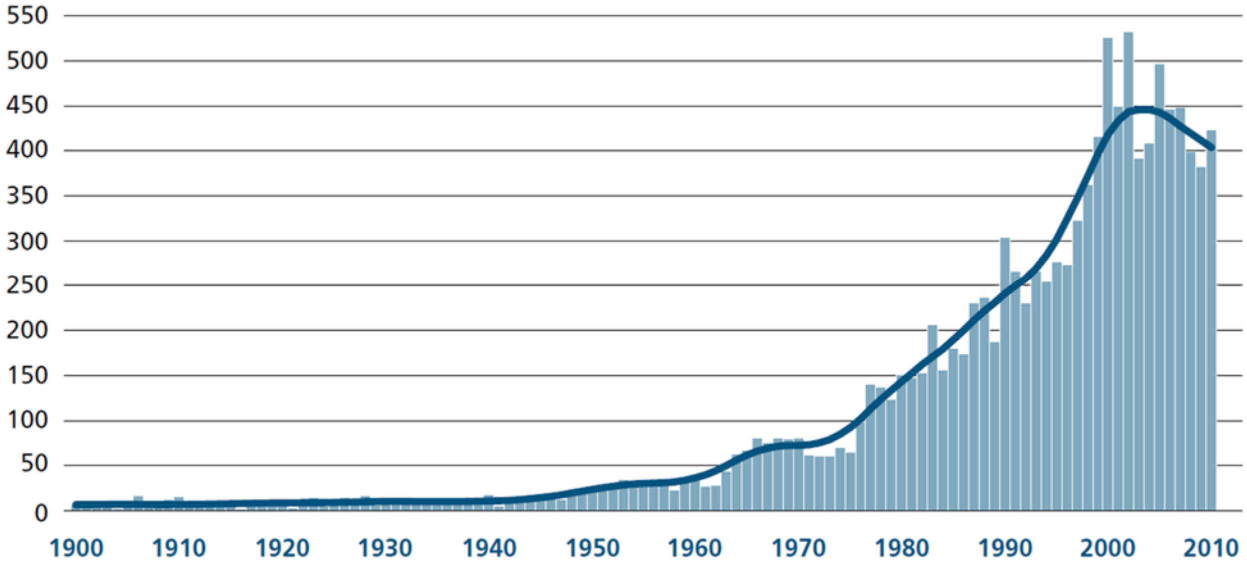

Figure 8. Natural disasters reported worldwide (FAO, 2012).

The condition for rearing fish may become extreme in some coastal regions due to floods and droughts, what, together with other climatic processes, may cause change of natural conditions for farming, such as water temperature and salinity. This may make it impossible to rear species in areas close to the shores (FAO, 2012).

Considering the interaction between environment and aquaculture industry, human health and introduction of genetically modified organisms in fish-food industry, the new regulations and measures appear in Nordic countries that have a strong influence on the industry within these countries.

In Norway, 37 National Watercourses and 21 National Salmon Fjords are closed for farming salmonids to protect wild stocks from disease and salmon lice spread. In addition, to obtain a green label for own products, producers have to follow particular rules. In 2010, there were two sites for salmon farming meeting this requirement (Paisley et al., 2010).

Since 2004, there is a new requirement to green labelling in Denmark, it is not allowed to use genetically modified feed and fish, the latter cannot be biologically treated as well, it is also forbidden to add colouring matters to feed. These and other environmental regulations together with low number of available sites limit net-pen aquaculture development. However, this does not have an influence on small amount of recirculating farms (Paisley et al., 2010).

In Finland, where fish farms produce about 12 500 tonnes of food fish annually, according to the Law 157/2005 it is restricted to use wild fish caught from brackish or marine waters for feed for farmed fish. The production is regulated in terms of use of fish feed per year, and if a producer use more than 2 tonnes he has to apply for a permit. Besides, the farmers have to fund programs evaluating influence of farming on local environment (Paisley et al., 2010).

Icelandic Environmental Impact Assessment Act requires an assessment of every establishing fish farm if it’s production exceeds 200 tons annually and waste waters empties in ocean, or if production exceeds 20 tons per year and waste waters empties in fresh water. While not many farms are interested in eco-labelling of own fish, land-based farms that rear most of smolts and slaughter fish use “pathogen free” ground waters and filtered seawater, together with geothermal energy to warm-up the water (Paisley et al., 2010).

Fish farming in Sweden follows the national and EU regulations that are demanding in terms of environmental affairs. Therefore, it is unlikely that number of farms will increase next years. In 2001 KRAV scheme is established in Sweden to label fish produced in an environmental friendly way. However, there is no high interest from the producers, so the total number of companies and productions accredited KRAV were three and six respectively, but now there are no companies approved in accordance with the scheme aquaculture sites (Paisley et al., 2010).

2.2. Advantages of RAS

Recirculating Aquaculture Systems (RAS) is an aquaculture system with integrated water treatment equipment, as a sequence of biological and mechanical filters, what allows to reuse 99-99% of the incoming water, with only 1-3% water consumption (Roll et al., 2008). RAS have been developed over the past three decades by Cornell university in New York and commercial research groups (Timmons and Ebeling, 2010). Among the latter are the Fresh water institute of

The Conservation Fund in Canada, Niri AS in Norway and others located in the USA, Canada, Denmark etc.

Due to water control, salmon reared in the indoor RAS are more protected from air and water-borne disease and contaminants comparing to open-air sea cages and ponds, where incoming water flow cannot be regulated at all, hence, as a direct contact with pathogens is inevitable, fish may be lost. Opposite to this, high degree of waste streams control makes it environmentally sustainable and excludes risks of spreading diseases or parasites in case of occasional introduction in RAS, besides they may be easily managed and effectively eliminated (Timmons and Ebeling, 2010).

The system considered in this thesis system has also a substantial advantage compared to the conventional system because of growth control by water condition adjustment, that avoid peaks and valleys of product supply to the market (Timmons and Ebeling, 2010).

One of the main factors influencing growth is temperature. Biological limit for Atlantic salmon is between 0°C and 23°C. While these borders may vary in different wild stocks, the optimal growth is achieved in the interval 12- l5°C. The reason is that oxygen saturation decreases from 14 mg/l at 6°C to 9 mg/l at 16°C in fresh water, therefore, as the fish can consume barely from one-third to half of saturated oxygen in the water, water supply at the upper temperature level must be three times more intensive (Figure 9) (Stead and Laird, 2002).

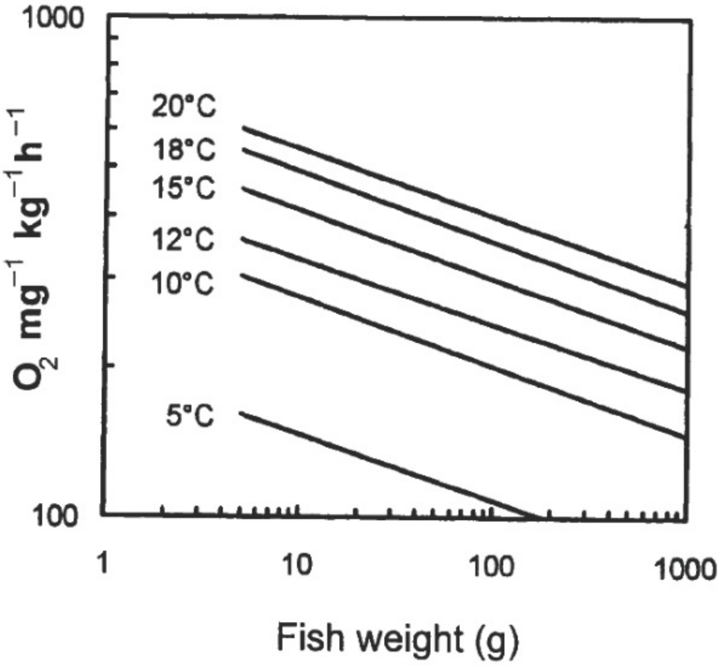

Figure 9. Oxygen consumption of salmonid fish (per kg body weight) in relation to fish (body) weight and water temperature (Stead and Laird, 2002)

Oxygen level is also significant for growth because of its impact on feed consumption. At the higher temperatures with lower level of saturated oxygen, feed consumption increases as well (Stead and Laird, 2002).

These two factors may be considered as a sufficient improvement of fish welfare that has a positive effect on both fish itself and farmer's competitiveness by reduction of the feed costs.

As one can see from Figure 10, an average seawater temperature in Norway is within the suitable limit only for seven months a year, while the optimal level lasts for 3-4 months. In this light, sufficient environmental condition for rearing Atlantic salmon is in Chile.

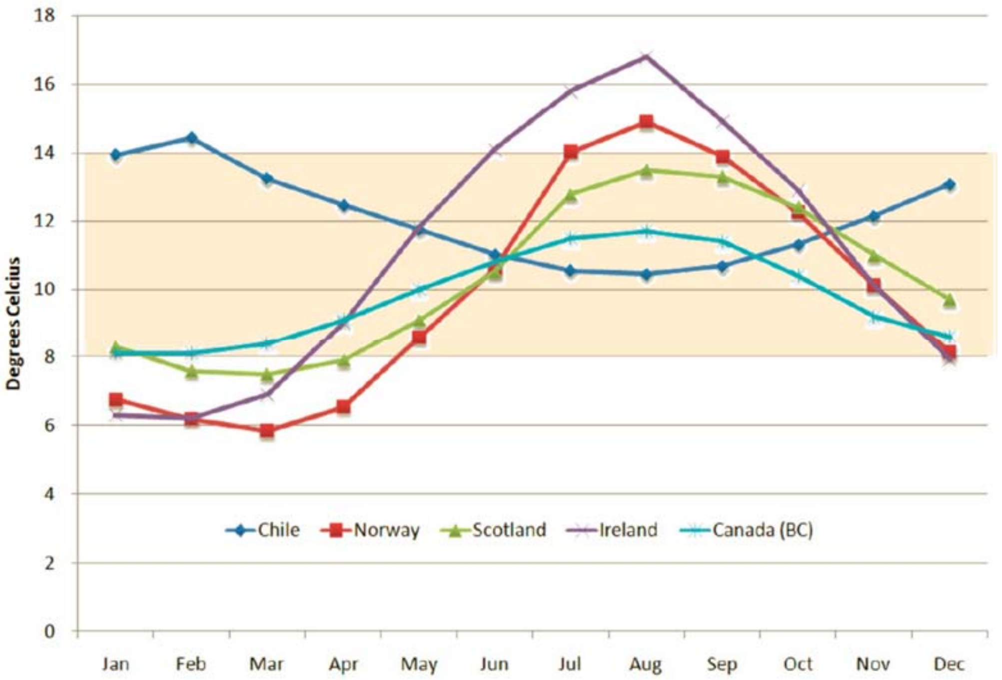

Figure 10. Average sea water temperature in the areas of active salmon production (Marine Harvest, 2014).

Controllable environment allows the farmers to control fish growth and hence to predict the harvest volume more certain. In addition, adjustable water condition by using of filters and heaters gives an opportunity to increase production per m^3 comparing to net pen systems (Timmons and Ebeling, 2010).

Fish escapees are considered as a significant environment impact, which in the conventional systems this may be caused by predator attacks, fails during net washing or transportation. As RAS is located on the land and has no direct connections between tanks and surrounding water bodies there is a remarkable advantage of elimination of fish escape.

Besides, due to the fish growth condition advantages in RAS, it has low environmental impact in relation to net pen and pond systems, therefore it may be placed closer to the consumer

(Timmons and Ebeling, 2010) and make benefit from prompt delivery and preferences to local and eco products, however for the Niri system a proper source of sea water is required. Also, land-based systems are widely used for production of smolts for further release in sea cages (Asche and Bjørndal, 2011).

2.3. Niri AS system design

The RAS considered in my work is designed by Niri AS. The company was founded in 2006 in Måløy, Norway, by engineers and marine biologists. The largest stakeholder of the company is the founder and main developer Arve Gravdal. Niri AS is aiming to develop on-land closed facilities for farming different types of fresh water and marine fish species, such as Atlantic salmon (*Salmo salar*), tilapia (*Oreochromis niloticus*) and Atlantic cod (*Gadus morhua*), allowing production at competitive price to conventional net pen systems used for fish farming at sea. As an important benefits of the considered system is minimising a possibility of any disease occurrence, and hence medication use, high water quality control and effective feed utilisation. At present, the company owns experimental stations in Ireland and Poland.

The facilities are designed in various option for production levels from 3 000.00 to 10 000.00 tonnes of fish. Besides, it is possible to integrate processing and auxiliary productions in the farm (Figure 11).

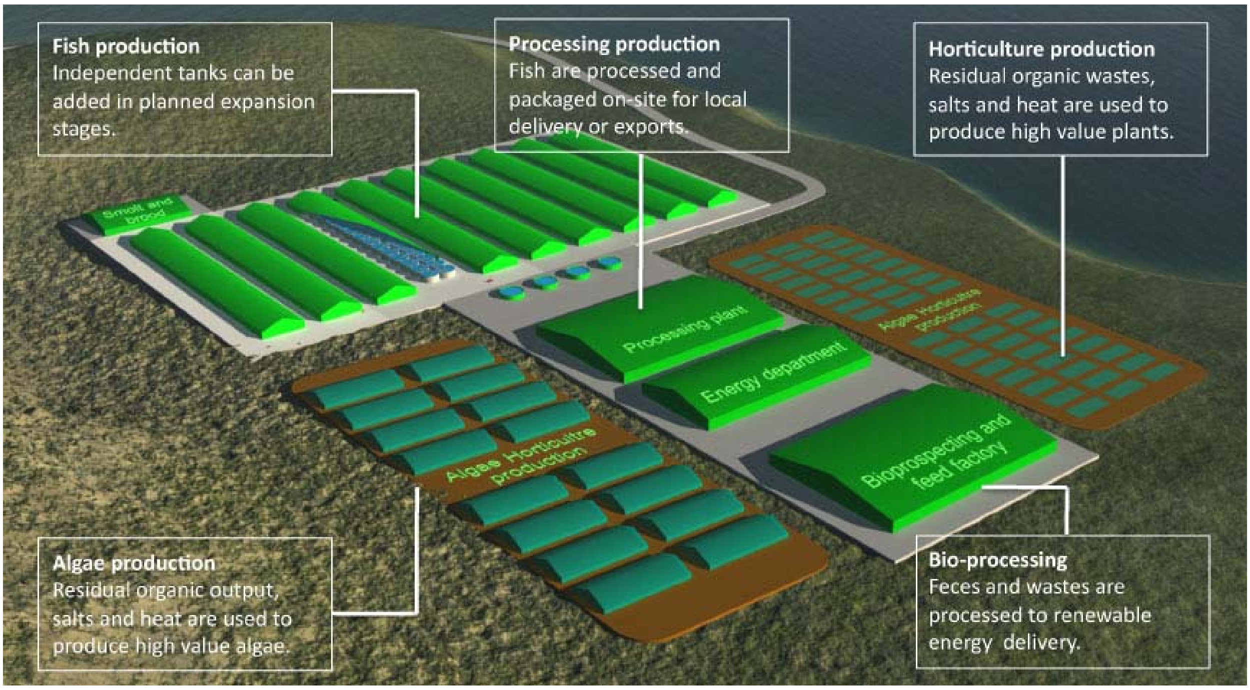

Figure 11. Niri AS land-based farm design (niri.com).

However, a conceptual facility considered in the thesis is described in “Profitability analysis of land-based salmon farming”, 2008. This facility is established on-shore with approximately production level 7,000 tonnes. According to the designers the system is specific due to recirculating equipment is in the single tanks, and tanks are independent of each other, what can allow blocking tanks in case of disease outbreak or easily expand the facility for necessary production increase. Construction has total rearing volume of 20 210 m^3, each tank is 20 m diameter, with total area at about 3 hectares (30 000 m^2). Seawater is supplied from a well at maximum 500 l/min tank flow rate. Average water temperature is to be kept at 14 °C all seasons. Schematically, the system is presented in Figure 12.

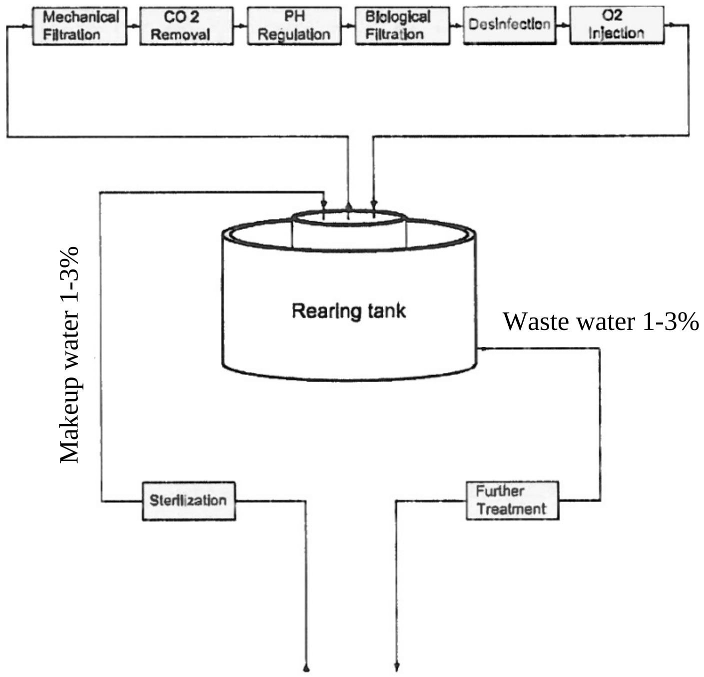

Figure 12. General RAS structure

The water is lifted to the system by a propeller pump for approximately 1 m height, afterwards it moves through treatment equipment by the force of gravity (Roll et al., 2008).

Recirculating in the system starts with solid particles removal, the particles are mostly uneaten or undigested feed. This procedure is crucial to efficient biofilter functioning, and therefore influencing water quality in the whole system. Implementation of filters with mesh size of 40-100 μm allows to lower amount of solids in the flow by 40-80%. For removal of smaller particles foam fractionation is used. In this process, air bubbles are produces in the bottom of water column, particles are attached to the coming up bubbles and then at the top they form a foam, that is channelled out afterwards (Roll et al., 2008).

CO_2 is a waste product of bacteria and fish respiration, to control its amount in the water is an important process to sustain high density of fish in the indoor RAS. Concentration of CO_2 must not exceed 10-15 mg/l for the long-term, to maintain this level packed column aerators are used. Carbon dioxide is removed by air gusted at the bottom of the column and shaking the water that falls (Roll et al., 2008).

Another fish respiration product is ammonia gas that is excreted from gills and further, forms ammonia nitrogen of two types: ionized NH_4^+ and highly toxic un-ionized NH_3. Total ammonia nitrogen (TAN) must be severely monitored and kept at the level below 10 μg N/L. For this purpose there was installed a biological filter, where bacteria *Nitrosomonas* and *Nitrobacter* are grown on a specific surface substance. Further, the first transforms ammonia into nitrite (NO_2^-) and then the *Nitrobacter* convert nitrite-nitrogen into nitrate , which is not harmful to salmonids (Roll et al., 2008).

In the initial project, to estimate fish respiration products amount and therefore water recycling rate the following models have been implemented in the design of the facility:

1) oxygen consumption – $MO_2 = 1.92W^{0.27}T^{0.63}10^{0.01C}$

where W – fish size, T – water temperature, C – current velocity;

2) carbon dioxide excretion – $MCO_2 = 2.14W^{0.27}T^{0.63}10^{0.01C}$;

3) ammonia excretion – $TAN_{excr.} = 0.036 + 0.26N_{in}$

where $TAN_{excr.}$ – daily ammonia excretion, and N_{in} is nitrogen intake by fish. However, the water flow rate has not been re-estimated in the present work

Suitable pH level for salmonids is from 6 to 8, this parameter is crucial for metabolic waste (CO_2, NH_3) treatment. Deviation from the stated borders makes the water toxic for the specie (Roll et al., 2008).

To prevent pathogens occurrence in the system ultraviolet radiation (UV) has been used. Correct dose of radiation inactivates microorganisms, however, the particles must be removed from the water before the operation (Roll et al., 2008).

2.4. Sea farm design

As an example of conventional system is considered a farm located in the western part of Norway in the climatic conditions similar to Bergen region, because about 70% of farms are located in the waters with such environmental conditions (Asche and Bjørndal, 2011). The company possesses three sites, free from pathogens, and available for operations. For fish rearing two plants are used, for each of them it is required a barge and eight plastic sea cages, 120 m in circumference and 40 m in depth.

3. Methods and parameters estimation

Net present value (NPV) has been used to evaluate the profitability of recirculating aquaculture and net pen systems. NPV calculates the present value (PV) of net cash flow minus initial investments of the project. To calculate net cash flow (CF) annual total costs incurred by the production are subtracted from total revenue for selling fish, further, this value is discounted by discount rate (r) to the initial date, what has PV as a result. Discount rate represents an interest rate to evaluate value of the future CF, it shows an alternative value that could be earned by investing money in other project.

Other parameter values that are resulted from authors’ observations or sophisticated calculations and are intrinsic to a particular condition have not been recalculated (Asche and Bjørndal, 2011; Roll et al., 2008).

3.1. Biological model

3.1.1. Growth

A yearclass of fish (recruits of the same age) are released into a grow-out facility and the yearclass’ development is measured in terms of the three key features over time t such as number of fish, $N(t)$, average individual fish weight, $w(t)$, measured in kilograms, and the total biomass, $B(t)$. The latter is fish weight multiplied by the number of fish:

$$B(t) = N(t)w(t) \tag{1}$$

where t is time, measured in years (Asche and Bjørndal, 2011).

The total biomass is an important parameter for aquaculture profitability analysis, therefore, it is necessary to be able to predict and manage future harvest volumes.

Considering that weight development is mostly sigmoidal, and the growth rate of individual fish changes with fish size, the estimation and description of fish weight changes with time may be done using coefficients obtained from empirical data, instead of the exact biological pattern (Jobling, 2002).

Taking into account the stated above, the individual fish growth development for the net pen farm is based on the modelled data from Asche and Bjørndal (2011) presented in Table 1. This weight development reflects seasonal changes in biology of salmon and therefore variation in weight increment.

Table 1. Individual fish weight for net-pen system.

Month number	Month	Fish weight, $w(t)$ (kg)
	Year 0	
1	May	0.106
2	June	0.171
3	July	0.294
4	August	0.523
5	September	0.835
6	October	1.202
7	November	1.569
8	December	1.934
	Year 1	
9	January	2.295
10	February	2.602
11	March	2.896
12	April	3.189
13	May	3.570
14	June	4.049
15	July	4.691
16	August	5.479
17	September	6.351
18	October	7.259
19	November	8.127
20	December	8.990
	Year 2	
21	January	9.835

Fish growth in RAS, however, differs from the one in the open sea because of regulated water temperature and water quality control, and therefore, only biological factors, excluding environmental, to be considered. Designers of the RAS-facility under review have based their fish weight forecasts on the specific feed type from Skretting AS. However, the related growth coefficients have been applied only to the fish weight up to 5 kg. Besides, the growth prediction made in the report by Roll et al. (2008) stated that desirable individual weight of 4.05 kg to be achieved in 52 weeks what does not depict the gradual development of fish weight.

In order to obtain a generalise salmon growth pattern a model suggested by Asche and Bjørndal (2011) was used as it is based on fish growth observation:

$$w(t) = 5.72t^2 - 2.08t^3 \qquad (2)$$

where $w(t)$ is fish weight at time t, measured in years from time of release.

3.1.2. Feed conversion ratio

In aquaculture industry feed utilisation plays a very significant role, the reason for that is that feed costs constitute the largest part of the operating costs. Therefore, optimal feeding strategy affects fish production profitability. To estimate efficacy of feed use on a farm feed conversion ratio (FCR) is used.

The simplest way to calculate FCR is

$$FCR = \frac{Weight\ of\ feed\ fed\ (kg)}{Weight\ gain\ (kg)} \tag{3}$$

To calculate weight gain the total biomass for the whole facility is used (Stead and Laird, 2002).

According to estimation purpose, FCR may be calculated in two ways. The first is biological FCR (FCR_b), which considers feed consumed to assess total flesh growth during production cycle including any dead or escaped fish (Boulet et al., 2010; Stead and Laird, 2002)

$$FCR_b = \frac{Weight\ of\ feed\ fed\ (kg)}{Weight\ gain\ (kg) + Losses\ (kg)} \tag{4}$$

For assessment of feed utilisation effect on farm profitability and not biological performance of fish economic FCR (FCR_e) is implemented. This way excludes any losses from calculations and considers marketable weight only

$$FCR_e = \frac{Weight\ of\ feed\ fed\ (kg)}{Harvested\ fish\ (kg) - Weight\ of\ smolts\ (kg)} \tag{5}$$

However, calculations may vary depending on farm and place (Stead and Laird, 2002)

In the present work the suggestion from Asche & Bjørndal (2011) is followed and FCR_e is used. The rate considered in the book for an average net-pen farm is 1.1, which seems to be very optimistic, as the official statistics shows an improvement from 1.35 in 2010 to 1.21 in 2012 (Fiskeridirektoratet, 2013), while Rosten et al. (2013) considered that it to be possible for 25% of open cage farms to reach 1.14 and 1.04 for only 10% of farms in Norway. Hence, the most up-to-date value of 1.17 from Marine Harvest (2014) is used, the best practice application is assumed.

In the considered RAS by Niri AS 1.0 value is observed, besides, on the other farm in Denmark observed FCR_e was 0.95 in 2013 (niri.com). However, a pilot project in Canada

(Summerfelt et al., 2013) showed FCR_e equal to 1.09, which may be related to use of fresh water instead of saltwater in culturing tanks.

While feed conversion ratios vary with fish age (Table 2), for simplicity, it is here assumed that FCR is constant over time.

Table 2. Feed conversion ratio according to Summerfelt et al. (2013).

Grow-out stage	FCR
Fry	0.75
Smolt	0.90
Pre-Growout	1.10
Growout	1.20

3.1.3. Mortality

An important factor affecting farmers' total costs is mortality. In spite of feed and technological improvements, the level of mortality varies due to site- and region-specific characteristics.

Previous RAS analyses considered, referring to Fiskeridirektoratet and Norwegian Food Safety Authority, that average annual mortality in sea cages are approximately 12 to 16% (Roll et al., 2008; Rosten et al., 2013). While, Marine Harvest (2014) suggested that mortality rate is 10% per year, Asche & Bjørndal, 2011 considered dynamic mortality changes at the rate 0.5% per month during the 0 year and till March of year 1, further the rate is 1% for March and April, 2% during May and June, July – 3%, August – 4%, September – 6%, October – 8%, November – 11%, December – 12%. The overall mortality for net-pen system is estimated to be 10% per annum.

For recirculating system designed by Niri AS the annual mortality level was estimated at 3.14% (Roll et al., 2008). While mortality varies over fish stages and is usually higher during the first months when recruits are just released, the rate is set constant over time to simplify calculations.

3.2. Economic model

For economic analysis it is necessary to assess the key factors influencing farm activity.

3.2.1. Revenue

Revenue is the amount of money a company can obtain from selling the fish at the market price. Revenue therefore it is

$$V_t = ap(w)B_{t+1} \tag{6}$$

where a = 0.99 is a coefficient representing necessary fish starving for 1% prior harvesting, $p(w)$ is price per kilogram of fish, B_{t+1} is the biomass of the next month, as biomass of the current month reaches its maximum at the beginning of the following month. Starving is not mentioned in Niri AS report, nevertheless, this method have implemented for both systems.

3.2.2. Price

Salmon pricing depends on the weight of individual fish, increase in weight leads to increase of value. Fish size distribution and corresponding inland prices are presented in Table 3.

Table 3. Fish size and price distribution.

Fish size, kg	Price basis, NOK	Price adjusted*, NOK
0-1	17.1	27.2
1-2	17.8	28.3
2-3	18.6	29.6
3-4	19.0	30.2
4-5	19.2	30.6
5-6	19.3	30.7
6-7	19.4	30.8
7-8	19.5	31.0
8-9	19.6	31.2
9-10	19.7	31.3

* the price adjusted calculation is presented further in the text.

Price basis includes data according to Asche & Bjørndal (2011). However, average inland salmon price did not decline beneath 20 NOK/kg level since 2005 (Figure 13).

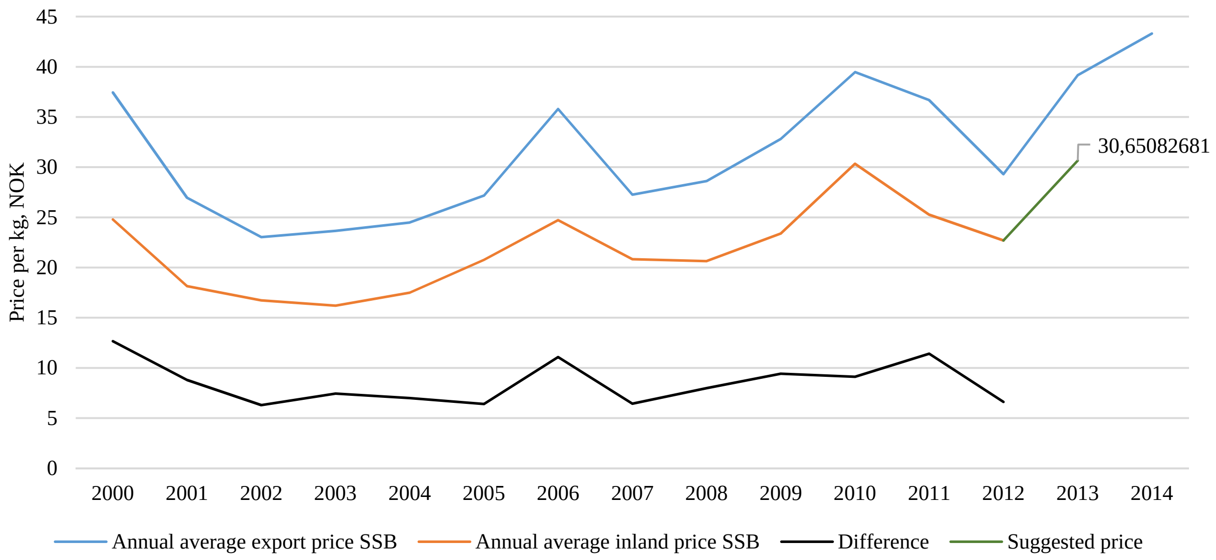

Figure 13. Norwegian frozen salmon price development from 2000 to 2014 (Statistics Norway, 2014).

Due to lack of information on inland price for 2013, it has been estimated on the basis of export price by doing subtraction of average difference between inland and export prices for the last twelve years from export price in 2013. The average difference is 8.5 NOK, as the export price in 2013 was 39.1 NOK/kg. The assumed average inland price is 30.6 NOK/kg.

Further, as the average price does not give an overview of fish size distribution, It has been assumed that the price corresponds to the weight of 4-5 kg as most traded (Marine Harvest, 2014). Then, the suggested price has been divided by the one used in Asche & Bjørndal (2011), and implemented obtained coefficient of 1.59 to the other prices. The latter presented in column Price adjusted in Table 3. When calculating biomass value, the price per kg of fish is also increasing gradually with increasing weight within the range.

3.2.3. Costs

Costs are funds required for purchase of production factors. Total costs (TC) is the sum of expenditures for all factors, are divided further into total fixed (TFC) and total variable costs (TVC) (Ison and Wall, 2006).

3.2.3.1.Fixed costs

Fixed cost are to be paid independently of production level and are constant over time (Ison and Wall, 2006). This includes managing and maintenance, as the functions must be performed by highly-qualified personal in spite of production stage, *e.g.* rearing, harvesting or remaining out of use (Asche and Bjørndal, 2011). For both models of salmon farming, this group of expenditures includes management and office costs.

According to Asche and Bjørndal (2011) functioning of net pen farm requires one manager, however, as land-based system is a more complex facility, therefore one executive and two additional middle-managers are necessary (Roll et al., 2008). Managers' salaries are stated similar for the both systems, and for middle-managers at the level of ordinary employees. All salaries are set in accordance with Asche and Bjørndal (2011), hence managers' salary is 1 000 000 NOK/year including office costs, and middle-managers' salary is 600 000 NOK/year including social taxes.

Other costs from this group are insurance on the machinery that is set at 0.05% level (If AS, 2014 [Telephone communication]), depreciation, calculated by the straight-line method in accordance with the project duration time scale. For RAS, as it is located on land, FC also includes land lease and rental fees, this costs are set as other operational costs and comprise 988 837 NOK in the first year of operation and 1 290 718 NOK annually from the second one. In addition, operational maintenance is fixed over the time for net pen farm, and smaller in the first year of operation for RAS. From the second year RAS maintenance is estimated as 2% of replacement value of the equipment, not including the land (Roll et al., 2008).

3.2.3.2.Variable costs

Variable costs are directly related to the level of output, hence increase of production volumes results in increased VC (Parkin et al., 2005). For the considered farming systems, however, the resources to be used in the production process differ.

Smolt’s quantity release is equal for the systems. However, because RAS has a very significant advantage as disease and pathogen control smolts are not vaccinated. In addition, the size of smolts is 30 grams instead of 109 grams as in sea cage, hence they are supposed to be cheaper, its price is set at 6 NOK/pcs (Iversen et al., 2013), while for net pen the it is set at 9 NOK/pcs (Marine Harvest, 2014). Insurance of biomass for net pen is considered 1% of the biomass value at the price per kilo at 25 NOK, for RAS value of fish is similar, however insurance rate is 2.3% (If AS, 2014 [Telephone communication]). Despite the both facilities imply different production approaches and may not have similar access to existing services and outsourcing companies, as slaughterhouses, it is assumed that harvest prices per fish are equal for the both systems. Harvesting cost is estimated in relation to fish quantity, $N(t)$ and not to biomass, $B(t)$, therefore it is calculated as:

$$C_H(t) = C_s N(t) \tag{7}$$

where C_s is fixed harvest cost per fish. This type of costs occurs only when the fish is harvested. Harvest cost is usually considered per kg of fish, therefore harvest price per fish was derived from average weigh harvested fish, 4.5 kg, and harvest price per kg, 3.5 NOK (Marine Harvest, 2014), what results in 15.75 NOK/fish.

Labour force required for net pen and RAS is five and eight employees respectively, as harvesting and processing functions are outsourced no additional labour force employed during this periods. Salary stated per worker is 600 000 NOK/year including social taxes. Besides, RAS is highly dependent on energy supply whole year round, it was estimated that annual power consumption is 13 195 514 kW, this amount is required for heating systems, pumping, filtration, and oxygen generation (Roll et al., 2008). While the electricity consumption was estimated for the facility operating in the continental Europe, is it assumed that heating regimes will be the same for Nordic countries, *e.g.* Norway.

The major part of the costs is feed costs that is necessary in animal production. Feed costs per month are estimated by:

$$C_F(t) = C_f F(t) N(t) \tag{8}$$

where C_f is fixed price per kg of feed and $F(t)$ – feed quantity consumed per fish, $N(t)$ – quantity of fish. C_f is stated at 9 NOK/kg for both systems (Marine Harvest, 2014).

Feed quantity per month per fish, $F(t)$ is a relation between feed conversion ratio (FCR_e) and fish weight growth, $w'(t)$:

$$F(t) = FCR_e w'(t) \tag{9}$$

Feed quantity is changing over time related to varying fish growth. Therefore, $C_F(t)$ takes into account changes in feed consumption caused by mortality, as $N(t)$ diminishing, and variations in growth change, $w'(t)$.

However, in contrast to harvesting costs the feeding ones occur monthly, in order to estimate total expenditures of feeding fish from release to harvest, all monthly costs must be summed:

$$TC_F = \sum_{t=0}^{n} C_f F(t) N(t) \tag{10}$$

3.2.4. Optimal harvest time

Considering the biological model one can see that as the total biomass grows, the value of the stock is also increasing. However, natural mortality affects the value in a negative way. Therefore, it is necessary for the farmer to find the optimal time for harvesting fish when it's present value (PV) is maximised, which is an estimation of the future value of the money invested today (Ross et al., 2003).

As farms are limited by legal, environmental or physical conditions in space and time for harvest it is crucial for farmers to utilise the available resources as useful as possible. Taking into account that harvesting makes pens empty, they are available for a new release. Besides, as fish growth declines with time the stock marginal value declines as well, thus it is more profitable for the farmer to replace old fish with fast growing recruits (Asche and Bjørndal, 2011).

In order to find maximum PV, net cash flow (CF) generated by investments is considered. Net CF is the sales revenue for harvested fish minus costs occurred in the previous months, but, as money losses value with time, to estimate PV the net CF is to be discounted to the time of investment, therefore

$$PV_n = \frac{V_n}{(1+r)^n} + \sum_{t=0}^{n} \frac{C_n}{(1+r)^n} \tag{11}$$

where $\frac{V_n}{(1+r)^n}$ is present value of revenue and $\sum_{t=0}^{n} \frac{C_n}{(1+r)^n}$ – sum of costs at the current and previous months or present value of costs. By calculating PV for all suggested harvesting months it is possible to find the one when PV is maximal (Asche and Bjørndal, 2011).

Another factor influencing the decision on harvest time is fish maturation. Since salmon mature its flesh quality degrades, what has a negative effect on the market value of the fish. The spawning period is temporary, and after this fish will be valuable as before, however, it takes another year to the farmer to keep salmon in water to pass though the stage, what will lead to higher costs per year class, as a farmer cannot replace mature fish with fast growing young one. For Atlantic salmon maturation is estimated to start twenty-eight months after smoltification (Asche and Bjørndal, 2011). This factor is neglected in the bio-economic model, however, it is expected to harvest fish prior the maturation.

3.2.5. Net present value

The net present value (NPV) is a financial mean to estimate economic feasibility of a long-run project. NPV represents the value acquired by the investors from undertaking investments. It takes into account time value of net cash flow, *i.e.* PV, summed for supposed years of the project existence and the initial investments (Ross et al., 2003):

$$NPV = -Investments + \sum_{t=0}^{n} PV_n \tag{12}$$

NPV has no serious disadvantages, therefore this value is an important solution for decision makers (Ross et al., 2003). When assessing a project the main criteria is whether NPV positive, equals zero or negative. In the first case, the project is profitable and must be accepted. In the second one, the project's worth is unchanged and the decision is more related to investor's preferences (Perman et al., 2011). In case of comparison of several projects, the one with higher worth to be accepted.

3.2.6. Internal rate of return

Another financial mean to be used in the analysis is internal rate of return (IRR). IRR, or discounted cash flow rate (Ross et al., 2003), is an alternative to NPV. IRR is the rate of discount at the level when NPV equals zero, or it is a maximum possible interest rate that the project can sustain:

$$-Investments + \sum_{t=0}^{n} \frac{V_t}{(1+IRR)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t} = 0 \qquad (13)$$

Where $\sum_{t=0}^{n} \frac{V_t}{(1+IRR)^t}$ is the present value of revenues for a defined period and $\sum_{t=0}^{n} \frac{C_t}{(1+IRR)^t}$ is the present value of the expenditures for the same period.

This tool is very important for a decision maker when choosing between alternative investment opportunities. For evaluating a single project, IRR higher than the interest rate makes the project acceptable (Perman et al., 2011). However, comparison of several projects leads to choose the one with higher IRR.

3.2.7. Project duration

As the aquaculture industry is based on biological peculiarities of the reared species, the whole production cycle for growing salmon from smolt to market size may varies from 14 to 24 months (Marine Harvest, 2014). Therefore, time supposed for the projects evaluation is ten years, as this time range will give an adequate picture of cash flow, because revenue occurs only at the year of harvest. In addition to ten years of operation, it is supposed that there is investment year when company prepare the facilities and necessary constructions.

3.2.8. Investments

In the present work the funds required to establish solely the operational part of facilities has been considered, assuming that a company already has licences, it is made because licence price will be equal for both systems, and hence has similar effect on viability.

Niri AS estimated construction costs of RAS in Poland (as described in Table 4). Due to this country has a lower living standard than Norway (Roll et al., 2008), all the costs for materials and works have been calculated at lower prices, therefore several assumptions have been made in the present work.

As the smolt supply and harvesting functions are outsourced, no filleting, gutting or incubation equipment was included in the investment assessment. Water treatment and quality control is a core part of the recirculating system, and is assumed to be specially designed by a Niri AS or an external manufacturer that supplies the equipment worldwide. Hence, technical equipment purchase price was remained as suggested in the report.

Construction works are difficult to estimate as it requires information on location of the facility. Therefore, as an additional reference, investment estimation was considered from the facility project, developed by The Conservation Fund Freshwater Institute and SINTEF Fisheries and Aquaculture. The land-based farm occupies area of 27 000.00 m^2, includes 40 000 m^3 volume of rearing tanks and the water flow is 885 m^3/min (Rosten et al., 2013). It has been suggested that overall investment is 192 mil. NOK, however this amount includes filleting equipment, thus, purchase price of the equipment at 20 550 000 NOK, as stated in Roll et al. (2008), was subtracted. Besides, unforeseen investments are stated at 10% of all others, therefore construction work cost have been adjusted to obtain estimated amount of 172 077 203 NOK as total investment for land based facility (Table 4).

Table 4. RAS investments

Investments				
Item	Quantity	Unit	Price	Currency
Land and land preparations	30 000	m^2	84 000 000.00	NOK
Well installation	500	l/min/tank	500 000.00	NOK
Buildings			13 305 600.00	NOK
Concrete work			10 048 800.00	NOK
Feeding system			2 500 000.00	NOK
Pipes			4 985 900.00	NOK
Electrical installations			5 560 000.00	NOK
Technical equipment			14 938 244.00	NOK
Tanks to culture fish	20 210.00	m^3	14 369 722.00	NOK
Systems for water treatment to maintain adequate water quality				
Carbon dioxide control - CO_2 removal	10-15	mg/L	725 000.00	NOK
Control of pathogens - UV			1 600 000.00	NOK
Dissolved oxygen control - O_2 injection	80	%	2 030 000.00	NOK
Wastewater disposal			807 500.00	NOK
Heating equipment	14	°C	880 000.00	NOK
Miscellaneous/unforeseen cost			15 625 076.60	NOK
Total			172 077 203.00	NOK

Detailed investments for net pen have been obtained from Asche & Bjørndal (2011) (Table 5), and comprised in total 36.2 mil. NOK what is slightly higher than the range from 30 to 35 mil NOK suggested by Marine Harvest (2014).

Table 5. Net pen facility investments

Investments			
Item	Quantity	Cost	Unit
Barge	1	6 000 000.00	NOK
Feeding system	1	1 400 000.00	NOK
Technical equipment		1 000 000.00	NOK
Miscellaneous/unforeseen cost		2 000 000.00	NOK
Pens	8	5 200 000.00	NOK
Total per plant		15 600 000.00	NOK
Necessary permits		5 000 000.00	NOK
Total		36 200 000.00	NOK

4. Results

4.1. Biological development

Fish growth pattern in net pen based on observation by Asche & Bjørndal (2011), shown in Table 1, is presented in Figure 14.

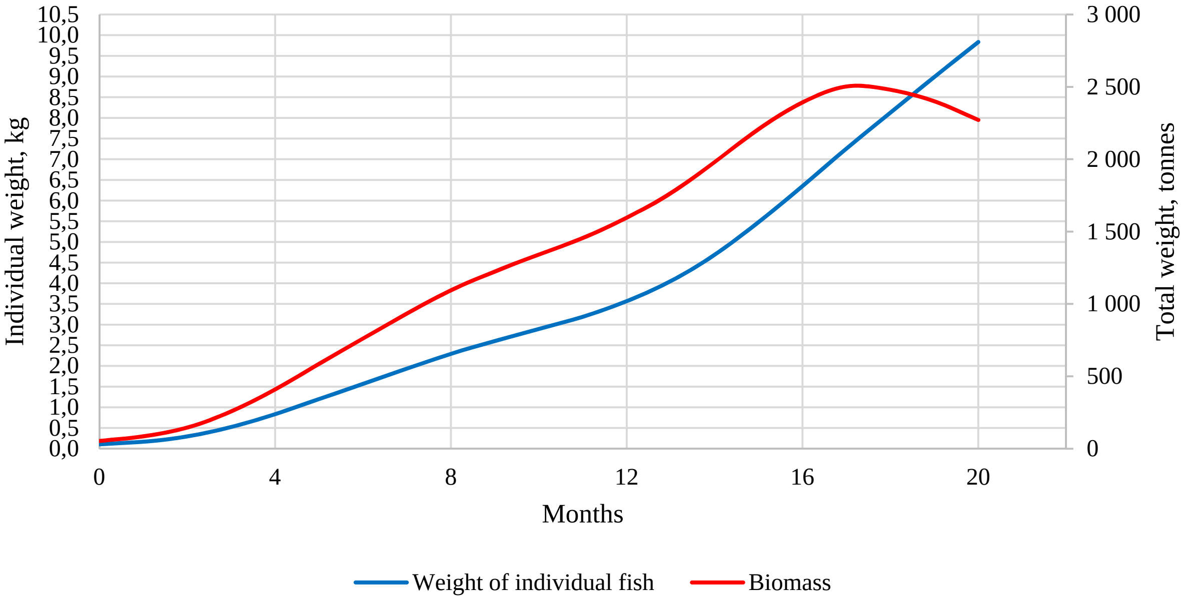

Figure 14. Net pen biomass development.

The curve does not have a clear s-shape and the growth is always positive, due to data provided is up to twenty-first month. However, total biomass is affected by mortality, stated at approximately 10% annually, and reaches its maximum on the eighteenth month at 2 502 976.73 kg, when the number of fish is 344 810 individuals.

To model fish weight development within RAS, equation (2) has been modified to suit the growth pattern estimated by Niri AS:

$$w(t) = 5.72\left(\frac{t}{12.05}\right)^2 - 2.08\left(\frac{t}{12.05}\right)^3 \tag{14}$$

The curve of individual fish growth in RAS (Figure 15) has a clear s-shape with visible peak-point in the twenty first month after release, at this time fish weight is 6.41 kg. At the same time, the total biomass grows gradually because mortality rate is evenly distributed over the grow-out stage. Besides, it peaks on the same twenty first month as individual fish growth at the level of 3 028 029.23 kg, This is caused by low mortality rate at 3.14% per year.

Comparing the two systems biomass it is remarkable, that in RAS individual weight reaches the value of 6.41 kg five months later than in net pen, in the latter 6.35 kg is reached on the sixteenth month. Nevertheless, net pen peak volume of 2 500 tonnes is obtained two months earlier in RAS.

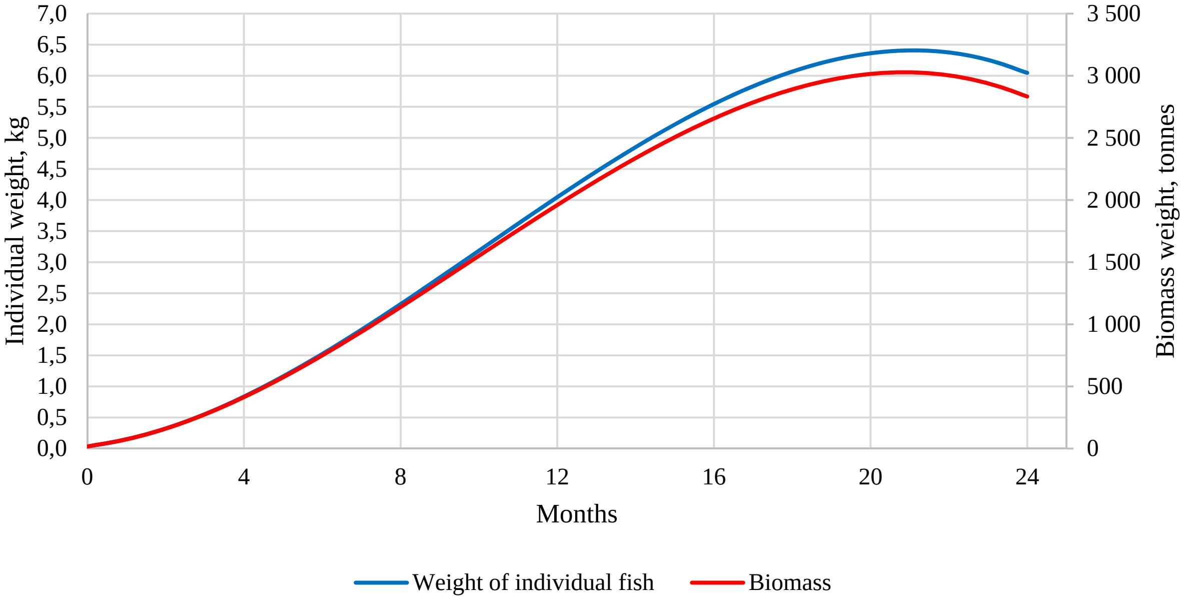

Figure 15. RAS biomass development.

4.2. Price and value

As the price is a function of fish weight, it reflects changes in fish weight (Figure 16); growth moves fish from lower size range to higher one what increases its price.

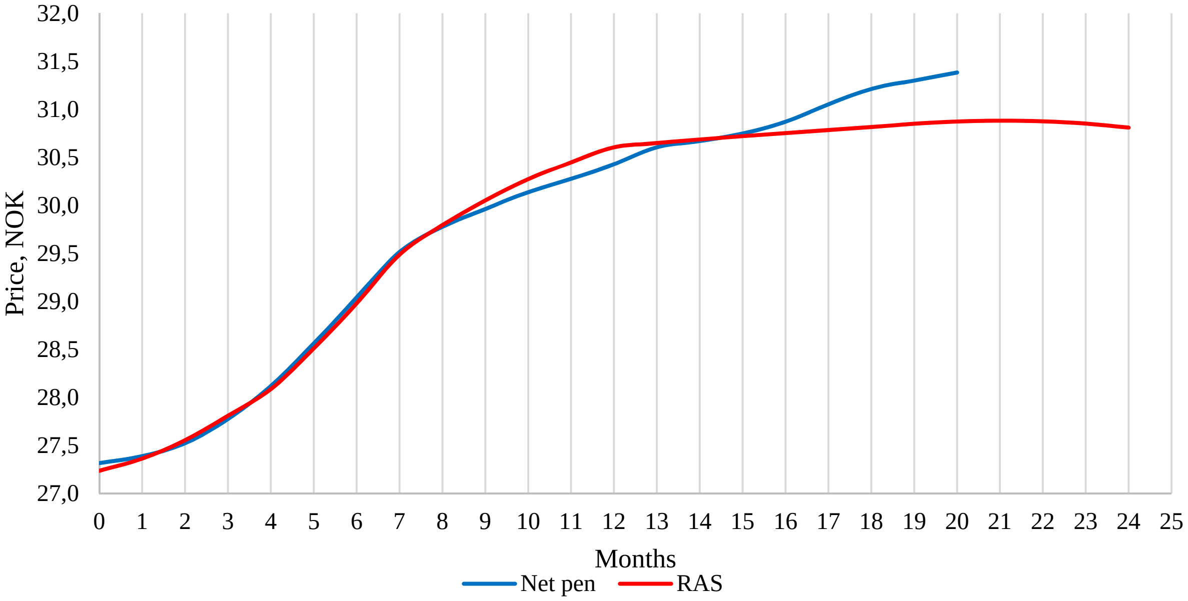

Figure 16. Price development comparison.

From release and up to seventh month the price increases gradually and almost evenly, despite the initial fish weight is different, 30 grams in RAS and 106 grams in net pen. Further, since fish in both systems reach 2 kg size range and the difference between the range prices decreases, development is not as rapid as before. Salmon in land-based facility passes two size ranges within the next four months while in net pen it takes five months, therefore the first has higher price from the eighth to thirteenth months. However, later growth slows down in RAS and after the twenty second month price even have a negative trend, so the fish in sea cage becomes more valuable.

The value of the total biomass depends on the total fish amount and is affected by mortality rate in addition to individual weight development and corresponding price. As biomass changes are similar up to seventh month, the total value curves have also the same shape (Figure 17), however, since higher mortality is being introduced in the net pen system the difference between the values becomes explicit.

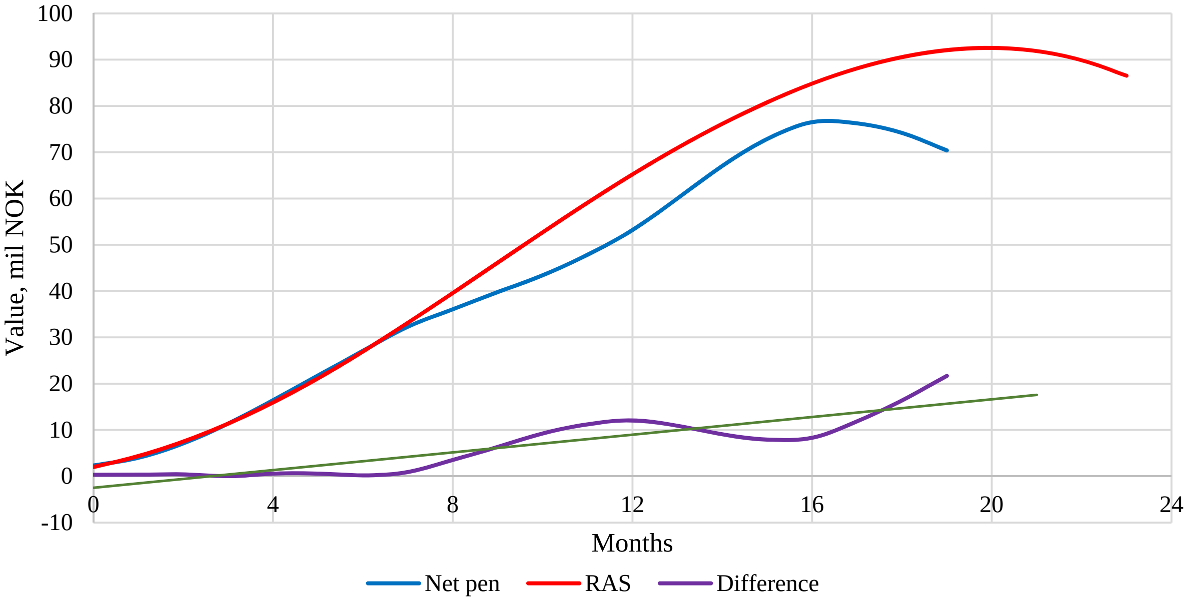

Figure 17. Biomass value development.

Despite difference between biomass values varies with time (purple curve) its trend is positive. Peak level of the biomass value for sea cage is obtained on the sixteenth month at 76.49 mil NOK, the value of the stock in RAS is 84.81 mil NOK at the same time, while it is still increasing. The peak value for land-based facility is 92.55 mil NOK reached on the twentieth month after fish release.

4.3. Optimal harvest time

The present value of one yearclass has been estimated to find the optimal harvest time. The present value (PV) is calculated in relation to feed and harvesting costs discounted back to fish release. The feed costs are accumulated during the whole grow-out period, while harvesting costs take place only at the time of harvest. Harvesting costs decrease with time because mortality affects the total quantity of fish and the costs are calculated per fish.

In the net pen facility, the estimated revenue discounted to the time of release reaches its maximum on the sixteenth month at 68.78 mil NOK, the total costs including harvesting and feed costs are 36.74 mil NOK (Figure 18). At this point PV is at the peak value of 32.05 mil NOK. From this, it is concluded that the optimal time of harvest for net pen farm is sixteenth month from fish release. This time is also within suggested by Marine Harvest (2014) grow-out period from 14 to 24 months.

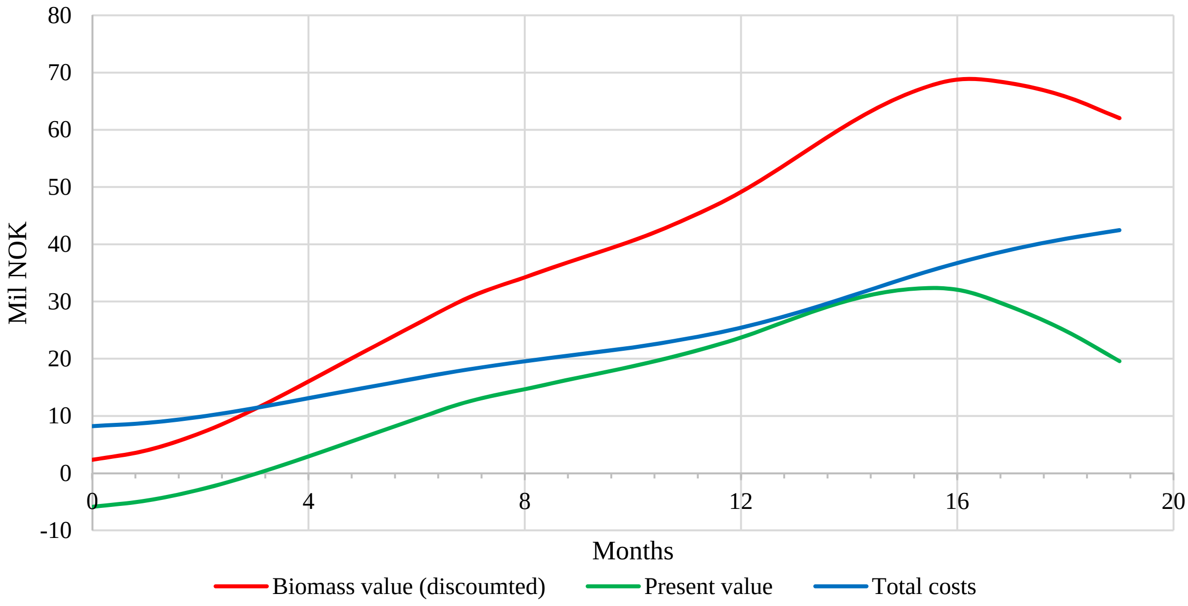

Figure 18. Net pen optimal harvest time estimation.

On the land-based facility, discounted biomass value is higher than in the sea cage (Figure 19). On the sixteenth month when the maximum value in the sea cage is 68.78 mil NOK, in RAS the value is 76.26 mil NOK and peaks on the nineteenth month at 81.16 mil NOK. Because of low mortality rate, quantity of fish is higher than in the other facility, and therefore harvesting costs exceed one in the sea cage. Nevertheless, improved FCR reduces feed costs significantly. Therefore, total discounted costs do not exceed 35 mil NOK level. As a result, PV of RAS maximum 48.47 mil NOK has been reached on the nineteenth month after release, what is three months later than in the sea cage.

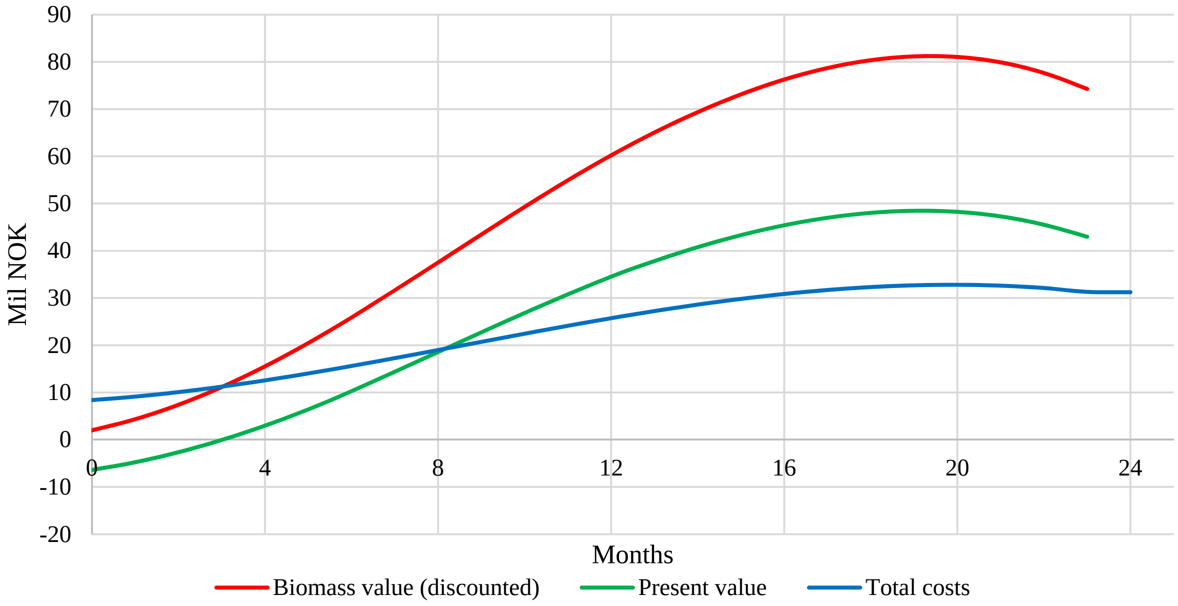

Figure 19. RAS optimal harvest time estimation.

This factor is not considered in the model; nonetheless, both systems' optimal harvest time is within this biological limit.

4.4. Production plan

According to the results from section 4.3 optimal grow-out period for net pen farm and RAS is sixteen months and nineteen months respectively. As the production of salmon is dependent on such factors as technology, biology and growth environment, grow-out phase will differ in the systems not only in terms of duration, but also in terms of time of smolts release.

Farming of Atlantic salmon at sea is driven by growth pattern of the wild species. Farmers usually follow the production cycle that commences from spawning in freshwater in November, further hatching takes place in two months in January. Prior the transfer to the sea cage the fish must pass smoltification, a stage of adaptation to salt water. This stage lasts for sixteen months for Atlantic salmon (till May), the fish grows from 7 grams after hatching to around 40 grams (one-year smolts) in the wild, however, modern improved hatcheries can rear smolts up to 140 grams within the same period and can be released after eight months in autumn. Consequently, rearing of two cohorts at sea may commence at the same year (Asche and Bjørndal, 2011).

Nevertheless, environment condition is out of control in net pen aquaculture, and therefore, smolts release in pens may be executed only during the months when sea water temperature is at proper level, from March to October. In practice, it usually happens in May and October. This dependency on smolts provision and a certain environment condition make rotation problem complicated (Asche and Bjørndal, 2011), but solvable.

According to the stated above the production schedule for net pen facility as following, the same amount of smolts of 500 000 pcs to be released only in May and October. As the company has two plants, the release of two first batches is carried out in year 0 on the first plant, while on the second plant release is performed in year 1. Every batch released in May is harvested in September next year, and batches released in October are harvested in February next year. The production circle is presented in Figure 20.

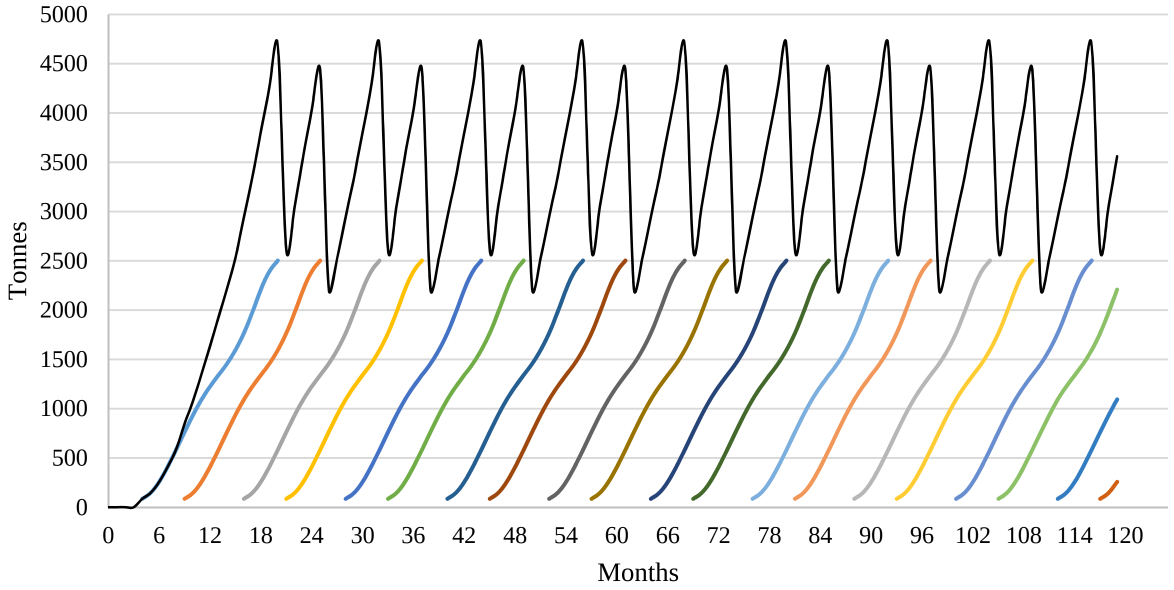

Figure 20. Net pen farm production plan. The raw of colourful curves at the bottom represents batches, the black fluctuating line above is a live total biomass level that drops sharply when harvesting take place.

Assumptions that have been made in respect of sea cage include an ability of the plants to sustain one million smolts release annually. Also, the company have three sites for operational use, in order to leave one of them empty for year every third year to comply with Norwegian regulations (Asche and Bjørndal, 2011).

Considering that water temperature is regulated in RAS, the production schedule is planned in respect of better space utilisation. In original report by Roll et al. (2008) it is suggested that release of smolts takes place every fourth month, as the fish grows, it is moved from smaller tanks to larger ones making the first available for a new release. Despite, the total grow-out phase in the report is twelve months, in the present thesis, the optimal harvest time in the nineteenth month has been considered. Therefore, after release of the first batch in January, the second commence in six months and the third in seven months (Figure 21). The variation in one month between release dates is caused by chosen harvesting time and a design of the facility, which implies smolts growth in first tank until they reach a particular size.

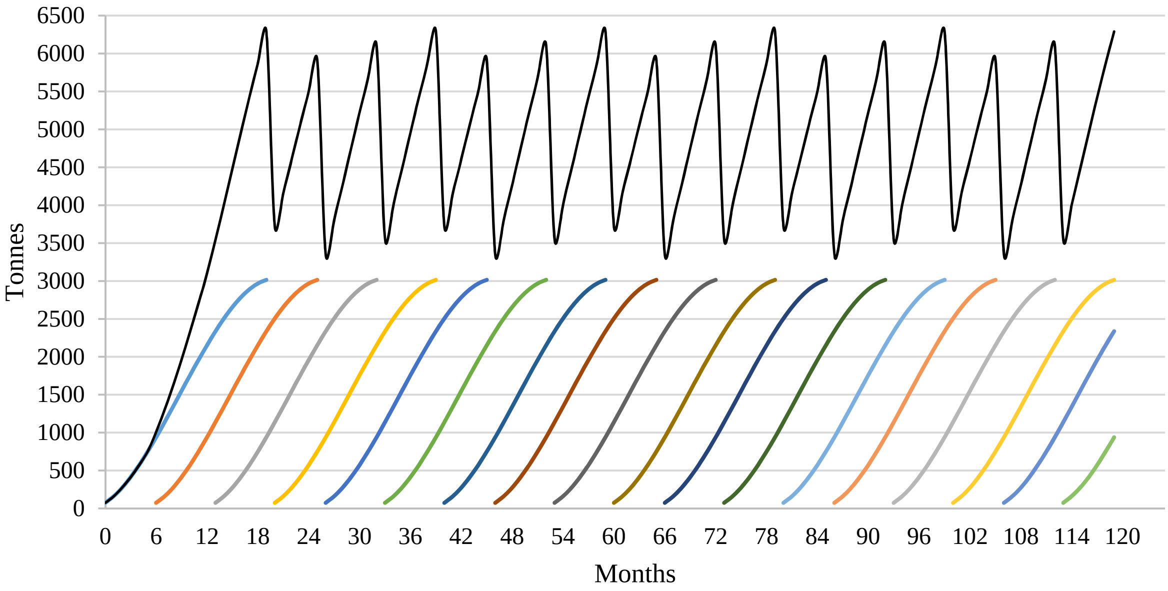

Figure 21. RAS production plan. The raw of colourful curves at the bottom represents batches, the black fluctuating line above is a live total biomass level that drops sharply when harvesting take place.

Assumption for the RAS is that the system can sustain the seven-month grow-out phase, tanks are suitable for larger fish density and no extra space required, also, planned filtration and pumping system can provide necessary water treatment without reconstruction and additional equipment. Besides, for both facilities it is assumed that smolts are available on demand.

It is implicit from the graphs above that despite there is no interruption between releases and harvestings in RAS the overall number of releases is lower comparing to the sea cage facility, eighteen and twenty respectively. Besides, total number of harvest is sixteen in the land-based facility against seventeen in sea cage. However, total weight of fish harvested per batch in RAS is 500 tonnes higher (3 015.06 tonnes) than in net pen (2 502.98 tonnes). At the same time, total live biomass in RAS peaks at volumes from 5 918.05 to 6 290.61 tonnes, while at sea maximum biomass is 4 430.63 and 4 685.47 tonnes, what means that the land-based facility with the stated assumptions has a higher production capacity than conventional system. As a disadvantage for the land-based farm the chosen production cycle does not provide equal number of harvests every year, so there is one harvest on the first and sixth year and consequently cash inflow from only one sale, while in net pen one harvest is in the year first only and two harvests all other years.

4.5. Net present value and IRR

In order to estimate NPV of the two projects cash flow (CF) analysis has been performed. According to section 3.2.7. the year 0 of the projects is time for preparation of the facilities, and there is no operational costs on production as well as revenue, only initial investments are considered and comprise 36.2 mil NOK for net pen farm (Table 6).

Table 6. Net pen cash flow analysis (Unit: mil NOK, Prod: 1000 tonnes).

	Investment year	Years										Total
		1	2	3	4	5	6	7	8	9	10	
Invest	36.2											36.2
Revenue	0.0	0.0	76.5	153.0	153.0	153.0	153.0	153.0	153.0	153.0	153.0	1 300.4
OC	0.0	28.0	80.2	93.5	93.5	93.5	93.5	93.5	93.5	93.5	93.5	855.8
Net CF	0.0	-28.0	-3.7	59.5	59.5	59.5	59.5	59.5	59.5	59.5	59.5	444.7
PV	0.0	-25.9	-3.2	47.3	438	40.5	37.5	34.7	32.2	29.8	27.6	264.3
Production	0.0	0,0	2.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	42.5
NPV	228.1											
IRR	46.4%											

During year 1 the company acquires no revenue as the fish has just been released. After sixteen months during year 2 the first harvest takes place and revenue for one harvest is considered. Further, since the farm reaches a steady-state production level of two harvests annually at year 3, equal revenues are obtained until year 10. Total revenue for ten years of functioning is estimated to be 1 300.4 mil NOK.

In contrast to revenue, operational costs occur since year 1. This parameter includes annual costs of smolts, feeding, harvest and labour. However, operational costs for year 1 and 2 differ to the one starting from year 3 to 10. The reason is that there is no harvesting costs in year 1 at all and only one harvest is in year 2. After this time, operational costs are the same every year as there is equal amount of fish in pens and two harvests are carried out annually. Total operational costs calculated for ten years are 855.8 mil NOK.

Both revenue and operational costs used in this analysis are not discounted in order to avoid double discounting when calculating PV and NPV.

Net cash flow is calculated by subtracting operational costs from the revenue. As one can see, net CF is negative when there is no revenue in year 1 and costs exceed revenue in year 2, however net CF is positive all other years and sums up in total 444.7 mil NOK at the end of suggested project period. Further, net CF is used to evaluate PV of the project, this parameter is positive all the years from year 3 what reflects the changes in net CF with the discount rate of 8% per year. By considering time value of net CF in terms of PV and initial investments, one can see that NPV of the project is 228.1 mil NOK, and hence future value of the CF exceeds the PV of investments.

Similar analysis of the RAS (Table 7) shows that the trend in net CF in the beginning of the functioning is the same as in the Table 6, however in year 6 only one harvest is carried out and therefore cash inflow this year is one-half of steady-state production what decreases net CF by almost 90%. Nevertheless, total net CF in RAS for ten years is substantially higher than in net pen, 645.03 mil NOK against 444.62 mil NOK. This can be explained by the fact that cash inflow in RAS exceeds the one in net pen by around 20%, what is an outcome of lower mortality rate and therefore larger quantity of fish to sell, while cash outflow is around 7% less, because of more efficient feed utilisation and therefore declined feed costs.

Table 7. RAS cash flow analysis (Unit: mil NOK, Prod: 1000 tonnes).

	Investment year	**Year**										**Total**
		1	2	3	4	5	6	7	8	9	10	
Invest	171.9											171.9
Revenue	0.0	0	92.1	184.2	184.2	184.2	92.1	184.2	184.2	184.2	184.2	1 473.6
OC	0.0	44.6	81.3	89.6	88.7	87.3	81.8	89.3	89.6	88.7	87.3	828.2
Net CF	0.0	-44.6	10.8	94.6	95.4	96.9	10.3	94.9	94.6	95.4	96.9	645.2
PV	0.0	-41.3	9.2	75.1	70.1	65.9	6.5	55.3	51.1	47.7	44.9	384.5
Production	0.0	0	3.0	6.0	6.0	6.0	3.0	6.0	6.0	6.0	6.0	48.0
NPV	212.6											
IRR	22.02%											

From the higher total net CF it is explicit that PV is also higher, so the present value in RAS surpasses the one from net pen by around 45% and comprises 384.5 mil NOK for ten years.

Initial investments taken into account, however, show that higher PV does not make the developing capital consuming technology as profitable as the conventional system. NPV of RAS is around 16 mil NOK lower than in net pen. Besides, land-based farm gives lower return on the investments as IRR in RAS is 22.02% comparing to 46.40% in net pen. The relationship between NPV and internal rate of return is presented in Figure 22. While in both systems IRR exceeds the required rate of return stated as 8%, it is preferable to accept the project with higher IRR.

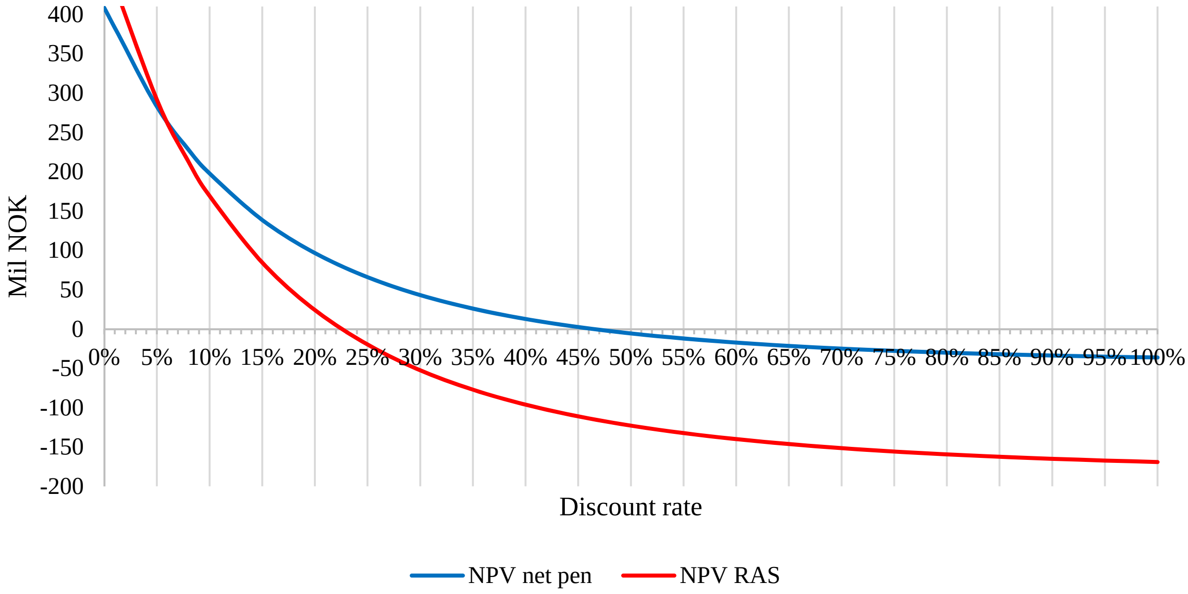

Figure 22. Net present value profile.

4.6. Average cost comparison

Independently of the decision made, it is reasonable to estimate competitiveness of the production by estimation average costs in respect of 1 kg of produced salmon. For this purpose, it is necessary to consider capital costs of the production, namely depreciation and insurance. As loans are not considered in the work, and therefore are not taken into account.

Table 8. Net pen annual depreciation per plant evaluation (Unit: 1000 NOK).

Item	Cost	Years	Depreciation
Barge	6 000.0	25	240.0
Feeding system	1 400.0	10	140.0
Technical equipment	1 000.0	10	100.0
Pens	5 200.0	10	520.0
Total			1 000.0

In Table 8 the elements necessary for the production at sea are listed, the list conforms to the investments from Table 4. According to Asche and Bjørndal (2011) depreciation period for barge is twenty five years, for pens – ten years. Depreciation time for feeding system and technical equipment based on Roll et al. (2008) is ten years. From this, total depreciation costs per year for the net pen farm is 2.00 mil NOK, as there are two plants in operation, the depreciation costs have to be doubled.

According to Roll et al. (2008), the life-span of the equipment and buildings required for the facility is ten years (Table 9), therefore implementing a straight-line depreciation method the total annual costs result in 5.12 mil NOK. This is more than two times higher than in the sea cage facility.

Table 9. RAS depreciation evaluation (Unit: 1000 NOK).

Item	Cost	Years	Depreciation
Buildings	13 305.6	10	1 330.6
Feeding system	2 500.0	10	250.0
Technical equipment	14 938.2	10	1 493.8
Fish culture tanks	14 369.7	10	1 437.0
Carbon dioxide control - CO_2 removal	725.0	10	72.5
Control of pathogens - UV	1 600.0	10	160.0
Dissolved oxygen control - O_2 injection	2 030.0	10	203.0
Wastewater disposal	807.5	10	80.7
Heating equipment	880.0	10	88.0
Total			5 115.6

To calculate biomass insurance costs for net live weight of 2 502.98 tonnes have been taken at the rate of 1% and value of 25 NOK per kg. For land-based facility live-weight biomass is 3 015.06 tonnes at the rate of 2.3%, what is similar to one used for hatcheries, and the fish values per kg is the same as for net pen (Table 10). Because of larger fish volume and percentage rate, the total biomass insurance for RAS is almost three times higher than for net pen.

Table 10. Insurance evaluation.

Net pen		RAS	
Insurance (biomass)	625 744.2	Insurance (biomass)	1 733 658.2
Insurance (equipment)	680 000.0	Insurance (machinery)	1 892 523.3
Total	1 305 744.2	Total	3 626 181.5

The insurance rate on machinery and equipment is the same for both systems – 0.05%, however in RAS more sophisticated equipment is included, consequently this item is also more expensive for land-based facility.

As it has been mentioned above, the production cycle for the land-based farm fluctuates in respect of fish grow-out period. This makes revenues and costs uneven from year three, in contrast to steady-state condition supposed by Roll et al. (2008). For this reason to calculate production costs per kg of fish in RAS average values have been used for expenditures for smolts and harvest. Besides, annual feed costs are calculated in relation to fish biomass actually presenting in the tanks, hence it varies from year to year. Therefore, feed costs are also averaged from year 3 to 10. In addition, annual production is averaged on the basis of period from year 3 to 10. The overall comparison and distribution of cost is shown in Table 11.

Table 11. Costs per production per kg of fish.

Item	Net pen		RAS	
	NOK	%	NOK	%
Feed	13.40	67.8	8.94	49.5
Harvesting	2.37	12.0	2.51	13.9
Smolts	1.80	9.1	1.01	5.6
Labour	0.80	4.0	1.25	6.9
Depreciation	0.40	2.0	0.91	5.1
Maintenance	0.30	1.5	0.54	3.0
Insurance	0.26	1.3	0.65	3.6
Interest on capital	0.43	2.2	0.73	4.0
Electricity	0.00	0.0	1.51	8.3
Total	19.76	100.0	18.05	100.0

For both systems the highest share belongs to feed and harvesting costs, but low FCR has a very positive effect and leads to substantially lower feed costs in RAS by almost 4.5 NOK. Low smolts cost is caused by use of unvaccinated fish, also the purchased smolts are smaller (30 grams) comparing to the one used in sea cage (106 grams), what definitely affects the price. Besides, lower mortality rate allows to share the smolts cost among larger production volumes what reduces their cost per kg as well. However, additional expenditures for electricity in the land-based facility is an important item, its share is comparable with essential costs for smolts in net pen. Another additional cost of RAS is labour that is almost two times as high as in the conventional system, due to necessity of hiring additional technical personal and management. Nevertheless, it is remarkable that production of one kg of fish is 1.7 NOK less expensive in RAS than in sea cage. Therefore, taking into account stated assumptions, production at land based facility is fairly competitive to the conventional system.

5. Discussion

The land-based farm has a significant advantage in terms of fish biomass growth, given assumed properties. This may be expressed by growth pattern until particular fish size and total rate of mortality. Individual weight of 4.05 kg is reached in RAS within twelve months (Figure 15), while in the conventional system within thirteen months, which may be a positive factor in certain markets. However, in the considered model larger fish size is preferable. In this term, sea cage farm showed a better dynamic with shorter growth period from four kg, salmon in RAS has reached its maximum of 6.41 kg on the twenty first month began losing weight. While in pens this size has been attained five months earlier and showed further increase, so on the month 21 salmon was in the average weight of 9.83 kg (Figure 14).

The growth model implemented in the thesis to RAS is based on observations of Atlantic salmon growth at sea (Asche and Bjørndal, 2011), and thus, it is not fully applicable to the closed system. This may be noted from individual fish weight development. While the model has been modified to suit the data estimated by Niri AS, salmon reaches 4.05 kg weight at the end if 12th month, the further development of fish is unrealistic in comparison to net pen system. The maximum weight of fish in RAS of 6.41 kg is obtained in nine months, after a fast growing phase from 30 grams to 4.05 kg, what also does not correlate with growth pattern in sea cages. The growth slows down and even becomes negative before reaching natural average size of the spawning age from 8 to 13 kg (Jones, 2004). From this point of view, the optimal water quality condition cannot provide an optimal growth condition to the salmon, what is also unrealistic. According to the stated above, a generalised growth model is not reliable in terms of RAS and a comprehensive data on individual fish weight development in optimal condition is required.

Exposure to external environmental factors as weather condition, illnesses, predation, etc. however has a very strong negative effect on the stock at sea. The stated 10% level takes into account a use of best practice and a particular external condition, and therefore may vary from farm to farm or in different climatic regions. However, even such an optimistic rate makes the total biomass start going down in seventeen months at the total level of 2 500 tonnes (Figure 9). At the same time, remarkably low mortality in RAS at 3.14%, based on the developers observations, allows to breach this volume two months earlier and still grow when in pen it is in decline.

When using economical parameters to assess biological model, the difference between the two farming facilities is also noticeable. Value of individual fish is even from the beginning until month eight, when fish growth follows the same patter on the farms. Then, faster growing salmon in RAS is slightly more valuable until month fifteen. However, since this time weight increment in sea cage is much higher than in the land-based farm. Hence, from perspective of individual fish value sea cage is preferable.

Comparison of total biomass values shows constant increase dynamic in RAS in contrast to the conventional system where the value fluctuates. Moreover, a delay in biomass increase for approximately two months leads to a similar delay in biomass value. Eventually, the maximum total biomass value in sea cage of 76.49 mil NOK in the month sixteen had been attained in RAS in the month fourteen. While the biomass value in net pen reaches its peak level, the value in RAS is 84.81 mil NOK, or 8.32 mil NOK higher, and keeps a positive trend until the twentieth month.

The maximum PV and peak of discounted biomass value coincides in the sixteenth month which has been stated as the optimal harvest time. At the same time, for the land-based farm it is more profitable to keep the fish in tanks for nineteen months, which is two months before maximum total biomass weight in the system is reached.

The substantial reason for such a difference, beside higher biomass value, is amount of costs related to feeding and harvest as key factors influencing the decision on harvest time.

Low mortality rate has a very positive effect on biomass growth. However, as the number of fishes in RAS is larger than in the sea cage, it increases costs for harvest, and hence, harvest in RAS costs more than in net pen (Figure 23). Feed conversion ratio, in opposite, improves feed utilisation and reduces required amount of feed. However, it is clear from the graph below that decrease in feed costs is also related to fish growth slow down after month twelve in RAS.

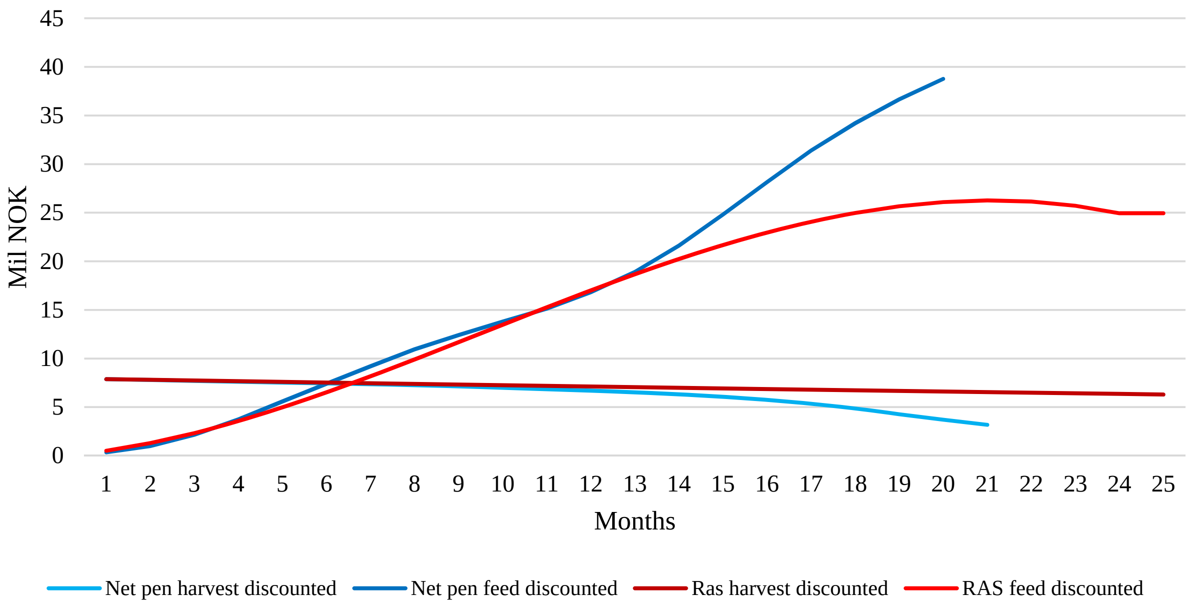

Figure 23. Development of discounted feed and harvest costs.

By using the defined time periods, production cycle in the net pen farm is planned in accordance with a common practice (Asche and Bjørndal, 2011; Marine Harvest, 2014). Meanwhile, for the land-based facility this stage is rather complex. As there is a certain number of tanks designed to sustain a defined fish density, the rotation must be implemented in a way to use the available space at maximum utility. Because the grow-out period has been extended from twelve months as suggested in the report by Roll et al. (2008) to nineteen, the time point for movement of fish between tanks has been also extended. The reason is that division of the grow-out period in the equal stages to make an uninterrupted rotation possible. However, the duration of the defined time range does not allow splitting it in equal parts. Therefore, it has been an issue resulted in imbalanced production cycle. That may be a serious problem when implementing this sophisticated fish production technology. Therefore, planning of production and facility design must be integrated and considered in details to avoid fluctuations of production and, consequently, cash inflow.

From comparison of NPV of the two projects, it is explicit that conventional system have return on investments at around 12 mil NOK higher than RAS, 228.05 mil NOK against 216.48 mil NOK. The reason for that, as it has been mentioned, is not balanced production cycle that cannot provide equal harvests annually.

In Figure 24 comparison of PV of the considered systems is shown. The figure includes estimated development of PV in the net pen and the RAS models described in the text above (RAS basic). Besides, it includes alternative variants of RAS development that are described further (RAS 1, RAS 2).

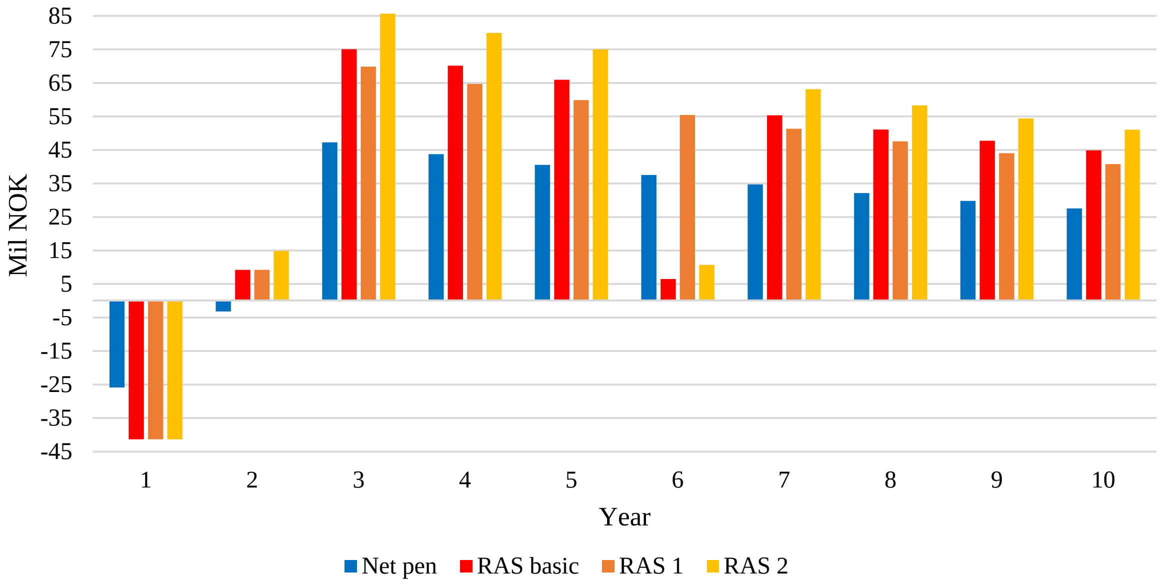

Figure 24. PV analysis for net pen facility and variants of RAS.

Annual net CF analysis shows a drop in year 6 from 184.16 mil NOK to 92.08 mil NOK for the considered RAS basic model and therefore PV this year is about 6.5 mil NOK (RAS basic, Figure 24). However, it is reasonable to suppose that the company would expect a steady annual cash inflow. It is possible to derive from this suggestion that regular net CF in amount of 88.00 mil NOK (RAS 1, Figure 24) from year 3 is a minimal level for RAS in the frame of stated assumptions to result in equal profitability as sea cage with NPV at 229.58 mil NOK. Nonetheless, such net CF is unrealistic, because increase of revenue requires additional operational and capital costs for introduction of another batch.

The RAS suggested by Niri AS as well as others facilities of this type has a significant advantage in respect of its location. In opposite to sea cages a land-based farm can have integrated fish processing plant and hatchery. While smolts production may require a significant extension of occupied area, processing plant has already been considered as a part the facility. From this perspective, it is reasonable for the owner to estimate the available opportunity. Assuming that processing by own means will require additional labour force of sixteen people per harvest (Roll et al., 2008), independently of the biomass weight, with a monthly wage of 50 000.00 NOK (Asche and Bjørndal, 2011), cost of harvest per fish will be reduced by almost 9 times from estimated 15.75 NOK to 1.69 NOK. Total harvesting costs for one batch of 473 833.33 fishes have been calculated 7.46 mil NOK if outsourced and 0.80 mil NOK if processed on the own plant.

Obviously, purchase of gutting machinery requires additional investments, the price of the equipment is taken 1.80 mil NOK as suggested by Roll et al. (2008). Improvement, however, results in increase of net CF from average 84.86 mil NOK to 97.36 mil NOK from year 3 to 10, and NPV comprises 278.08 mil NOK (RAS 2, Figure 24). That is 50 mil NOK higher than the NPV for the conventional system. This extreme reduction of operational costs is explained by no necessity of a wellboat employment and extra facility construction to keep the fish prior harvest, besides, the personnel for harvesting is hired temporarily.

Assessment of these changes in harvest will also affect depreciation and consequently average production cost per kg (Table 12). Depreciation of the gutting equipment is 0.18 mil NOK per year.

Table 12. Average costs of production per kg of fish.

Item	Net pen		RAS basic		RAS self-harvest	
	NOK	%	NOK	%	NOK	%
Feed	13.40	67.8	8.94	49.5	8.94	56.4
Harvesting	2.37	12.0	2.51	13.9	0.27	1.7
Smolts	1.80	9.1	1.01	5.6	1.01	6.6
Labour	0.80	4.0	1.25	6.9	1.25	7.9
Depreciation	0.40	2.0	0.91	5.1	0.95	6.0
Maintenance	0.30	1.5	0.54	3.0	0.55	3.5
Insurance	0.26	1.3	0.65	3.6	0.66	4.2
Interest on capital	0.43	2.2	0.73	4.0	0.73	4.6
Electricity	0.00	0.0	1.51	8.3	1.51	9.5
Total	19.76	100.0	18.05	100.0	15.86	100.0

While costs distribution differs to the RAS basic model and some of them became more significant, the total cost has declined by 2.19 NOK. This makes RAS with own slaughterhouse even more competitive to sea cage farm and reduce the average production cost by 3.9 NOK per kg.

Besides, direct slaughter from the rearing tanks could avoid the mortalities related to the transportation of live salmon in wellboats, caused by laboured respiration and increased amounts of metabolic products in high fish densities (Stead and Laird, 2002) and holding the fish in slaughterhouses' facilities, that cannot sustain large amounts of live fish (Midling Andreassen, 2009).

The present NPV comparison of net pen and initial RAS model is made for facilities with different production level and it is reasonable to evaluate viability of the farms with the same annual output. It has been suggested, that RAS is more sensitive to changes in size than net pen, because of advanced technologies involved in the process. Therefore, NPV of sea farm has been scaled from 228.00 mil NOK with annual production of 5 000 tonnes to 271.96 mil NOK corresponding to production of 6 000 tonnes of salmon such as has been estimated for RAS. From this perspective, the difference between basic RAS model and conventional system is even larger and comprises 55.5 mil NOK.

Comparison of IRR is closely related to NPV and as a result conventional system is preferable. This can be explained by high level of investments costs for land-based facility (RAS basic) that exceeds the one in net pen by more than four times. Nevertheless, in both projects initial discount rate is lower than IRR, therefore, they are viable.

The land-based farm has also a very attractive level of production per m^3, 276.93 kg in respect of average annual production, while in pens this level is at 13,65 kg level. However, in terms of investment costs per m^3, net pen requires 98.72 NOK in contrast to significant 8 504.49 NOK in RAS.

Investment costs is a key factor when comparing NPV of projects, and while this item is unified for net pen facilities, land-based farms for growing-out salmon are more unique. Project and designs of RAS constitute of similar components defined by biology of the species to be reared in the system, however the overall organisation of facilities varies from company to company. From this point, the chosen reference for investment costs – Rosten et al. (2013) is questionable. In comparison with Roll et al. (2008), the area required for the two RAS is approximately similar. 30 000.00 m^2 for Niri AS and 27 000.00 m^2 for suggested by Rosten et al. (2013), however the total rearing volume is two times larger in the latter, 40 000.00 m^3. Taking into account that the facility modelled by SINTEF and The Conservation Fund Freshwater Institute includes hatchery, that requires additional tanks volumes and equipment, considers lower total annual output, 3 900 tonnes comparing to 6 000 tonnes in the Niri AS facility, and lacking data on location of the modelled farm, the assumed investment costs are unlikely to be applicable in practice.

Besides, initial investment level is highly dependent on the recirculation degree in the facility, because it affects the type of equipment. Investigation from Billund Aquakulturservice A/S has shown, that total investment rate per kg of production capacity changes dramatically from approximate 25.37-33.83 NOK (3-4 Euro) in facility with partial recirculation to 84.56-101.48 NOK (10-12 Euro) in intensive recirculating facility (Olsen, n.d.). By applying the latter rate to the RAS considered in the present thesis, the total amount of investment costs is composed in the range from 507.36 mil NOK to 608.88 mil NOK. However, in the present work, investment costs per kg of production capacity have been estimated in amount of 7.23 NOK for net pen and 30.71 NOK for RAS. Therefore, investment costs for land-based aquaculture farm is a big uncertainty depending on many factors.

From the prospective of national economy and social impact, aquaculture industry has a significant influence on countries and companies involved in the production of salmon. It provides employment not only in the industry itself, but also in the accompanying sectors related to production of technical equipment, feed etc. To estimate an optimal harvest time, a one-time release method has been considered for both systems. This method takes into account maximisation of PV of one batch, and is widely implemented in sea cage aquaculture. However, it is more economically efficient to estimate salmon production viability for a long run. For that purpose in some industries, utilising renewable natural resources, an optimal rotation time is used.

Optimal rotation has been developed by Martin Faustmann for forestry industry. It underlies a shorter grow out period of a resource which growth slows down with time, and therefore, harvest makes the limited space available for young fast growing individuals (Asche and Bjørndal, 2011).

The equation to estimate PV for optimal rotation time is following (Asche and Bjørndal, 2011):

$$\pi(t) = \frac{V(t)}{(e^{rt} - 1)} \tag{15}$$

where $V(t)$ is cash flow and $\frac{1}{(e^{rt}-1)}$ is the component that takes rotation and discounting into account. Implementation of the equation to RAS moves the optimal harvesting time from the nineteenth month to tenth with the maximum PV equal to 37.64 mil NOK. The same calculation, when harvest and feed costs are introduced, moves harvest time to the twelfth month where the maximum PV equals to 20.88 mil NOK.

Nevertheless, this method has a number of constraints for applying in aquaculture: it assumes an immediate release of the new batch after harvest, release should not be dependent on season, availability of recruits throughout the year and a price independent of the size of the individuals (Guttormsen, 2008). While environment condition is the most significant limiting factor for sea cage farming, in RAS water temperature and quality are controllable, what gives an outstanding competition opportunity to the land-based farms in terms of production cycle planning, and hence, rotation problem solution (Bjørndal, 1987).

The aquaculture industry is in deep relationship with transport industry due to remoteness of the facilities performing necessary functions in a sequence of farmed salmon production (Mathisen et al., 2009). The transportation increases not only because of production growth but also processing plants centralisation (Norwegian Scientific Committee for Food Safety, 2008).

The most common way for smolts transportation is wellboat. Also there is possibility for transportation by air, helicopters (Mathisen et al., 2009) or in containers by plane, or trucks (it has been estimated that there is about seven vehicles registered in Norway with tanks volume of 20 – 30 m^3 each) (Norwegian Scientific Committee for Food Safety, 2008).

Considering the generalised costs of transportation, including time and damage costs and fares, in relation to remoteness, road transportation is the most cost efficient for short distances (Figure 25).

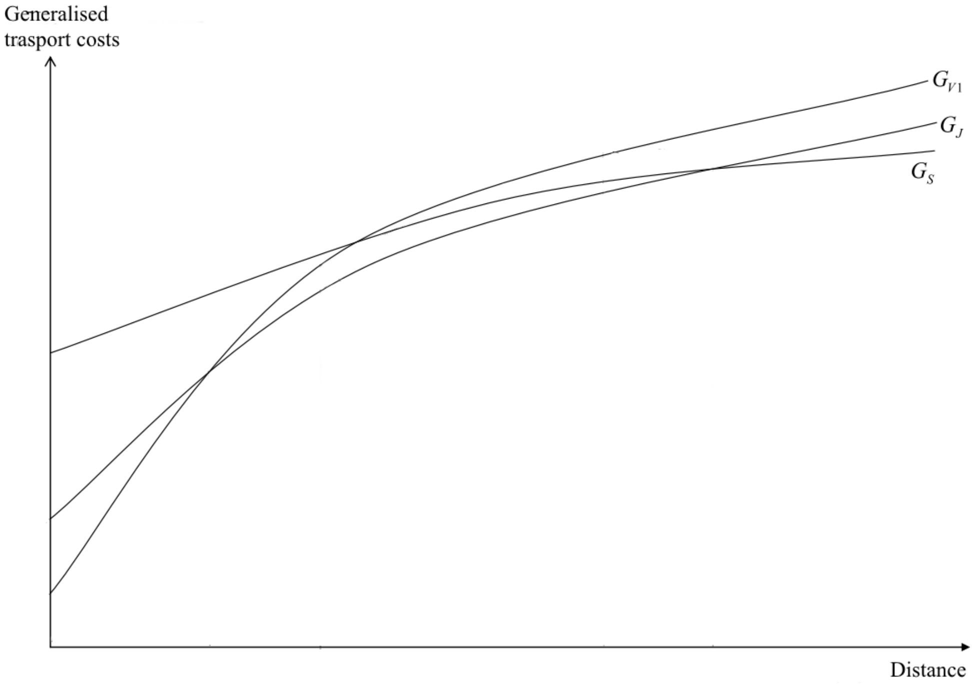

Figure 25. Comparison of generalised costs to distance for road (G_{V1}), railroad (G_J) and marine (G_S) transports (Mathisen et al., 2009).

Nevertheless, for transportation for longer distances railroad and marine transport are more preferable. However, when the time is of high importance on-land transport is better alternative to air (Mathisen et al., 2009). This estimation is made in respect of fish export, however, the dependency between costs and distance may be extrapolated on all production stages. Besides, due to concern over disease outbreaks transportation in closed systems, i.e. on-land transport, may be required by governmental regulations (Norwegian Scientific Committee for Food Safety, 2008). In addition, use of on-land transport may significantly reduce supply cost, for instance for feed (Boulet et al., 2010).

Together with benefits, transportation system meets barriers that can be specific for a particular region. In general, they are related to infrastructure location, roads capacity and interruptions, such as water bodies or fjords, and, consequently, necessity to use ferries. Also natural, environmental and organisational condition may be an obstacle, among them are floods, accidents and roads maintenance (Mathisen et al., 2009).

Interaction of recirculating aquaculture systems with an outer environment has shown to be of minor degree, comparing to the net pen system. Among the benefits is minimised water makeup requirement, what also leads to small amount of wastewaters to be treated. Sufficient water treatment and absence of direct connections of rearing tanks with natural water bodies may allow locating this type of farms in the regions where the governmental regulations in respect of environment are very strict, and in some cases, such systems could be connected to a public water supply facility (Tucker and Hargreaves, 2009). At the same time, estimations performed by The Norwegian Institute for Water Research has shown that net pen farms are responsible for the phosphorus discharge larger than from agriculture, population and industry, and more than a half of nitrogen effluent along the Norwegian coast (Roll et al., 2008)

Water treatment has also a mutual positive effect on the environment and the farm itself, when considering diseases spread and fish roaming. Filtration and UV sterilisation avoid any presence of bacteria, that is a costly problem of the existing sea farms. For example, a slaughterhouse in Roan municipality has been forced to invest 9.8 mil NOK in closed pens after PD outbreak, beside, work had been stopped for several months (Sæther and Mienert, 2014). Preventing of fish roaming, avoids possible genetic interactions with wild species and disease spread as well. Impact from escapees may be significant, in 2002 The Norwegian Directorate for Nature Conservancy informed that 48% of caught salmon and trout in Namsen river, are escapees from sea cage farms (Roll et al., 2008). Presence of predators and necessity to wash nets, what may cause a fish roaming by humans failure, are also eliminated as the facility is located on land within a closed system (Tucker and Hargreaves, 2009).

While the general concept of RAS underlies low impact on the environment, the actual impact will be dependent on the technical solutions implemented in the design and location of the facility. Land-based facilities are highly dependent on the electricity, and the production of the latter is related to natural resource use. Therefore, CO_2 footprint estimation of RAS depends on the energy source used by the power plants in the region (Ayer and Tyedmers, 2009).

The considered system by Niri AS, has significant environmental benefits in front of net pen, as the wastewater are treated, the measures preventing escapes are implemented and the country of location, *i.e.* Norway, produces 95% of energy from hydro power plants (Statistisk Sentralbyrå, 2013).

6. Conclusion

Comparison analysis of conventional net pen aquaculture system and recirculating aquaculture system for Atlantic salmon has shown that RAS has lower operational costs than the sea cage farm, average 87.79 mil NOK and 93.45 mil NOK, respectively. The reason is that the efficient feed utilisation decreases feed costs significantly in RAS, in spite of a demand for additional labour force and electricity consumption. At the same time, more sophisticated equipment and buildings increase costs of depreciation by almost 2.6 times in comparison to net pen. Besides, there is additional insurance costs for RAS. First, it is expressed in higher insurance rate, 2.3% against 1%. Second, there is the insurance cost of additional equipment, although the rate is the same – 0.5%. The equipment insurance in RAS is almost three times higher than in net pen, 1.89 mil NOK against 0.68 mil NOK, correspondingly. Total insurance costs for land-based farm composes 3.63 mil NOK and exceeds the one in net pen (1.31 mil NOK) by almost three times.

Growth model adapted to the predictions by Niri AS results in slower growth rate after the twelfth month in RAS, what can be marked as a disadvantage of the system. Nevertheless, low annual mortality, 3.14% against 10%, provides RAS with higher revenue than in net pen. The value of the fish in water in RAS has shifted the optimal harvest time to month nineteen, which has a negative effect on production planning. Because of defined rearing tanks volume and equipment settings for sustainable rearing condition supply, number of harvests is imbalanced resulting in a gap in revenue in the year 6. However, it is preferred to have equal revenues annually when the farm is in steady-state. Competitiveness comparison has shown that lower operational costs make the land-based facility more efficient in terms of present value of the cash flow, 388.35 mil NOK against 264.25 mil NOK. Lower operational costs in RAS leads to significantly lower costs per kg of production, and therefore the system is more flexible in terms of price fluctuation than the conventional one. However, investment costs are around five times higher for the land-based farm, and although the NPV is positive, lead to lower profitability than the conventional system for ten years horizon, 228.05 mil NOK against 216.48 mil NOK, respectively. From this point, the net pen system is preferable to the land-based one.

According to the stated above, the hypothesis 1, that the recirculating aquaculture system has higher cost per production than the conventional net pen system, is rejected, while the hypothesis 2, stated that the recirculating aquaculture system is less profitable than the conventional net pen system, is retained.

From the present work, it has been found that the growth model based on salmon growth at sea is not applicable in terms of closed-containment system with optimal environmental conditions. Comprehensive information on the fish development is required when specific rearing conditions are taken into account, because predictions based on the growth data only for a range from 30 grams to 4.05 kg may not reflect the real changes of individual weight in the long run.

The RAS technology nowadays is rather unique than universal. From this point, assumptions made on the short description cannot give a clear understanding of a capability of the farm and its flexibility. Therefore, manipulation with physical equipment requires either an expert in this field or a specific knowledge. This information is crucial for scaling and expenditures estimation, because extension or diminution of the production is related to the purchase of expensive equipment and facility components.

Major part of available information about RAS investments corresponds to particular projects, developed to suit specific external conditions. Taking into account that every project has own design, it is complicated to implement the investment costs to another model. Investments are influenced by the choice of country to locate the farm in, as this may raise constraints in form of availability of components in the market and price of the components and construction works, in addition to communal and labour costs. This will in turn affect cost of production per kg by changes in depreciation and insurance. Furthermore, licence cost or annual fee on salmon production is an inevitable part of investment costs for Norway or operational costs in other countries, *e.g.* Scotland, and will definitely have a profound effect on investment decision.

Considering the opportunities of RAS in terms of additional facilities integration, it seems that own harvesting and processing facility is rather necessary than optional. In contrast, the wellboat use in such farm is complicated as it may affect the overall farm design, choice of location and produce additional issues related to logistics.

Recirculating aquaculture technology is very promising in the light of changing environment and increase demand for seafood products. Nonetheless, diversity of projects and their high investment costs, leads to necessity of comparing the RAS projects and technologies with each other rather than RAS with conventional sea farming systems.

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