Faculty of Engineering Science and Technology (IVT)
Department of Industrial Engineering

Arctic Agriculture by Using Fish Farming Waste in Northern Norway

A study based on aquaponics Northern Norway

Stud. Techn. Mathias Sæterbø

Abstract

With the growing aquaculture, improved management of the environmental, logistic-managerial, social, and economic aspect are vital to preserving sustainability in the industry. The dissertation addresses the potential processing of the fish waste in aquaponics (a combination of two highly effective production technologies: hydroponics and recirculating aquaculture). Involving a suggestion for sustainable management by implementing a circular business model to the industry, lessens the ecological footprint, and supports an environmental friendly production of both fish and plant. Aquaponics in Northern Norway has definite potential. However, no blueprint for success exists, which means each individual producer needs to carefully assemble the system to utilize the available local resources.

In Norway, the cold water species, salmon and trout, are the most extensive farmed, showing great potential in an aquaponic system. With mapped living, nutritional, and environmental requirement, the dissertation combines salmon and trout to potential plants. The plant types taken into consideration were selected in terms of economic viability, system design, plant category, and the nutrient match between the plants nutritional value, and the nutrient value of the aquatic species waste emission. During the analysis of the potential of aquaponics in Northern Norway many factors were taken into considerations, among these, the electricity costs were proven to be one of the critical aspects, while others, such as existing facilities and already established water connections, were found to be suitable for the development of the system. Therefore the thesis consists of an extensive cost-benefit analysis of the electricity costs, with a significant focus on lighting and heating costs. Four plants were analyzed, tomato, parsley, tomato and lettuce where it was the herbs: parsley and basil, that proved to bestow the greatest potential with the highest overall profit margin with the electricity and lighting costs taken into considerations. Additionally, Rakocy defined feed rate ratio is used in the calculations with 60g/m3 for the leafy herbs and 80g/m3 for fruity plants to balance the ecosystem, determine the annual plant productivity, and in that regard the annual profit potential.

Keywords

Aquaponics, hydroponics, feed rate ratio, recirculating aquaculture system (RAS), circular economy, sustainable aquaculture, sustainable agriculture, waste management.

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This dissertation paper are supposed to help students/professors/researcher or other interested parties to understand the potential of fish farming in Northern Norway. First, I would like to thank my professors at UiT for supporting me during the period, Especially Svein Møller Nilsen for good feedback and discussions. Additionally I would like to thank my main supervisor at UiT, Wei Deng Solvang and Co supervisor Hao Yu, for agreeing to supervise my master thesis. Then I would like to thank Beijing Institute of Technology, Changhao Liu my supervisor here at BiT, and Summer BiT coordinator for accepting me into BiT and assisting me during my stay in China. Finally I would like to thank Halldor Arnarson and Hans Ivar Arumairsasa my student collegues here in China.

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1 Introduction

Norway is a rich country, a lot because of the available natural resources we possess, and how we manage them. Fishing is something that always been highly available and has been taken advantage of for thousands of years in the Nordic countries, with the widespread coast along the entire country together with the multitude of fjords running through the country [1].

Aquaculture contributes to a substantial revenue in many countries including Norway, being the fastest growing food-producing industry[1][2]. The growth can be elucidated by the ”blue revolution”, that refers to the growth in aquaculture from the mid-1900s to the present. For Norway it was in the 1970s the aquaculture began with the technological breakthrough of the first construction of cages, even though it can be dated back to the 1850s by hatching cod[3]. Since then the aquaculture has seen a tremendous technological and economic growth growing from a pioneering niche to one of Norway's largest food producing industries[4]. Aquaculture is an industry that is growing and will have to continue to grow to meet the increasing demand for seafood. But the growth will not be sustainable if the management is not improved significantly. That is why there is a need for both local, national, and international management of the environmental, social, economic, health, and animal welfare aspect. As will be seen through the next chapters is that the aquaculture potentially can have a large negative effect on the environment considering genetics, water quality, ecology, health, and resource[5].

For Norway, it is definitely the farming of Atlantic salmon that poses the greatest market and profit. With the extensive farming and growing industry, it naturally occurs large quantities of organic matter and nutrients from the farming process that when accumulates poses a significant environmental impact unless taken appropriate action to counteract. Processing of the waste is a new concept, that supports a sustainable aquaculture, by including a circular business model to the industry and lessens the ecological footprint. Today multiple methods exist in handling the waste. Most commonly, the waste is deposited, but with small or no financial gain. Alternative methods have been looked into the recent years, includes the use of waste as biogas to produce energy, or utilizing the fish sludge in the agriculture, called aquaponics. Aquaponics is a new concept and a method of food production that combines two highly effective production methods, hydroponics (soil-less agriculture) and aquaculture[6]. It has gained a lot of momentum the recent years due to the possibility of a more sustainable way of growing food in a recirculating ecosystem that utilizes the waste from the aquaculture in the plant nutrients.[7][8].

The different aquaculture system consists of multiple parts. The thesis will base its research in utilizing land-based fish sludge; therefore, the hatcheries are the most relevant source existing today. However, with the technological advancement, the wish for environmental improvements, and expanding industry, more and more are looking into the concept of closed system land-based fish farms. Even though we have great success with open sea farming of salmon, this can always shift. For Norway to stay in front of the fishing industry as we do today, it is imperative we manage to stay up to date with the technological improvements. I.e., if land-based fish farming will be the new standard as it very well may be, it would be highly advantageous to be the leading researcher in the field, especially with our reputation for good quality seafood and already years with experience in the industry.

1.1 Objective of the thesis work

The thesis work is two folded, where the first part will be to develop knowledge on relevant themes/research. During this part, the main focus is:

- Conduct a literature review on aquaponics in the perspective of Northern Norway
- Conduct a literature review on fish farms, their infrastructure, supply chains, and waste management techniques.
- Conduct a review on Arctic agriculture such as potentials and countermeasures.

From these themes, determine possible implementations of aquaponics in the Northern Norway region, both regarding technological solution and economic possibilities. To later on, be able to make scientific decisions to compose a solution. Determine ways to take advantage of the fish farming waste, and implement it into the agriculture.

The second part is the research part of the project it is the main part of the thesis work, and are allocated two-thirds of the projects time. During this time the following tasks are defined:

- Review what fish species are grown at the various hatchery in Norway.
- Define, study and analyze the various aquaponics parameters, such as feed rate ratio, optimal plant nutrient composition, sludge content and quantity
- Identify the possible and/or suitable plant(s) to grow in Northern Norway regarding of the availability of fish species as well as other relevant factors, i.e., temperature match, bacteria, fish, and plant.

With the accumulated knowledge from the literature review, alongside the mapping of the Northern Norway's aquaculture, the objective of the dissertation is to identify and analyze the potential for the development of a full scale commercialized aquaponic facility in Northern Norway. The dissertation will answer critical questions towards challenges related to the function of aquaponics, but also towards possibilities in Northern Norway's infrastructure regarding water resources, electrical, and facility locations.

2 Literature review

2.1 The Norwegian aquaculture

Aquaculture is the process of catching fish, plants, algae and other organisms in a controlled environment, and can be done either in fresh water, sea water or brackish water[1]. Since the aquaculture came into existence, it went from providing 6.5% seafood for human consumption in 1980, to 25.7% in 2000, and 46,8% in 2016 which can be seen in (*fig: 1*) [9]. Showing that the production and export of seafood are growing and becoming more and more viable as a way of securing food to the worlds population.

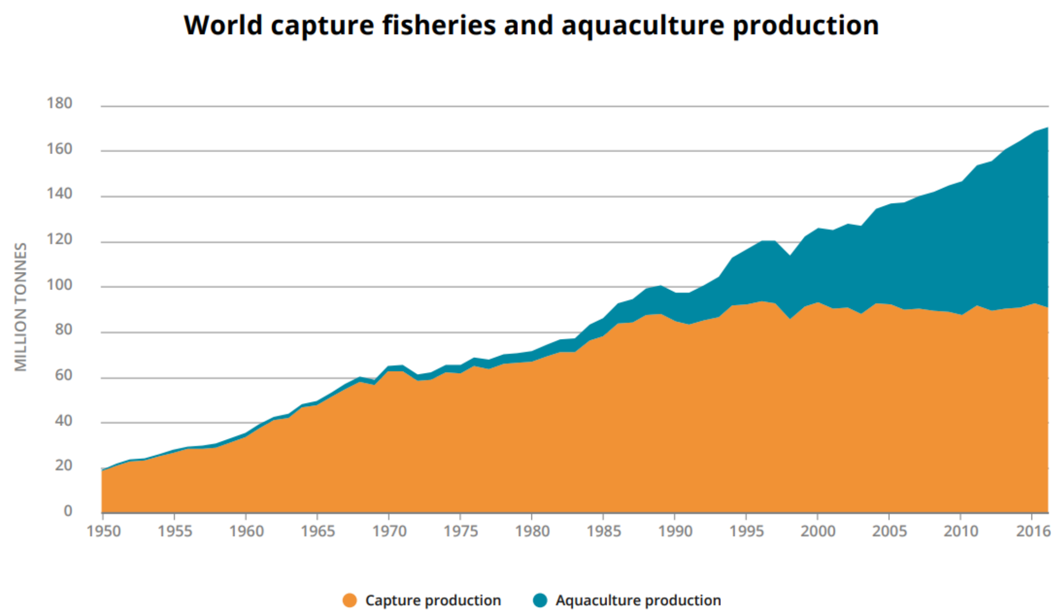


Figure 1: In the provided data aquatic plants are exluded[9]

The aquaculture industry is an important export industry in Norway, under constant growth, and has more than doubled since 2007 (*see fig: 2*). Even though it is small compared to the mineral/oil/gas industry, aquaculture, and fishing are said to be a conditional renewable resource, i.e., as long we do not over fish or destroy the environment the fish will renew itself [1]. Compared to fossil fuel such as oil and gas that eventually will run out. The rapid growth in aquaculture export is supported by the constantly increasing demand, especially from the new emerging markets from Poland, France, USA, and already well-established trade agreements. The Asian market, even though significantly smaller than the EU, are becoming more and more important for Norwegian export. The growing middle class in many parts of Asia, gives rise to increased seafood consumption, increasing the demand for high quality seafood which Norway is known for.

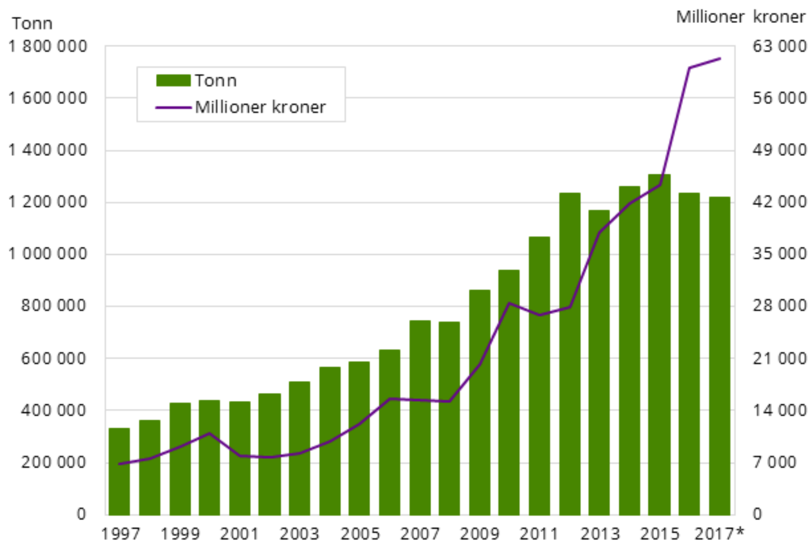


Figure 2: Statistics showcasing the Norwegian seafood export revenue the recent years[10]

With today's global competitive market, It is imperative that Norway manages to stay in the technological front. Due to an ever growing market for Norwegian seafood, which has caused the demand to surpass the supply. Factors such as inflation have had some effects on the industry. Also, the general price level of the goods has increased, but at the same time, the production costs have increased even more. The increased value cannot alone be explained by the effect of inflation, but rather the relationship between supply and demand. In the world, there are only a handful of countries able to produce salmon in large enough quantities to have any significant effect on the global market, including, Norway, Chile, Scotland, The Faeroe Islands and Canada[11].

The main focus in Norway is by far the breeding and farming of salmon, but we do also export other species, such as cod, trout, mackerel, and pollocks which poses a significant revenue for the country. Even though Norway is leading in the farming of Atlantic salmon, we are becoming small when compared the annual production of seafood with the largest actors, such as China producing 58.5 million tons, where Norway only produces scarce 1.3 million tons[12].

Today we are not able to produce enough to satisfy the demand, meaning there are huge potentials for new technology to increase production. From statistics the recent year (*see: fig: 2*) it is clear the production in tonnes has stagnated the recent year, but the prices are continuously increasing.

2.1.1 Environmental concerns

Despite the popularity of aquaculture, it holds a darker negative impact on the environment. The main challenges are the high sea lice densities that have the potential to kill the fish. The large waste of organic matter and nutrients that are not being salvaged, but rather spread into the ocean[2][13]. Together with the escapement of salmon in open pen farms resulting in high direct economic losses, cross spawning between wild salmon and hybrid populations[4].

In the aquaculture both land-based and offshore, there are a large waste of resource in the shape of organic matter and nutrients deriving from the fish together with unprocessed fish pellets. Metabolic waste originating from fish farms (see *fig: 3*) consist mostly of high levels of phosphorous (P) and nitrogen (N). Both substances, if released into the environment, would result in potentially large negative impacts. The levels of each depend on a multitude of factors, such as the diet, size, life stage, type of fish(red or white), rearing system, and genetics[14]. That is why a thorough mapping of the production is essential, and an overall overview of the mentioned points are required for determining the sludge production.

High levels of phosphorus in surface waters often leads to forced eutrophication, giving rise to high levels of algae production, which again in nature can have a severe effect on the ocean habitat. Especially at the seabed where the Biomass Pyrolysis Process occurs, i.e., the thermal decomposition of the residue in the absent of oxygen[15], which in terms can result in a dead and lifeless seabed.

Figure 3: Fig 3 showcases the possible effect bad waste management. Effluent water pumped into the ocean from an intensive shrimp pond[5].

That is why in modern fish farming as we have gained a better insight in the consequences of bad waste management, companies have started thinking more about the environment, together with alternative ways to make money. Terms such as circular economy have arisen, finding new and innovative ways to make money, by taking advantage of all the resources, instead of disposing of them.

2.1.2 Categories of aquaculture

Aquaculture has become a large industry and is not only a simple cage as the earliest constructions were, but consist of an entire system depending on where the fish is in its biological life cycle. It can be classified in the following three areas:

- Hatcheries
- Post smolt, often in open pen farming system located at sea.
- Fish slaughter

Where again the different aquaculture system is either open or closed constructions. Closed systems, as the name suggest, are entirely shielded from the environment, placed either at sea or land, such as in land-based hatcheries. While open systems are the most common which are open pen farming system existing along the coast of Norway today.

Today aquaculture technology is in a shifting phase between open and closed. Most construction today are open, being both cheaper and easier to manage. Mainly because of the natural circulation from the sea, instead of expensive circulation equipment and constant surveillance of the water. However, this results in a high amount of organic emissions from the fish itself and unprocessed fish pellets due to the wind and sea currents. That is why the industry has taken a step towards a more environmentally friendly aquaculture. From September 2018 up to 18 application for semi closed system at sea are registered[8]. ”Salaks” is an example, where they have applied a new innovative farming system, that is partly closed called fjordMAX. A construction that can produce a substantially larger batch by using a fraction of the area normal open pen farming would use. Besides, they propose to be able to retrieve up to 90% of the waste emitting from the fish, to lessen the effect on the environment and be further used as a resource by an appropriate facility[16][8].

2.1.3 land-based constructions

Hatcheries are land-based, and is the facilities that fish are kept in until they are grown to approximately 70 grams, then they are moved to larger construction at sea[8]. Even though the use of fish waste will be more directed at hatcheries, it is important to consider the future potential that land-based construction may supply the industry. Meaning instead of moving the fish fry to open pens at sea, they can be moved to a larger tank in the same facilities.

The principle of land-based aquaculture is relatively new, and have not yet successfully been implemented on the same scale as open pen sea farming. However, with the increased development of closed system at sea, some of the technology in the various projects could potentially be transferred to closed land-based system, as they have comparable problems. The reasoning why land-based aquaculture is struggling are still a mystery to scientists. It has been established that salmon thrives in brackish water around 12 ‰, but with a fish size above 1.5 kg, the mortality rate drastically increases[8]. land-based closed aquaculture would eliminate or alleviate some of the main problems with open pen farming. Including escapees, sea lice, and spread of disease[4] such as ISAV infection - Infectious salmon anemia virus which, when remained untreated, is deadly for the salmon[17][8]. Besides, it would enable for 100% collection of residual waste, which poses a huge environmental concern today. On the other hand, it offers a much more complicated system, that requires better and more expensive technology, and expert management, required to be continuously operational as a pump malfunction for instance potentially could wipe out the entire batch.

2.2 Waste management techniques

Proper management of the waste is central for the thesis work. That is why mapping of existing ways the fish waste from the aquaculture are being handled today, together with the potential financial gain is crucial to suggest solutions for a more sustainable operation of the Norwegian aquaculture. Reducing the amount of waste into the environment is considered to be a key activity in maintaining sustainability in the Norwegian aquaculture, but also the global aquaculture. Especially in how land-based aquaculture are gaining momentum, and potentially can be fully integrated into the industry the next decades[8]. As mentioned the waste from the aquaculture is rich in valuable minerals, enzymes, pigments, and flavors sought by many industries[18]. Finding innovative ways in handling the waste could provide the industry with an entirely new revenue source if appropriately managed. There are however challenges before the sludge can be used as a marketable product, such as continuous access to enough raw material, the wide geographical spread of the farming sites, storage and disposal[19]. The concept is new, and supports a circular business model, which leans towards a more sustainable supply chain, and lessens the environmental consequences. In contrast to the more traditional linear business model that uses the principle of take - make - dispose[20].

Discarded a few pilot projects there are few effective solutions for sustainable utilization of the waste from the Norwegian aquaculture resulting in most of the waste being deposited, with no financial gain. Besides, effective solutions require a logistic chain that so far has few financial advantagesc[8].

Important to consider is that there are regulations in place while conducting aquaculture activities. The Norwegian environment agency has said that the wastewater is to be considered environmental waste which is required to be treated, such as depositing to appropriate facilities[21]. Norway has many regulations in place, such as the pollution act.

> *The manufacturer of food waste will ensure that the waste is brought to a legal waste facility or undergoes recycling so that it ceases to be waste or otherwise benefits by replacing materials that would otherwise have been used[22].*

§ 32.Handling of food waste

In the following chapters, the existing ways of handling waste from the aquaculture are discussed, with their opportunities and challenges.

2.2.1 Combustion

The fish sludge as mentioned contains a high amount of nutritious substances in addition to a high energy level making it ideal for combustion. The advantage is that it diminishes the use of other sources of fossil fuel thus helps reduce climate emissions, but on the contrary, even though it produces energy it results in a wasteful process where the nutrients are incinerated and not brought to use. The combustion of the fish sludge induces a high amount of waste of resources[8].

2.2.2 Bio production

The production of biogas is not a new technology and has been used in a multitude of other industries, but in the aquaculture industry, it is a relatively new concept where the nutrients in the waste can be retrieved in addition to the production of energy. The biogas is highly energetic, retrieved from the sludge by anaerobic decomposition of the organic matter[23]. The gas is a flexible energy carrier and has a variety of uses such as fuel or production of power and heat[8]. ”Cermaq” and ”Smøla hatchery” are two examples that have been able to produce biogas by the help of fish sludge[24][25]. The use of biogas shows great potential by incorporating vertical integration in the fish farming supply chain by being partly self-sufficient. The idea is to use the energy from the biogas to heat the water, supporting a circular business model, replacing an alternative energy source such as oil or current.

2.3 Arctic Agriculture

Traditional agriculture is defined as the process of cultivating the earth to produce food, plants, and other vital product to feed the society. The development of the Norwegian agriculture has drastically changed the last century. From possessing around 250 000 farmers by the end of World War 2 to around 40 000 today. The cutbacks of farmers are due to a growing industry with a higher value creation per employee[1], but at the extent of huge fossil fuel and irrigation inputs that are not sustainable.

Agriculture, as conducted last centuries following a linear business model, is simply unsustainable. Year after year with cultivating the lands resulting in soil erosion, poisoned land/water, and many other problems. This leads producers and researcher to look in a new direction. Instead of the linear use of resources, that is neither economical nor sustainable. The principle of circular economy arises. CE has been put as a key strategy in many places of the world as a way to resolve problems of resource depletion and environmental depletion[26][27].

With any agricultural system, an important aspect to take into account is the energy input. It is a massive amount of solar energy going into the agriculture to grow our food. Various research and models give us an approximately crop productivity or photosynthetic efficiency of 2-5% [28][29] i.e., efficient use of the energy in sunlight depending on the plant species. For plant productivity, there is a multitude of environmental factors that affect the plant development, light, temperature, humidity, water, nutrients, gravity, etc. - with light being the most important, due to the providence of energy to the photosynthesis[29]. However, with the Northern climate, solar energy alone is not capable of providing energy for the plant production, and artificial lighting is required. Growing by the help of LED lights (light-emitting diode) naturally requires energy, and forces us to look at efficient methods of taking advantage of available energy.

Very little of the food we consume is being grown in Norway. In fact, we only stand for 30% of the total national consumption[30][31], where the rest originates from import agreements. The limited agriculture is due to several factors. In Northern Norway, the summer usually is very short, with relatively low temperatures, which leads to immature crops. West Norway, with their small and steep areas, are not fit for agriculture, resulting in the southern and eastern Norway the only effective place to conduct agriculture activity. Food safety is an important issue that states that everyone should have access to sufficient and safe food, not only local but also abroad. The Norwegian government works to increase the agricultural output of Norwegian food production focusing on increasing and maintaining the self sufficiency[32].

Due to the various cost associated with indoor agriculture, determining the type of crop to grow is a crucial economic aspect. For instance, growing wheat with a very low kilogram price would not be sustainable, and would result in a little or no profit depending on the operation cost. During the research part of the thesis, the plant types will be identified, and further looked into as to which can be the most beneficial in Northern Norway.

2.3.1 Soil- less agriculture

With the industrial revolution, new and better ways of farming were made possible. However, the ambition to maximize production and yield led to an over farming of the land year after year which in turn led to an increased need of fertilizer, fossil fuels and various chemicals to protect the crops[1][33]. The result was a huge overhead cost for farmers and an undesirable environmental footprint leading researchers to look in a new direction. Enter soil-less agriculture. A method of growing crops without the need for soil[33]. As it is not dependent on land, it can be grown anywhere, in a controlled environment, such as in large indoor facilities. The most common type of soil less agriculture is called hydroponics, which replaces the soil with a nutrient based water solution which the root system of the plants are submerged into[6]. The principle of hydroponics are illustrated in fig: 4.

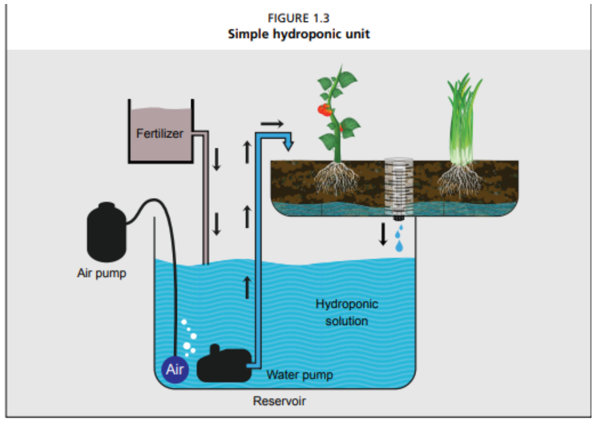


Figure 4: Illustrating principle of a hydroponics unit[6]

The main inspiration for the invention of hydroponics is the increasing demand for off-season crops together with the intention to maintain a steady supply throughout the entire year. For CEA - controlled environment agriculture to be able to compete with traditional open field agriculture, an increase in the production rate is essential to match the increased production cost associated with CEA[6]. That is where hydroponics enters, with the advantages of a higher efficiency towards water use and fertilizer use, decreased chance of diseases, and higher control of the production cycle. With the developed knowledge it can be expected that hydroponics is the most suitable farming technique in Northern regions due to the limitations of short summers unstable weather, low percentage of arable land and lack of local food production. The process is however more complicated, especially in the installation phase as a considerable financial investment and coordination are required with relatively high risks. The media for plant grow will be discussed further in *sec: 2.4.4*

2.3.2 Indoor farming system - Vertical farms

One method of farming that might be viable is vertical farming by using fish farming waste as fertilizer. The principle is new and would enable us to take advantage of the nutrients and organic matter in the water, together with good space management. Besides, it enables to be combined with hydroponics. There is a huge potential for the implementation of vertical farming system in Northern Norway, with the already high availability of fish farms, and hatcheries, together with possible land-based aquaculture being researched upon. The waste will be circulated which supports a more environmental friendly production, and guarantee the food security

There are multiple projects involving vertical farming worldwide, with various technology. There is definite a potential, but due to the technology utilizing LED lights instead of the sunlight requiring a substantial investment cost and energy to supply, many researchers are questioning if it is sustainable. The positive is that the efficiency and price of LED lights have significantly improved the recent years, with the ability to increase crop productivity, giving rise to this discussion[34][35]. However, multiple projects are operational and have succeeded in implementing the idea of vertical farms. BySpire - in Økern[30] and AeroFarms[36] are two examples.

2.4 Aquaponics

Aquaponics is defined as an approach that combines two highly productive systems in their respective fields. Recirculating aquaculture and hydroponics[6][37]. The technology has gained a substantial momentum the recent years with its increasing popularity as a way to introduce a more circular economy to the aquaculture and hydroponics. Together with the ambition to assure a more sustainable practice to the industry that can be justified by its higher yields, better use of water, simpler method of pollution control, improved management, higher quality of products and greater food security[6][7]. The technology is still relatively new, with its associated challenges due to most aquaponics application being more directed towards research. Making an extraction of practical guidelines for a business development a major challenge despite the involved technology becoming more and more known. Aquaponics is said to be a sustainable technology, which accompanies various challenges, risks, large investments, and late return on investment[37]. However, it enables collaboration between two industries, and a method of fish and plant production in areas normally not fit for agricultural activities.

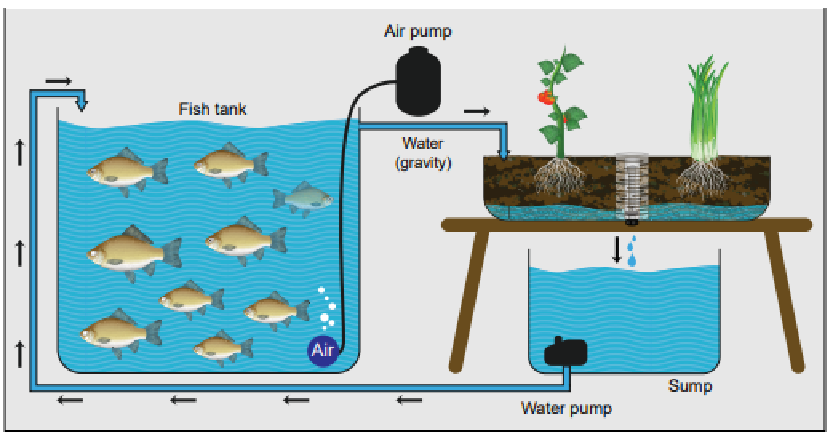


Figure 5: Illustrating the principle of an aquaponic unit[6]

Aquaponic, in contrast to traditional hydroponics, does not require the same amount of added supplements in terms of fertilizer to supply the plants with the needed nutrients to grow. It takes advantage of the enriched mineral water that arises from the aquaculture. Which allows for the use of the wastewater that normally would be disposed of. To understand the process of aquaponics several subjects have to be included and explained. Aquaponic consists of three main organism, the plants, the aquatic species, and the bacteria. All of which works together symbiotically and acts as an entire ecosystem of the aquaponic process[6][38]. The biological process, water characteristics, oxygen levels, bacteria, plant, fish, management, design, and disease prevention are only a few keywords related to the operation of an aquaponic system. The process illustrated in *fig: 5* briefly summarizes the principle of an aquaponic system. It describes how the effluent water containing the waste from the fish ventures through filters to act as nutrient source for the plants, before being circulated back to the fish tank.

2.4.1 Recirculating aquaculture system

RAS - "Recirculating aquaculture system" can increase the productivity of an aquaculture system by reducing the amount of water, stocking the fish more densely, and is the most applicable method for the development of integrated aquaculture and agriculture systems[39][40][7]. Today almost all new land-based aquaculture facilities are built with this technology[41]. Achieved through the use of waste treatment techniques such as mechanical filters and biofiltration, but at the expense of more concentrated waste, a substantial increase in price due to higher investment, energy and management cost[6]. The use of RAS do also require constant surveillance and good management as it poses a huge risk in terms of flaws and accident in the facilities. Due the various systems are interconnected, the consequences of a nonfunctioning pump could in the worst case cause the entire batch of fish to perish.

The RAS cycle used in aquaponic would need to be modified from a traditional RAS that cleans the water and sends it directly back to the fish tank. Today most aquaponic systems are operated as a recirculating loop, circulating the wastewater from the fish to the plants via filtration as shown in *fig: 6*. There are however drawbacks related to this method. The water quality is specially made to fit the fish species requirements, and suitable plants are chosen to fit the fishes environment. Normally the fishes requirements are not completely aligned with the plants. Resulting in sub optimal growing condition for the plants that cause the plants to never reach their full growth potential[7].

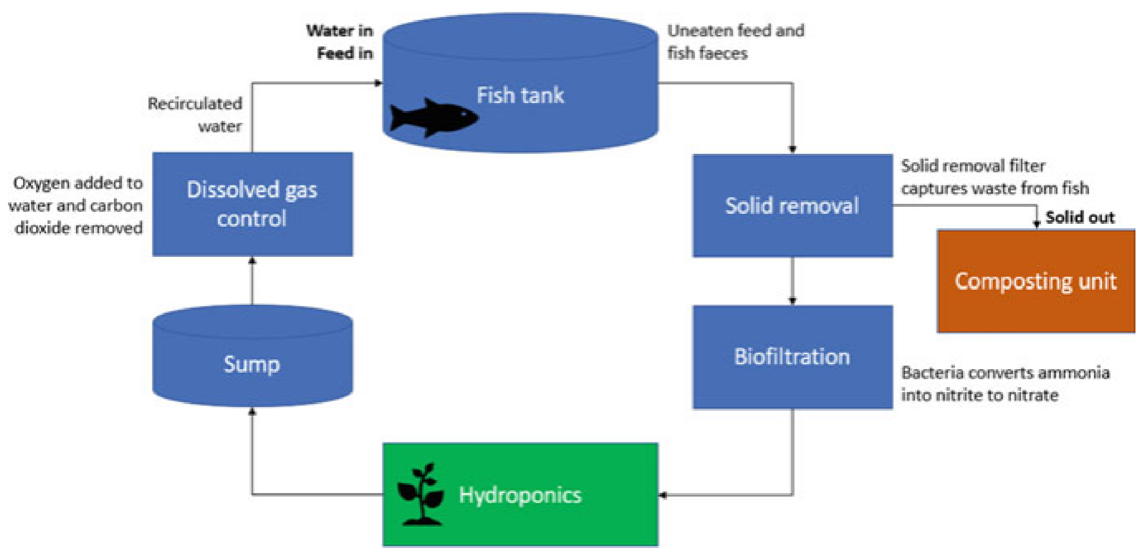


Figure 6: Showcases a standard aquaponic unit[7].

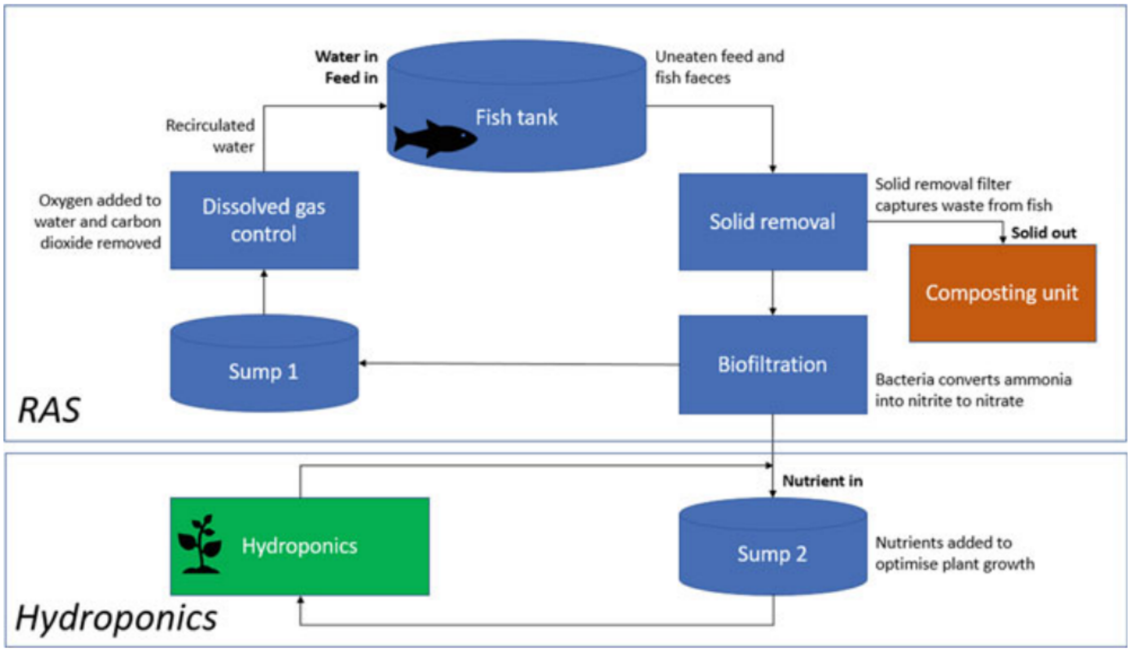


Figure 7: Showcases the principle of a DAPS [7]

That is why a solution shown in figure 7 have the potential to grant better results. DAPS - Decoupled aquaponic system, a system where fish, plants, and if applicable, remineralization are integrated as a separate functional unit. Here the individual water cycles can be controlled independently[42][7][43]. The idea is to divide the water into two independent subsystems by including an additional "sump" where various nutrients can be added to assure optimal plant growth, and in it enables the producer more freedom when choosing the type of plant to grow instead of being bound by choosing entirely based on the cultivated fish. The system would secure optimal conditions for both the fish and the plants. It also acts as a fail safe in case of emergencies such as faulty equipment. If a problem occurs in the fish or plant compartments, each section could be isolated until the problem is fixed, and in the worst case, only one part would be wasted instead of losing both.

2.4.2 Biological process

The waste from the fish tank do not only contain nutrient rich water, but rather solid waste together with effluent water containing high values of ammonia, among others. As stated, there are many important subjects involved in operating an aquaponic cycle. The initial step is the separation of the water from the solid waste through a mechanical filter (e.g., Drum filter or settling tank)[6].

Nitrification

After the removal of solid waste, the effluent water enters the biofilter where the nitrification process starts. The nitrification is perhaps one of the most important in the biological process where the main task is to convert ammonia from the fish waste into nitrate. The waste accumulating from the aquaculture contains high values of ammonia (NH^3), and by the help of nitrifying bacterias, and through an oxidation process the ammonia is converted into a more accessible nutrient for the plants, nitrite compounds ($N0_2^-$), and then nitrate compounds ($N0_3^-$)[5]. First, the ammonia is turned in nitrite by the help of AOB - ammonia oxidizing bacteria, then NOB - Nitrite oxidizing bacteria turns the nitrite into nitrate. Where genus Nitrosomonas and genus Nitrobacter is the most commonly used bacteria used respectively. Plants can use all mentioned substances, but nitrates are shown to give overall best growth results[6][38][5]. The whole process are summarized in *fig: 8*

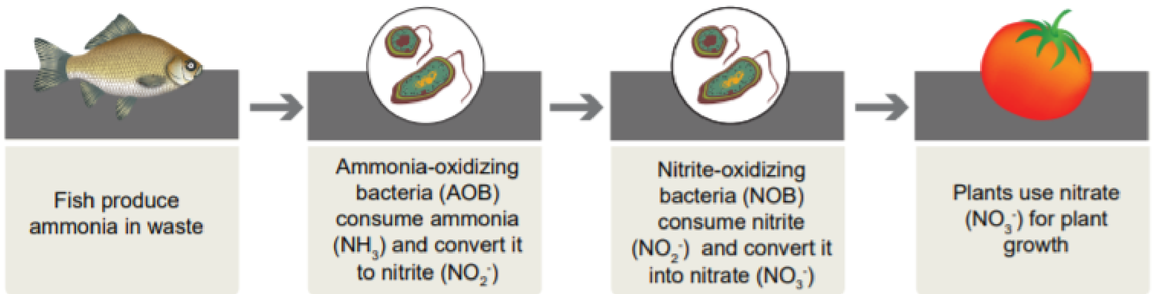


Figure 8: Nitrification process[6]

Mineralization

To build a system with zero or close to zero waste emission, there are potential to put the discharged solid waste to use. There are researched upon different methods to achieve this such as using it as compost, feed for other fish, in vermiponics[1], or by circulating it into the system by the help of a mineralization process. Mineralization is an important process in aquaponics. As we learned how nitrification is essential for the plants in removing toxic ammonia from the water, mineralization is equally important in which all other minerals are extracted from the fish waste that plants need to grow[5]. The processing of the solid waste is different from the biofiltration and requires separate consideration. Organic matter is metabolized into individual macro and micronutrients. Similar to how bacteria works in nitrification, heterotrophic bacteria are added to the solid waste that dissolves it[5][6].

2.4.3 Plants

From *sec: 2.3* it's clear that for plants to grow, there are a lot of factors that have to be satisfied. The nutrient requirement of the plants was one of the mentioned elements. Plants need both macronutrients and micronutrients to grow[43]. All together, plants need 16 different nutrients to achieve optimal growth[45]. However, in aquaponic systems, the exiting water from the fish tank contains many of the needed nutrients in both solid and liquid state which are solubilized to ionic form in the water that the plants can absorb (nitrification)[43]. However the content of the waste in terms of nutrients will vary depending on factors such as the

[1]Vermiponics is the combination of hydroponics and vermiculture that is decomposition with the help of worms[44].

fish species. That's why for the farmer and producer to maintain optimal growing condition the values of macro and micronutrients have to be carefully monitored, and in coordination with the preferred plants carefully chosen nutrients could be added by for instance using a DAPS system(*see sec: 2.4.1*)

Balancing the ecosystem to ensure that the plant, fish, and bacteria are at a dynamic equilibrium, is an important activity in running an operational aquaponic system[6]. Meaning that the amount of fish should match the number of plants. However, it is a complicated process. As the fish grows the amount of excrement and waste produced by the fish will increase, and the number of plants and bacteria need to be adjusted. Failing to balance the system successfully could potentially result in severe consequences for the system. There are three scenarios[6][46].

- If the biofilter and fish are at a balance, but there are an insufficient amount of plants in the system, it results in an abundance of nitrate. Not harmful to any parts of the system as nitrate itself is not toxic to plants or fish, but the system is said to be underperforming.
- The next scenario is when there are too many plants compared to fish, and not enough nutrients are produces leading to underdeveloped crops.
- If the size of the biofilter would be too small compared to effluent water produced i.e., not enough bacteria to convert the ammonia to nitrite and nitrates. The water would become toxic.

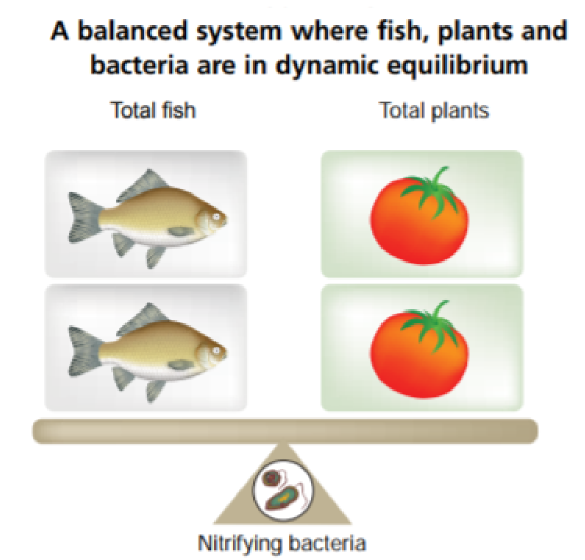


Figure 9: Illustration of a balanced system[6]

There have however been conducted research on optimal ratios between the fish, plant, and bacteria[6], but still, it is a field of aquaponics that is still new and have been much debated. Today there exist different methods of sizing up the aquaponic system, still most being closely tied up to one ratio, the feed rate ratio[47][6]. Related to the feed rate ratio, there are mainly two methods that show promise, the UVI/Rakocy method and the aquaponic solution/Lennard method.

Research conducted by James Rakocy where he says it can be based on the feeding rate ratios. Where *the feeding rate ratio is the amount of feed fed to the fish daily per square meter of plant growing area[45]*, but this varies depending on a multitude of factors. Such as the type of fish grown, bacteria colony, the pellets used to feed the fish, the frequency of the feeding, the system design, chemical composition of the water, type of plant being grown and the plant bed[43]. The method developed by Rakocy is only an approximation where they recommend a ratio of 60-100$gfeed/m^2$ of plant growing area[47]. It is not clear how transferable the already existing studies are too dissimilar plant production systems, and growers are often forced to use their best estimate in determining the optimum ratio for their system. Ideally, for a large commercialized facility, empirical evidence should be obtained to achieve full effectiveness and avoid the mentioned downfalls. Unfortunately, current methods used to collect these data requires experiments that would take months to complete. On the contrary, determining faulty balancing would be easily achieved, by simple visual inspection or by the help of cheap equipment.

2.4.4 Hydroponic subsystems

The hydroponic subsystem or the hydroponic growing bed system is the media the plant are placed within. The different system discussed below all offers advantages in various degree depending on independent uses. Today there are many different techniques, although the three main techniques widely in use worldwide are[6][38][48][43]:

- Media based growing bed
- DWC - Deep Water Culture
- NFT - Nutrient Film Technique

In hydroponics, there are two main techniques. Medium culture and solution culture. Solution culture is the cultivating of plants when there is no solid medium, only the nutrient water. Where again in solution culture, there are three main subsystems:

- SSC - Static solution culture
- Continuous-flow solution culture
- Aeroponics

In SSC, the water solution does not move, often a container or basket is used that easily can be aerated. Normally this type is filled with opaque material[2] to prevent algae growth by blocking the light from the root, before it is placed in the water[49]. The water is carefully monitored, and when the nutrient level drops too low, the water is changed, or there can be a

[2] A material that prevents light from entering.

steady inflow of nutrient to the water. DWC uses this technique discussed in the next chapter. Continuous flow solution is as the name suggest a method where the water constantly flows through the roots of the plants. NFT discussed next is an example using this technique. The final system is the mist or aeroponics, where the roots are misted with a nutrient solution[50].

Media based growing bed

Media based growing bed is a solid media filled bed that can consist of e.g., gravel and clay[38]. The working principle is relatively straightforward where the nutrient filled water is fed in an ”ebb and flow” pattern. Media based growing beds would be suited for small scale aquaponic units as the substrate could be used as both mechanical and biofiltration. The filtration function is often the most common reason this type of system is chosen. However, with larger systems, the price quickly rises with increased maintenance, as the media would require frequent replacement due to clogging in the substrates[43].

A small scale system, would not benefit from high cost equipment requiring complicated management due to the small production that would give small or no financial gain. That is why if aiming for a private/home aquaponic system, the media bed system would be the ideal method due to the low cost and simplicity. Although the user area is important while choosing the growing bed another important factor to take into consideration is the plant species.

Nutrient film technique

NFT is a method where plants are grown in horizontal pipes at a slight angle, and the root system of the plants are submerged into the pipes where a shallow stream of nutrient rich water is flowing through[43] as seen in *fig: 10*.

Figure 10: Illustration of Nutrient film technique[51]

Unlike media beds, NFT would require a thorough mechanical filtration to avoid clogging of the pipes[6]. NFT fit both small scale and large commercialized scale system, it is also one of the easiest to operate as it is easy to clean and maintain in between batches and requires less energy and water than DWC discussed next[43]. The pipes however can not be too long, as eventually the oxygen and nutrient content would be depleted. The nutrient uptake may also vary, as the contact area between the roots and the water are small.

NFT has been successfully implemented in multiple projects and countries, such as Svinna, a company collaborating with the university in Iceland[38]. They are utilizing RAS technology together with nutrient rich wastewater as the nutrient source for growing tomatoes, lettuce, okra, and beans[43]. Many other companies can be looked into for further inspiration in the field. Nibio(Norway - Grimstad)[52], SME-ponica (Slovenia), Eureka Farming (Italy), are just a few examples[38]. It's essential that this is not a standard system, each system is tailored, which means that they are specially made with the resources available, Iceland is an excellent example since they benefit from geothermal energy that can be used to heat the water to the ideal temperature for whatever fish selected.

Deep Water Culture

The DWC - Deep water culture system similar to NFT is the cultivating of plants directly in the water. DWC also commonly known as the raft system consist of floating rafts in large water tanks, where the plants are inserted into the rafts, with their roots hanging in the nutrient rich water[6][43]. DWC is an example of a system that uses Static solution system. DWC can be used for both small scale and larger scale system, but are shown to be especially ideal for large scale production, and being very space efficient. Comparable to NFT, it is crucial with a thorough mechanical filtration prior to entering the hydroponic bed. Lack of solid waste management would result in waste settling at the bottom of the tank or at the roots which leads to an anaerobic state, starving the plants from oxygen and eventually death[6].

A large advantage over the other system is in the case of a power outage, pump malfunction or an other critical error, due to the size of the water tank, the plants are able to survive a certain amount of time without the continuous nutrient inflow. Obviously under sub optimal conditions with less growth effect, but the plants would survive.

3 Identification of Norwegian land based aquatic species

First, to specialize aquaponics towards Northern Norway, many factors must be included. The initial step is to look further into the Norwegian aquaculture and investigate the fish species that are grown in Northern Norway. From the literature review, it is clear that the production of juvenile salmon, trout, and cod all are popular production methods in the Norwegian aquaculture. Salmon is undoubtedly the most popular and common species grown in Norway, and naturally the source of the largest amount of waste. However, as will be seen is that salmon is only one of many species grown at the various Norwegian hatcheries and open pens today.

As of today, there are approximately six companies that have gained a permit to conduct land-based farming of fish for consumption[8]. This does not include hatchery production and juvenile production of fish to be placed at open sea farming. If we were to include these, there would be a much higher number.

When analyzing the various available facilities and thus trying to map the most popular species, obviously salmon is one of the most significant production units, but there are also many other species. This becomes clear when looking at the aquaculture register[53]. As of 28.01.2019, there are 19093 permits for both land-based and offshore aquaculture. By analyzing the register, it is apparent that salmon, trout, and rainbow trout are the most popular holding 5731, 5428, and 5510 permits respectively. Together posing 16669 or roughly 83% of the total permits[53].

However, this includes all aquaculture activity, both land and offshore. We are more interested in land-based aquaculture. By sorting the permits, it is clear only a small part of all permits are placed at the land — 2412 out of the 19093, or only 12%. Ideally, RAS equipped facilities are the most relevant. Unfortunate today, there is no recent official statistic for commercialized RAS facilities, and to check if a facility is equipped with RAS, each of the facility would be needed to be investigated separately. The previously available statistic was dated to 2013 where there were 23 facilities[8], but it is worthless today as modern RAS facilities are becoming more and more popular, and the amount of RAS equipped facility has increased significantly. Mapping of today's facilities is a process that is needed and way overdue. A tedious process of analyzing each facility and placing it into a register that needs to be continuously updated and/or monitored as more and more facilities are built, and old ones are shut down.

From the statistic the directorate of fisheries provided of available permits, it is clear that there are a lot of different fish species grown in Norway. One hundred eighty-nine different species are grown at the land-based facilities. However, out of these 189, it is three species that stands out.

- Salmon
- Trout
- Rainbow Trout

Table 1: Showcases the different species grown at the Norwegian land-based facilities[53].

Species	Data	
	Permits	Percent
Salmon	316	13.1 %
Trout	278	11.5 %
Rainbow Trout	299	12.4 %
Others (190 species)	1519	63.0 %
Total	2412	100 %

By investigating tab: 1, almost 70% of all land-based facilities hatches salmon, trout and/or rainbow trout. Then with the data above it is natural to base a Norwegian aquaponic facility around salmon and/or trout/rainbow trout. Supplementary with the accumulated knowledge from the literature review of the growing market for Norwegian seafood, especially salmon, it would only be natural to build an aquaponic facility with salmon as the building block. However, for the sake of the further work, futuristic opportunities, and biological similarities, both trout and rainbow trout are included and will be investigated further. To gain a broader understanding in the field of aquaponics, but also in terms of actually establishing the foundation for a future facility. Additionally due to most hatcheries producing more than one species basing the research on multiple aquatic species gives the thesis greater credibility and broader spectrum.

From the initial description, the thesis is directed to Northern Norway's aquaculture and agriculture. Which means it closely tied to already existing hatcheries established in Finnmark, Troms, and Nordland.

- Troms - 15 land-based facilities[54].
- Finnmark - 16 land-based facilities[54].
- Nordland - 63 land-based facilities[54].

It is especially in Nordland county there is a potential for building an aquaponic facility in combination with the already existing hatcheries even if both Finnmark and Troms have a substantial amount of facilities[53].

3.1 Future trends in The Norwegian aquaculture

A new trend seen in the last couple of years that furthers the potential of aquaponic facilities in Norway is the increasing focus on closed land-based facilities. It has been a considerable focus on increasing the fish size on land before placing into the traditional open pens at sea[8]. It is accomplished by moving the first phase of the fishes life cycle normally placed at sea, over to land. Meaning in addition to the smolt production in hatcheries, as the fish grows bigger, they are moved to a separate and larger tank under the classification as post smolt. Illustrated in figure:11 I)[55].

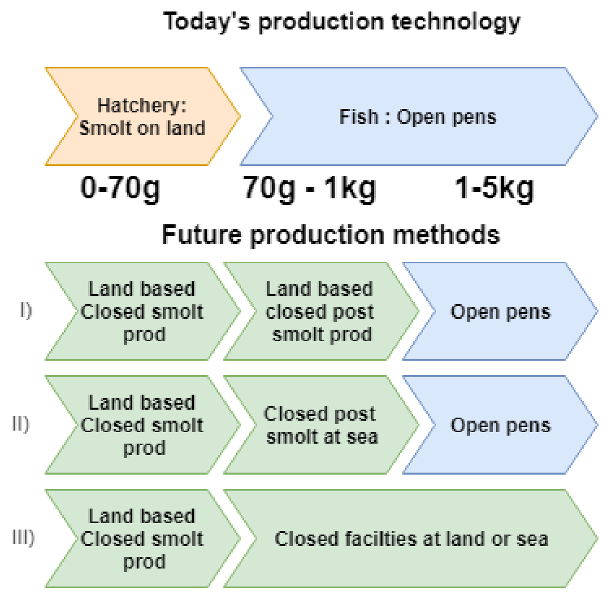


Figure 11: Today's and future production technologies[55]

"Salangfisk AS" is a good example. "Salangfisk" is a facility under the company Salaks that is located in Salangen in Troms. They are one of the companies that have implemented the new RAS technology, and through new and innovate ways are growing the fish to larger sizes than before(70-100grams), up to 250 grams before putting the fish in the sea. They are basically moving the first phase of the salmon life in the sea to land[56].

3.2 Salmon - Trout - Rainbow trout

Figure 12: Illustration of Atlantic salmon[57]

Atlantic salmon, trout and rainbow trout, all belonging to the Salmonidae family, or more familiar the salmon family. They are classified as an anadromous fish species, which means they are born in freshwater, then migrates into the ocean as they become juvenile[3]. The life cycle of wild salmon and farmed salmon are however slightly different. The farming of salmon requires both saltwater and freshwater operations, but proper management of the farming process accelerates the life cycle of the salmon to 1 year or less in freshwater, and 10-15months in saltwater[58]. Since both salmon and trout are classified as an anadromous fish species, it complicates the growth process. Today, the fish usually begins their life cycle in freshwater hatcheries, and are in a later stage transferred to seawater facilities. However, the scope of my thesis will be directed to the freshwater operation, due to saltwater aquaponic being an extension of normal freshwater aquaponic, which would require even further consideration.

Most fishes are categorized as ectotherm. It is fish that relies on the ambient water temperature to control their temperature. Ectothermic fish can not use any internal process to regulate their temperature, unlike endothermic fish that can, such as tunas and some shark species, which means they are at the mercy of the environment[6][59]. Trout, rainbow trout and salmon all are categorized as ectotherm, and the temperature has to be continuously monitored and kept at satisfactory levels to uphold optimal growth and avoid unnecessary deaths.

As learned from the literature review was that to operate an aquaponic facility good filtrating, mechanical- and biofiltration, was required. The filtration is crucial due to all the waste fish expel. It is the nitrogen that is most relevant which can be seen expelled in three ways[6]:

- Ammonia from gills.
- Large production of diluted urine through the vent in a process called osmoregulation[3], especially important for freshwater fish.
- Solid waste through the vent.

Water quality is a major theme in aquaponic and will be discussed further in the next chapter. What is seen is that it's important to monitor the water, as high levels of ammonia in the water cause the fish to have trouble diffusing the ammonia through the gills, which can result in a high concentration of ammonia in the blood, that eventually causes death. This does also relate to one of the major concerns and challenges in land-based aquaculture today, a high mortality rate.

3.2.1 Growth stages of salmonidae

As seen in chapter: 2.1.2 the fish resides in three facilities dependent on where they are in their life cycle. The life stages of the fish are categorized dependent of the size of the fish and understanding the classification at any given time is important due to based on the life cycle of each aquatic species, the nutritional requirements changes.

- egg
- Larvae
- Fry
- Fingerling/parr
- juvenile
- Adult fish

[3]Highly important process that maintains the salt and water balance in the body[60]

- Adult fish (broodstock)

The two first phases of the fishes life cycle are the egg and larvae stage, during these stages the fish do not consume any external food, but rather get their nourishment from the egg and an attached yolk sack respectively[6]. The following is the fry phase, which is the stage where the eggs have hatched, turned into a larvae, and can start feeding themselves. After the fry stage, the fish enters the juvenile stage, which lasts until the fish is fully grown and can produce spawn themselves. In the juvenile stage, the fish first becomes fingerlings or parr, which is where the fish have developed scales and fins. After the parr stage, the fish are classified as juvenile as it grows, and after a while into full grown salmon. Subsequently, the fish becomes broodstock, which means they have reached sexual maturity. This is the final stage, and fishes growth drastically stops as most energy is devoted to developing sexual organs[6]. The different categories normally have to stay isolated
The duration the fish spends in each stage are dependent on the species and the growing conditions. The different fishes do also have different adolescence, salmon, for instance, undergoes a physiological development for life in salt water in a process called smoltification in the juvenile stage, thus being classified as smolt[61]. Naturally, not every stage would benefit an aquaponic facility. Obviously, during the egg and larvae stage the fish do not produce enough waste for the plants. However, during the fry, fingerling, juvenile, and adult phase, the fish produces waste with increased benefits for the plants the further the fish gets in their life cycle

3.2.2 Analysis from Smøla hathery

This can also be seen from data collected from Nofima that have analyzed the content of the waste from various RAS facilities for smolt production[62]. Including waste from Smøla hatchery in Smøla, Marine Harvest facility at Tusna and Nofima facility at Sunndalsøra. The nutrient content was analyzed in which the dry matter, main nutrient content, and minerals was unveiled. Interesting about this project was the variation in dry matter and energy from the various facilities, but also within the same facility at different times.

Smøla hatchery, for instance, are mainly producing smolts to be put in the sea at spring (April), and in the autumn (September/October), naturally the highest amount of waste is produced in the weeks/months before the salmon are transferred to sea, and less amount in October- February and May - July. By analyzing data collected from three of their hatcheries, SMØLA 1, SMØLA 2 and SMØLA 3 in the period of 2010-2011, it is a clear difference between the waste output at different times during the year (see figure: 13,14 and 15). In Smøla 1, where the fish grows to 5 grams which is is the first phase after hatching, the waste output naturally isn't very high, while in Smøla 2 and Smøla 3, which is the growing tanks the waste output is significantly higher.

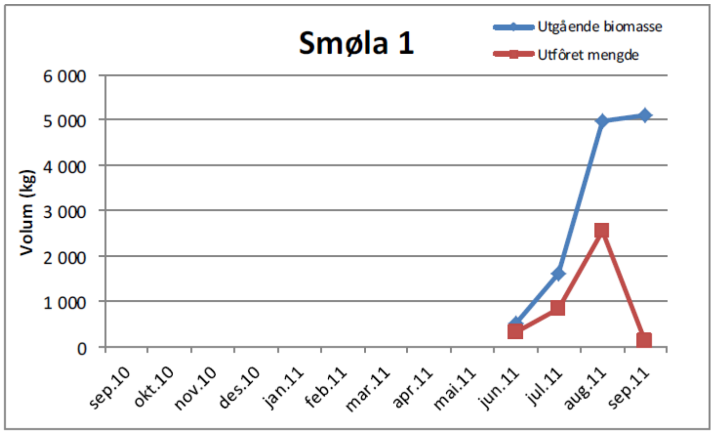


Figure 13: Amount of feed, and associated waste from feeding fish fry up to 5 grams[62]

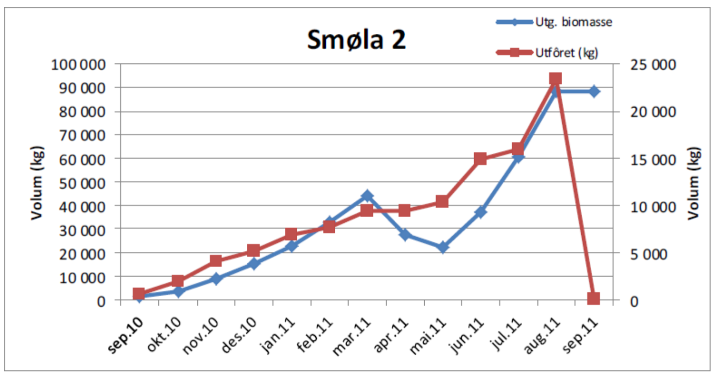


Figure 14: Amount of feed, and associated waste from the growing tanks[62]

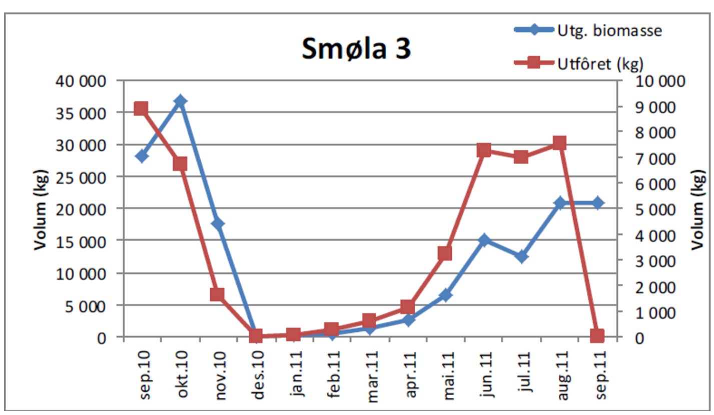


Figure 15: Amount of feed, and associated waste from the growing tanks[62]

3.3 Fish feed

When conducting aquaculture activity, it is imperative to make sure that the fish gets both the right and enough nutrients to grow and promote optimal fish welfare. Feeding the fish might seem simple enough, but on the contrary, it is a highly complex process. It is important to maintain an optimal appetite for the fish, independent on factors such as environmental changes, temperature changes, lighting condition, and stress, which all can affect the appetite. It is also one of the most expensive inputs in an aquaculture facility[6], together with being one of the most important components for the entire aquaponic ecosystem as it is the main feed for both the plants and the fish. The fish requires a balance of various nutrients such as:

- Proteins
- Vitamins
- Minerals
- Lipids (fats)
- Carbohydrates
- Energy
- Amino acids

There is a reason why fish cultivated in aquaculture systems grows substantially faster than wild fish. It is due to the difference in the feed, while wild fish feed on other aquatic species, captured fish are fed formulated feed tailored to fit their specific needs to promote optimal growth[63]. Where fish pellets have very different nutritional values than wild prey, it is clear that nutrients and energy are crucial for fish growth. Fish are also known to utilize proteins better than other nutrient sources such as carbohydrates and lipids, resulting in protein to be known as the main building block for optimal fish growth[64]. However It is important to understand that like all fish species, they do not have a specific protein requirement, but instead requires the essential amino acids that protein are made up of[65]. The fish themselves can produce some of the amino acids, but some have to be added supplementary in the pelletized fish feed[66].

3.3.1 Protein requirements

However good it is to grow salmon and trout, they possess a vital feature making it ideal for aquaponics. Trout and salmon requires a very high amount of protein compared to other aquatic species. Comparing for instance trout and salmon to other widespread aquatic species grown around the world. it is a clear difference in protein requirements *See tab: 2*[67][68][69][70]. Especially in the fingerling - small adult phase that are most relevant for an aquaponic facility. With the increased protein amount added, there is an increased nitrogen emission into the water due to ammonia being the main end product after protein metabolism[14]. Which again results in an increase in cultivable plants.

Table 2: Protein % in different aquatic species, data is collected from FAO (Rainbow trout, salmon, tilapia and common carp)[67][68][69][70]

Crude protein % in fish feed					
Aquatic species	**Life stage**				
∼Grams	**Fry (0.02-1g)**	**Fingerling(1-10g)**	**Juvenile(10-25g)**	**Small adult(25-200)**	**Broodstock(>1500g)**
Trout	45-50%	45%	43%	42%	35-40%
Salmon	50-55%	45-50%	45%	42-45%	45%
Tiliapa	40%	35-40%	30-35%	28-32%	40-45%
Common carp	43-47%	34-37%	34-37%	28-32%	28-32%

The weight of each stage varies from fish to fish, and from species to species. Therefore the weights provided in the table are not considered accurate. They are just provided to give an overall idea of the weights of each stage. Especially when we know that fish typically are transferred to open pens when they reach approximately 70g in the growing phase after the smoltification process is completed(50-80grams). This does also vary from the producer to producer, as some, for instance, Salangfisk, are keeping the smolt in the land-based facilities until 200grams (*see sec: 3.1*[56]).

3.3.2 Pelletized fish feed

In Norway, four main producers deliver high quality feed for the aquaculture - EWOS, BioMar, Skretting being the biggest[71], and Polarfeed, a slightly smaller company. Common for the various companies is that they yearn for an optimal nutritional value for the fish. They are known for their high quality of fish feed, with years of experience ensuring a healthy and problem free production. Even with these producers available, it is still a viable option for each aquaponic producer to produce their own feed, with the help of the ratios published and available from FOU, or other available research. However, this requires a substantial amount of work, and would in most cases only be beneficial in some rare cases of a small aquaponic system. Therefore in most cases, it is best to purchase from the already well established and trusted producers we have available. Also, in a larger system, depending on the production stage as discussed in section 3.2.1 it should be a carefully planned diet fitted to the individual fishes growth potential to maximize the daily energy intake[72].

3.3.3 Feeding patterns of salmon and rainbow trout

One of the most important things when producing the feed is to understand the feeding habits of the aquatic species. This is due to there being many different types of feeding pellets. BioMar and EWOS, for instance, have custom made feeds in the transition phase, for RAS systems, feed made to either float or sink depending on the porosity, or special feeds in extraordinary situations such as stressing conditions, for countering sea lice or to counteract diseases[72][73].

Trout and salmon in aquaculture are fed formulated feed[4] through their production cycle. Most of the feeds are manufactured by the help of extrusion technology, a technology that

[4]Formulated feeds are feeds that are specially made to maximize the yield, and increase the fish size in a short period.

prolongs the floating time or reduces the sinking time of the pellets.

The pattern and frequency of the feeding various from the sizes as well as the water temperature. The smaller fish has larger metabolic rates and therefore needs more frequent and more feed relative to their weight. Since salmon and trout are cold blooded, their body temperature and thus their metabolic rates vary with temperature in the water. However, as a guideline, the first feeding fry, should be fed continuously. The fry should be fed eight times per day as soon as possible after this first stage. When the trout reaches 1-2grams, it should be fed 4-5 times per day, to 2-3 times when it grows larger than 5grams. The feeding habits for salmon is very similar, where it is fed 8-12 times in the first stage and reduced to 3-4 times for fingerling and parr.

However, the feeding must always be monitored. Even if overfeeding might seem like a secure way to ensure the fish gets enough nutrients for optimal growth, this is not the case. Excess feed not consumed by the fish will decompose in the water and use oxygen, increase the levels of ammonia in the water, and potentially clog the mechanical filter. All of the above can possibly have a severe negative effect on the fish population[6].

3.3.4 FCR- feed conversion ratio

With basic knowledge of the feeding of the Atlantic salmon and trout, an important ratio is introduced. The FCR- Feed conversion ratio. It describes how efficiently an animal can turn the feed into growth[6]. Fish has one of the best FCR, where species such as tilapia have an average FCR of around 1.7. The FCR of salmon and trout can vary but are much better than tilapia. What is seen is that Norway has one of the best FCR for salmon and trout farming, where Atlantic salmon have an FCR of 1.0-1.4 (average value 1.2) where most other salmon farming countries have around 1.2-1.5. For trout Noway have an FCR of around 1.1-1.3 (average value of 1.2)[74]. Meaning to produce 1 kg of salmon you need 1.2 kg of fish feed. Salmon is known to have a very low FCR compared to other species. The ratio often reflects the quality and digestibility of the feed.

4 Water effects in aquaponic

The water in aquaponic is vital and is said to be the lifeblood of the system, and understanding how it affect the system is essential[6]. In the cultivation of fish and growing of plants, both water quality and water temperature plays a leading role. The water affects every part of the system, which later will be clarified throughout the text. Since the system combines both plant and fish production it has exceptional water chemistry requirements, and monitoring and making sure that the water is at an optimal level for every part of the system is crucial to maintain a healthy and functioning system[75]. As simple as it might seem to make sure the water is at optimal levels for both the plant, bacteria, and fish, it is a complicated process and requires expert management, treatment, and constant surveillance. The initial step already begins outside of the facility by choosing the source water. The source water can range from well water, municipal water or surface water[75], but Norwegian hatcheries are almost exclusively using surface water as the source[76]. Either way, wherever the water originates from its essential to have it checked for contamination and that it meets the requirements of both the fish and plants.

Newly established aquaponic systems need to be tested daily, in case adjustment needs to be made. Once the nutrient cycle is balanced testing can be done less frequently, such as weekly tests depending on which tests are carried out. The testing of the system should be recorded and documented at all times[75], as it helps in analyzing trends and comparing weekly levels to avert the potential of future problems. Worth noting is that sudden changes in fish stocking, density, growth rate, feeding rate or water volume are typical reasons for changes in the water quality[77].

Fish raised in aquaculture and aquaponics require excellent water quality, and making sure the water is optimal is imperative. Different water quality parameters have to considered in the operation of an aquaponic facility, but it can be limited to five main ones that constantly needs to be optimized. These includes, but are not limited to[77][6][75]:

- Temperature
- Dissolved Oxygen (DO)
- pH
- Ammonia
- Water alkalinity

4.1 Dissolved oxygen

All of the parameters plays an important role in maintaining a healthy system. Perhaps the most important one is the DO - Dissolved oxygen[77], not only for the fish, but for all the three organisms involved in an aquaponic facility. The DO level describes how much oxygen there are in the water. DO being one of the water quality parameters that, together with the others, have the largest effect on an aquaponic system. For instance, in the nitrification process, the oxygen is a critical factor as it is an oxidative process, which means oxygen is used as the chemical reactant[6][75].

An important reason fish perish in an aquaculture system is due to the lack of oxygen, which again is due to a loss of water flow[78]. Therefore keeping the oxygen at optimal levels is essential in the operation of an aquaculture system, but when adding plants and bacteria in an aquaponic system, it gets even more critical, as the oxygen level does not only affect the fish but the bacteria in the biological filter and the plants. Estimating and monitoring the oxygen level is a huge and essential part of aquaponics. Unfortunate measuring the DO in the water requires equipment that can be both expensive or hard to come upon[6]. However, there are alternative ways of measuring the DO. The fish and plants can be continuously monitored, and checked for abnormal behavior. This is though not recommended for a larger system, as the consequences of a faulty DO level is very high, and it would be better to invest in the necessary equipment in this case. Either way, expert management in this field is required[78], but this is outside the scope of the thesis, which instead focuses on the waste emission, and the implementation of fish and plant production in Northern Norway.

In normal conditions, the natural oxygen absorption through the surface would be sufficient for the fish to survive, however in very dense fish cultures, the natural intake would be insufficient. For these cases, oxygen needs to be supplemented by using pumps or aerators to create air bubbles in the water[6]. It is important that the oxygen level is kept at optimal levels for all three living organisms. For cold water fish such as trout and salmon, the oxygen levels should be kept higher than warm water fish of about 6-5PPM (mg/liter) to ensure optimal welfare[6][79]. Even though fish can survive with lower values for a short period it is always recommended to keep the levels above 5PPM at all time, as there is no risk of adding too much oxygen, since excess oxygen will dispense out of the water[75].

Salmons and trout being cold water species have difference DO requirements than warm water fishes. For typical warm water fishes, it is recommended to keep the DO level above 5ppm, while for cold water fishes it is recommended to have a higher DO level above 6-7[79]. It is also recommended to have the oxygen saturation of salmonoids of around 70-80%, as lower slows down the fishes growth and higher levels increases stress and chance of diseases[79].

4.2 Water temperature

Temperature is the most important parameter that will be considered in my further thesis work. The temperature plays a vital role on its own, but it is also essential to consider how it affects the other water parameters. The temperature is for instance, very closely tied to the oxygen levels in the water, The warmer the water, the less oxygen the water can hold[75][77]. Together with the other parameters, it affects all parts of the system, and it is essential that the temperature is tailored to fit the specific fish, bacteria and plant in the system. The temperature is a fundamental matter, and due to the electricity cost of heating/cooling down the water, it is important that the fish, bacteria, and plant have an aligned temperature match.

4.3 pH

The pH alike the other parameters is important; it describes how acidic or alkaline the water is. pH is ranged from 0-14, 0 being highly acidic, and 14 being alkaline[75]. The pH affects many of the other parameters, as will be seen in the next sections. It is not only the fish that are affected by the pH level in the water but the plants as well. In the same way as with the temperature and DO, it is dependent on what type of plant and fish that are cultivated. To give an idea of the pH level, tilapia, for instance, thrive in pH levels of 5,0-10, plants in a range of 6,0-6,5, and the bacteria in the nitrification process ideally above 7,5[75][6]. Keeping the pH levels at the right levels are just as important as the oxygen and temperature. If one were to keep the value too low in the biofilter (below 6), then it would result in the bacteria being unable to convert the toxic ammonia to nitrate and nitrite[75].

The challenge is keeping the pH at a specific level. Ideally, the pH would be held at optimal levels for all different parts of the system, but it would be a tedious process, and for most aquaponic system keeping the pH between 6-7 would suffice in most situation[6]. Still, this is only a general rule, and the bacteria, fish, and plant should be investigated for their optimal pH levels.

4.4 Ammonia

The ammonia level in the water that occurs from the fishes waste was discussed in the literature review where the importance of the nitrification was clarified, but it was only a brief introduction, and the biological aspect around the ammonia is of utmost importance to understand when running an aquaponic facility. The ammonia being expelled from the fish comes in two shapes, unionized and ionized[79], that together makes the total ammonia nitrogen (TAN) It is the unionized ammonia that is extremely toxic for the fish[75] and needs to be processed before reaching high levels to avoid wiping out the fish population. What we know about the water parameters are that they are all connected in some way, the same way the oxygen level depends on temperature, the ammonia concentration depends on pH levels and temperature.

The ammonia is at its crucial point when establishing the bacterial colony in the startup phase, also referred to as biofilter establishment or cycling[75]. The biofilter establishment is an essential step in an aquaponic system, and it often lasts until there are developed a steady level of ammonia and nitrite, and the nitrate level reaches the desired level (see figure 16). It is not possible to start growing plants until the cycling phase is finished. There are two ways to cycle, either with fish which takes 4-6 weeks, or fishless cycling by adding ammonia compounds to the water and letting bacterial colonies develop in response which usually takes 2-3 week[75]. Fishless cycling might be advantageous above cycling with fish because it is no risk of accidentally killing the fish during the process, and it only takes half of the time. Unless the fish needs to be added instantly fishless cycling gives better security, and enables to grow crops in the hydroponic part of the system faster.

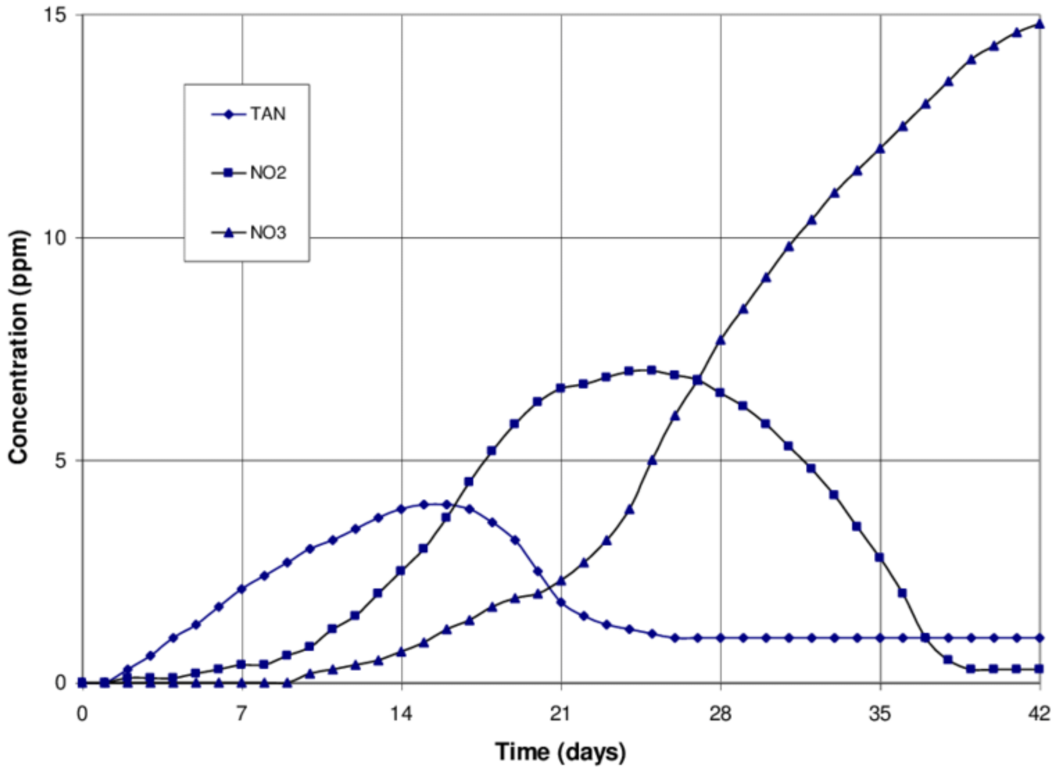


Figure 16: illustration of establishment phase of a bio filter[79]

It is uncertainty related to the ammonia levels and what levels are considered safe. No safe levels are defined, but FAO has recommended 0.025 mg/L as the maximum unionized ammonia(NH3) concentration[78]. A TAN level of 1mg/L is recommended for cold water fish, and 2-3 for warm water, because cold water fish such as salmon and trout are more sensitive to ammonia in the water[78]. In most aquaponic system existing today, it is important to measure the ammonia level in the water regularly. Even though it is the toxic ammonia that is important to keep control of, most water measuring device today are only able to measure TAN - Total Ammonia Nitrogen[75][6]. Both the ionized and the unionized ammonia combined. Even though the water test kits are unable to measure the unionized ammonia, it can measure TAN, which together with the temperature and pH can be used to calculate the unionized ammonia levels[75].

4.5 Water alkalinity

The fifth of the water parameters is the water hardness, that again consist of two main types, general hardness and carbonate hardness, which is also referred to as alkalinity. For an aquaponic system, it is the alkalinity that has the greatest effect[6]. The alkalinity refers to the buffering capacity of the water and refers to the ability to resist changes in pH of a solution[75]. The water alkalinity needs to be accounted for when controlling the water environment, but will not be focused further on in the thesis work.

4.6 Optimal parameters

Optimal parameters are as explained previously, not a set solution but rather tailored to each independent system. Table: 3 shows the aquaponic water quality parameters for a system in general, tilapia one of the most popular grown aquatic species, salmon, and trout. However, as we have seen through the mapping of the aquatic species, it is salmon and trout that are most relevant for Northern Norway's case. These possess other requirements than most other aquatic species. Comparing salmon/trout with for instance tilapia there are both similarities and differences.

Table 3: Optimal parameters[80][81][75][6]

		Aquaponic system in general	Tilipa	Salmon	Rainbow trout
Temperature	Vital	18-30 celsius	14-36	6-18	10-18
	Optimal		27-30	13	14-16
pH		6-7	7	6.2-7.8	6.5-8
Ammonia (TAN)		<1 ppm (mg/L)	<2	<1	<1
Nitrite		<1ppm (mg/L)	<1	<0.1	<0.3
Nitrate		5-150 ppm (mg/L)	5-150	<100	<100
Dissolved Oxygen		>5 ppm (mg/L)	>5	>6	>6
KH		60-140 ppm (mg/L)			

For nitrite and nitrate, the values are very similar. TAN and pH have some similarities, but warm water fishes are more tolerant to ammonia toxins than cold water fish, so the TAN levels should be held at lower levels for salmon/trout to be on the safe side. Freshwater fish are also more tolerant to ammonia toxins, which has to be considered in the smoltification process when the producer transfers the salmon and trout into saltwater. When analyzing the temperature and DO. From the table salmon and trout thrives in colder water than both tilapia and general aquaponic systems. Proving that salmon and trout grown in northern climate is ideal. This conclusion can easily be drawn, as trout and salmon by far are the most popular aquatic species in Norway as seen in *section: 3*. The DO is confirmed to vary from tilapia, but then again the DO levels are very connected to the temperature, and the main difference between the fish is the different temperature preferences, thus naturally the DO will vary.

To ensure that the system is healthy and operates as intended measuring both the TAN, pH, and temperature regularly is an important task in the operation of an aquaponic facility, especially in the startup phase, when the values tend to fluctuate. The pH levels in most cases decrease daily in response to the nitrification process and should be monitored daily, and appropriate action should be taken if the levels drop to low. Keeping the temperature at a suitable level is luckily easy, both to measure and to adjust if needed. Therefore measuring the temperature should together with measuring the pH be done regularly. Unfortunate it is a costly and energy-intensive, as the amount of water needed to be heated normally is very large, especially in large commercialized facilities.

5 Nutrient content of fish waste

Developing a thorough understanding of the nutrient content of fish waste are crucial before developing an aquaponic facility. The values can be used to determine the type of plant viable to be grown together with salmon and trout. Additionally, it will determine how much added nutrients would be required to fulfill the chosen plants needs. All of which will be discussed in the later sections. The nutrient value of the waste will vary dependent on feed content, water temperature, water quality, pH level, aquatic species, and rearing size. Some of which discussed already.The principle of the fishes nutrient cycle are explained in *Figure: 17*.

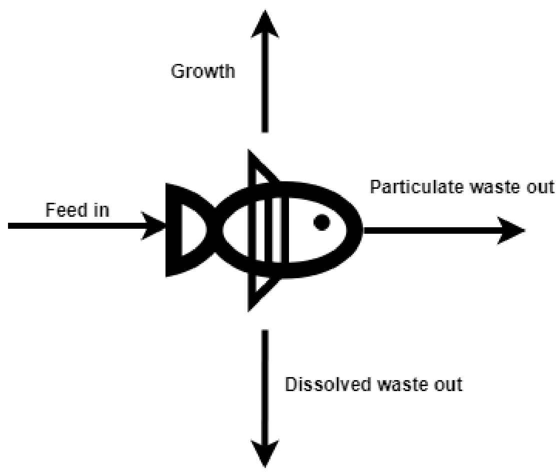


Figure 17: Principle of waste process in fish[63]

The main elements released from fish farming was briefly touched in the literature review. It consists of carbon (C), nitrogen (N) and phosphorus (P)[82]. From these fish release the nutrients in three ways. As dissolved inorganic N(NH3+), and P(P04 3-) (DIN and DIP), released as excretion. Particulate organic nutrients in solid form, where the particles of C, N, and P (POC, PON, POP) are released mostly through defecation and the feed waste. Then finally, as dissolved organic nutrients (DON, DOP) through the dissolution of the solid particles[82]. In an aquaponic system, the solid waste (fecal waste, uneaten feed) needs to be removed before entering the hydroponic bed, as an accumulation of these particles will deplete the DO level as it decays, and in worst case if the sludge decomposes anaerobically it can produce methane and hydrogen sulfide which is highly toxic[83]. The suspended solids (SS) however are more interesting, as they have a role in an aquaponic system, if the SS would enter the hydroponic bed they may accumulate on the plants root system, which can prevent the plant from getting enough nutrients. Then again, a small accumulation of the SS can be beneficial due to the mineralization process mentioned in section: 2.4.2. When the solids decompose, they release valuable nutrients into the water, and without these a larger nutrient supplementation is required[83].

There are limited empirical knowledge/data of the content of the wastewater from new, modern, and larger hatcheries. The existing knowledge is mostly outdated, and would not be accurate due to the content of the waste varying a lot dependent on the feed, rearing size, aquatic species, among others. The content of wastewater is highly variable. It depends on many parameters. Interesting is that studies show that the waste quantity is directly linked to the temperature[84][85], and that higher temperature increases the rate of metabolism that again increases the waste output. Other components in the waste are feed-derived waste, antibiotics, and some hormones[85][86]. Where the feed-derived waste are found in two states either dissolved or in a solid phase referred to as suspended solids, that contains elements such as phosphorous - P and nitrogen - N. These solids are known to carry 7-32% of the nitrogen and up to 30-84% of the phosphorous, where the rest is carried out in a dissolved fraction. In other words, it is the dissolved wastewater that carries the most significant part of the nitrogen emission, and smaller part phosphorous, while the solid particles carried the largest part phosphorous, and a lower part of nitrogen[82].

The sludge production from a given hatchery are proportional to the fish production, which also is linked to the amount of feed used in the production. The sludge content needs to be analyzed carefully, as the content are dependent on how much feed wastage there are in a given facility. From chapter 3.3 the nutrient content of the fish feed was determined which has to be included in the determination of the sludge content, mainly since the feed and the fish waste contains slightly different nutritional values. Fish feed, as seen, contains high amounts of proteins and fat, while the fish waste contains high values of minerals and carbohydrates. The amount of waste output from the aquaculture can, however, be calculated through mass balance models such as a model based on statistical information about the feed and fish production. This, together with details about feed loss, N and P components in the feed and the fish [63]. This method is proven to be accurate for N, but gives a higher uncertainty for the P components. Another approach is to estimate the waste output through dynamic metabolically based modeling of the fish, feed, growth, and metabolism[63]. Most of the mass balance models are however more directed to open system[87]

Included in the mass balance models is a highly relevant parameter, the maximum fish density. The fish density, are dependent on fish size, species, and characteristic of the rearing environment and management skill[78]. Normally it is set between 10-25 kg per square meter[6][88]. However, it should only be used as an approximation, as maximizing the density are highly profitable if done correctly. Which also will be used in further calculations to determine the profitability of the hydroponic bed. However, further consideration are not included as part of the thesis work.

6 Plants

The plants in an aquaponic system are equally important to the fish. The literature review briefly described the plants in the aquaponic ecosystem. With salmon and trout identified as the ideal Norwegian aquatic species and with documented living condition, nutritional requirements, and nutritional output, the decision of the most suitable plant species can be initiated. Many factors have to be satisfied, and choosing the plant depends on both technical possibilities, biological factors, economic viability, environmental , and product demand.

6.1 Economic possibilities

When cultivating and growing plants in an aquaponic system, it is a large economic potential, and the economic aspect is one of the most important to consider when developing an aquaponic system. In many commercialized facilities existing today the plant aspect is equally or even more profitable than the fish part. Indubitably not the case for all farmers, and the high demand and price of salmon would be hard for the plants to compete with. On the contrary, this does not mean the plant production will be insignificant as it will give a substantial increase in the revenue in an otherwise unused part of the system. For instance, to get an idea of the potential profit, the Norwegian company Nibio predict the plant part of the system giving up to 60% of the economical gain[52].

When looking in an economic perspective choosing the plant and fish on the same temperature level is very important, and choosing plants and fish adapted to the local climate are in many situations best, but not necessary which will be investigated through the further chapter. For a facility to commence a profit, all variable and fixed expenses must be added and subtracted from the total income, indicating the total profit[89]. Investigating ”windows of opportunity” (the favorable period for selling crops or fish) might provide the process with an increased income and thereby increased profit. Either way, with the increased dependency of aquaponic, fish plant and bacteria all interconnected, increases the potential revenue but also increased the risks.[89].

6.2 Soil- less agriculture

In the literature review, arctic agriculture was reviewed. Two main types of systems were discussed, soil based and soil less agriculture. Even though the two methods are entirely different, they still share some similarities, such as plant biology. One challenge related to farming outside/indoor in the soil is that as a farmer, you are not entirely free to choose the type of product. Some of the more traditional Norwegian grown crops will be revealed in the next section, but as will be seen is that the plants are limited by the effects of the soil and the Nordic climate, and many crops are not growable in the cold environment. Norway has a low arable land percent compared other countries (2.2056% farmable land) and due to the areas topographic, most of the farms are scattered on many different small patches[90], which means that for Norway to produce enough on their own, artificial farming is a must. Soil less agriculture doesn’t affect the nutrients uptake to the plants as the plants root are being directly submerged into the nutrients solution. Making it a lot easier to explicitly create a nutrient pool that is ideal for the plants[6][33].

By implementing indoor soil-less farms, shielded from the environment, effects such as climate pose minimal effect, it is possible to farm a much larger variety of plants, and the challenges with soil are removed. The production rate significantly increases with a higher yield (20-25% increase over soil based) due to the roots being directly submerged into the nutrient pool where farmers have full control over the nutrient intake of the plant[6]. However at the expense of higher costs. Both management and initial setup costs. It is clear that soil-less agriculture is the future and the only way to go for Norwegian agriculture. The challenge is the cost. It requires a very high investment cost, and by combining hydroponics with aquaculture, it makes a system even more expensive and harder to control. Requiring expertise management, and high reliability of electricity as an error can wipe out the entire fish population and plant batch. On the contrary it is only the initial phase that is challenging. The planning, building of the system, and teaching the employees the routine are very costly. Once this first phase is over, the aquaponic facilities become operational, and the employees learn the routines, the operation of the facility becomes easy[6].

6.3 Plants nutrient values

Before optimizing a new crop for commercial use, there are several growing conditions and selection of genotypes that are required[85]. It was earlier stated that there are two major categories of plant nutrients, macro-nutrients, and micro-nutrients. Both compromising of 16 nutrients. The macro-nutrients are the elements that are required in a relatively large amount and are said to be consisting of nine elements[38][6][83].

- O - Oxygen
- H - Hydrogen
- C - carbon
- N - Nitrogen
- P - phosphorous
- K - potassium
- Ca - calcium
- Mg - magnesium
- S - sulfur

The oxygen, hydrogen, and carbon are supplied by the water and atmosphere, also known as structural elements. The following three commonly referred to as the fertilizer elements or the primary macro-nutrients are the nitrogen, phosphorous, and potassium. Calcium and magnesium and sulfur are the secondary ones. Then there are the micro-nutrients. Seven main elements are required by the plants but in a much lower quantity.

- Iron
- Manganese
- Zinc
- Copper

- Boron
- Molybdenum
- Chlorine

The scope of the thesis does not cover how every nutrient affect the plant, but what is seen from *sec:5*, is that through the dissolved wastewater and degraded solid waste from the fish the nitrogen in the form of nitrate following the nitrification process is the major element, together with smaller levels of phosphorus. It is from the dissolution of the solid waste most of the remaining nutrients together with phosphorous derives from. This is a secondary operation of the biofilter, where particulate matter and dissolved waste are processed[91], Both operations being imperative in an aquaponic facility[91].

6.3.1 Added supplements

It's important to understand that a clear formula does not exist for the nutritional value for a given plant/vegetable and that it depends on a high variety of requirements, such as the life stage of the fish and environmental conditions[91]. However, trends from existing facilities, is that there are some nutritional deficiencies, especially for potassium, calcium, iron and sometimes phosphorous[91][6]. Only due to fishes having very different nutritional requirements than plants, and that fish feed is specially made to fit the fishes need, not the plants. Iron, potassium, calcium, and phosphorous are not required in the same amount for fish, as it is for plants. It is especially potassium and calcium that are the main nutrients needed in a much larger degree in plants than in fish[47]. In these cases, when deficiencies are measured or seen through inspection, it's necessary to add these in the nutrient solution. Something that very easily can be done by including an additional nutrient pool by using a DAPS system, as discussed in chapter: 2.4.1. In section: 4.4 it was clear that the biofilter needs some time to establish a bacteria colony, and during this time there may be a need for supplements, as the plant most likely will suffer from nutrient deficiencies. Alternatively, while the biofilter is adjusting and building up the nitrate levels(as seen in fig: 16) plants requiring lower nutrient levels, or a lower amount of plant should be considered implemented to avoid underdeveloped crops. However, even after the aquaponic system and the biofilter are balanced, the plants may suffer from nutrient deficiencies.

As stated, there can be a need to add supplements as the wastewater are not able to provide sufficient nutritional value for optimal plant growth. With this discussion, it should be weighted if it is worth doing it. Plants with short cropping cycles such as various types of lettuce might not need added supplements[91]. As stated for salmon and trout, the largest amount of waste and feces are produced in the months and week before the transfer to sea. This can be seen from SMØLA hatchery analysis in *sec: 3.2.2*. Here it was stated the highest amount of waste was in April and September/October[62], and naturally, the plant production should be adapted for this. While added supplements might be needed in the low production months (October-February and May-July).

The water quality parameters were discussed in section: 4 on both a general basis and for the Norwegian aquatic species. The water parameters for plants, however, do have different requirements than both the fish and the bacterial colony in the biofilter. Without going into further detail, it should be noted that the pH and temperature do have the most significant impact on the nutrient uptake for plants. pH levels should be the most important parameter and should be kept at between 5.5-7.5, while the temperature varies a lot depending on what plant and vegetables are grown[6].

6.4 Crops

Choosing the plant to be grown in Northern Norway is no easy task, it has to be suitable with the nutrient values of the waste produced by salmon and trout, and with relatively matching conditions(temperature/pH/oxygen, etc.). Additionally, the social and economically aspect need to to be considered. Meaning the plant products needs to be profitable and demanded by the local actors and customers. Today there are more than 150 different plants that already have been grown successfully in aquaponic[6]. However, from known research leafy green plants, and fruity plants such as tomatoes, cucumber, and peppers do well in aquaponics. With the broad quantity of possibilities, the plants can be divided into two main categories

- Low nutrients demanding plants (examples)
  - Lettuce
  - basil
  - parsley
  - leafy green herbs
- High nutrient demanding plants (examples)
  - Tomatoes
  - strawberries
  - peppers
  - botanical fruits

Additionally, some vegetables require a ”medium” amount of nutrient that can be placed in either category such as cabbage or broccoli. Plant selection for economically viable food production for Northern Norway discussed in further detail in 8

It should be noted that naturally that there are some plants that do better in aquaponics than others, both in an economical and biological sense. Typically root vegetables do bad in a hydroponics system and grow better in soil, these include, potatoes, yams, turnips, onions, carrots, etc. The same goes while looking in an economic aspect. There would be no gain in growing plants that would give a low return on investment. Plants that fall in under this category is radishes, some lettuces and greens. Although these are not recommended, they should never be written off as an alternative as there may exist niche markets paying above market prices for off-season crops. Another factor that might pose a challenge is space restrictions. Large fruit trees or nuts fall into this category, the size of the reservoir and the facility would be huge to house to the root system and the plant itself[92].

6.4.1 Harvesting cycle

There are immensely many factors that have to be considered. The harvesting cycle of the plants is one. Harvesting all of the plants at once would result in an unbalanced system. The fish would continue to create biomass, and the biofilter would continue to produce nitrate without the plant part being present to utilize the nutrients would be a very wasteful process. In the very end of the plant life cycle, they would require a higher amount of nutrients something that could cause nutrient deficiencies as the fish would be unable to provide enough of all of the necessary nutrients. Various methods could be utilized such as harvesting the plants together with the fish, or in otherwise low biomass production period. However, the recommended method is to use staggered harvesting and replanting cycle[6]. Meaning having plants grow at different life stages, some mature, while some seedlings.

7 Aquaponic design

One of the major challenges is to successfully size up the amount of fish and the number of plants in an aquaponic system, the fish to plant ratio. Today there exist many different approaches to size up the ratio most being closely tied up to the feed rate ratio[47]. Two main methods show promise, Rakocy method and the aquaponic solution/Lennard method.

7.1 Feed rate ratio

A correctly designed and balanced aquaponic system, are based on the feed rate ratio[45], and it is the most successful way of balancing an aquaponic system[6]. It is a ratio that summarizes three important variables:

- The daily amount of fish feed in grams
- The plant type
- The amount of fish feed fed daily per m^2 plant growing area

Obviously when balancing the system, it is clear that the basic balance is between the waste output of the fish, and the amount of waste(nutrients) the plants require[47]. Although, not as easy as it might seem. From the statement, many connections can be made. It is clear that the amount of waste produced by the fish is highly dependent on the amount of feed fed to the fish. Then again, the amount of plants produced is also highly dependent on the amount of nutrients available, which again is dependent on the amount of waste produced by the fish. Therefore it can be said that the amount of feed fed to the fish is directly linked to the amount of plants produced[47]. Balancing the system is no easy task, even though the only predictable ratio associated is between fish feed and the number of plants, multiple variables have to be included. The capacity the system functions at, the aquaponic production method, fish type, fish feed, plant type, plant production method, environmental and water quality conditions, and filtration methods[6].

7.2 Design

Rakocy's method First of Rakocy developed a method that means to feed the fish enough feed, so that the level of all the nutrients except potassium, iron, and calcium are high enough for optimal growth. Which means this approach entails feeding the fish elevated amount of feed and supplementing the additional nutrients in carrying buffers. The main challenge with this is the excess nitrogen being expelled into the water. However, Rakocy solved this by the help of a denitrification[5]. The Rakoczy method shows great potential due to the high amount of fish produced in addition to the plants. Worth noticing is that Rakocy method is directed to growing tilapia, and it is not known how transferable this is to other species, and other crops, seasonal changes are not included either[46].

Lennard's method Then it is Lennard's method. It is slightly different as it means to feed the fish and produce plants in a way that the nitrogen is balanced. Lennard's method, however, showed that additional nutrients in addition to potassium, calcium, and iron were lacking, such as phosphrous[47]. Lennard approach enables the producer to predict the amount of fish feed and therefore, the amount of fish needed by growing a set amount of plants. Important to note is that Lennard's approach does not have a set feed rate ratio, as every plant and every fish have different requirements and their own ratios. Due to the method comes from balancing the nitrate, and some of the nutrients lacking, Lennard has enabled to utilize the solid waste through mineralization in a process called "offline aerobic solid mineralization"[93]. The method is simple and can be implemented with any RAS facility conducting solid filtration. It involves first separating the solid waste from the rest of the aquaponic system and placing them in a separate tank. This tank is filled with highly aerated water, where the solid waste will start to dissolve by aerobic mineralization. After the process is finished and the solid waste has dissolved, it can be added back into the system as supplemental nutrients.

Comparing these pioneers they are both completely correct in their research. If the system wants to be supplied entirely by itself, there will be excess nitrogen in the system, and if balancing the nitrogen, there will be nutrients deficiency. Rakocy provides a feed rate ratio on 60-100g/m^2 per day[47][6], where low feeding plants such as salads need around 60g/m^2 per day, while other higher demanding plants such as tomatoes or peppers requiring higher levels up towards 100g/m2/day. Lennard does not provide a set feed rate ratio due to the variation depending on fish and plant selection, and it is given in the amount of feed pr plant number (kg of feed pr plant). Rakocy method produces a very high amount of fish(more than any other approach) while Lennards is more specific and directed to large scale commercial production of plant and fish in particular conditions where each producer needs to choose what fits best for their system.

8 Aquaponic in Northern Norway

When the aquaponic system is directed to commercial use, a well carried thorough study has to be performed. It is clear there are high start up cost associated with an aquaponic system,

[5]Removal of nitrogen, by converting nitrate to nitrogen gas that flows out of the system[47]

and it can take some time before the producer gets a return on the investment. Therefore a complete mapping of the cost associated with building the system as well as running it needs to be mapped, in addition to the time it will take to start getting a return on the investment. Due to the system being connected to a very high initial investment, it is advised to follow already existing design guidelines. This is where we come to the part including Northern Norway. It has already been established that we in Northern Norway has multiple existing hatcheries that can be expanded to include a hydroponic system. Which saves a lot of capital as there are no need to build an entirely new facility, but rather change the design of already existing one. When discussing the further design, even how good it might seem to have a system outside utilizing the natural sunlight for Northern Norway it simply is not possible due to the environment (harsh weather, wind, snow, rain, and limited sunshine).

8.1 Food demand and security

As discussed the choice of crop to grow in the aquaponic system is not only dependent on biological and environmental matches, but also on social and economic factors, and the relationship of supply and demand. It is imperative to analyze the market demand before deciding on the agricultural product. Growing a low demanded and low priced crop would be a total waste, and result in food wastage and a considerable loss for the aquaponic system. Forecasting the market demand can be the difference between success and failure for many farmers, as both the sales and price are directly linked to the marked. Demand function can be utilized to predict the potential effect related to the farmers revenue[94]. In Norway, in recent years, the amount of locally grown food has increased significantly, as farmers and producers have shown great ability to innovate and reinvent farming techniques[32]. Exactly the case with aquaponics, allowing for an entirely new source of locally produced food, guaranteed food security and a supported local marked.

8.2 The Norwegian market

It is two important factors that need to be satisfied before choosing the plant in terms of the economic aspect, the demand of the plant, and price. Both seen from the figures below (with data collected from ”OFG - Opplysningskontoret for frukt og grønt” Information office for fruit and vegetables and kolonial.no one of Norway’s largest retail stores[31][95]):

Vegetable	Norwegian	Import	Total	Percentage imported	Sales (1000 NOK)
Carrot	35952	5069	41021	12,36 %	NOK 851 393
Tomato	13242	23631	38873	60,79 %	NOK 1 601 121
cucumber	17634	8270	25904	31,93 %	NOK 940 532
Squash	300	2804	2904	96,56 %	NOK 69 269
Pepper	102	18993	19095	99,47 %	NOK 728 612
Rutabaga	12047	717	12764	5,62 %	NOK 134 982
Cabbage	10130	1196	11326	10,56 %	NOK 131 336
Broccoli	3599	7918	11517	68,75 %	NOK 303 815
Cauliflower	5896	5307	11203	47,37 %	NOK 218 572
Brussels sprouts	415	212	628	33,76 %	NOK 32 259
Red cabbage	304	230	534	43,07 %	-
Chinese cabbage	1835	1683	3519	47,83 %	NOK 59 037
Leeks	1791	1842	3633	50,70 %	NOK 80 134
Rod cellery	730	1375	2105	65,32 %	NOK 58 553
Cellery	2086	817	2903	28,14 %	NOK 82 532
Asparagus	26	1534	1560	98,33 %	NOK 106 982
Onions	21483	7259	28747	25,25 %	NOK 540 488
Scallions	452	991	1443	68,68 %	NOK 120 025
Garlic	0	1327	1327	100,00 %	NOK 82 557
Champignon	0	7392	7392	100,00 %	NOK 177 046
Various mushroom	0	311	311	100,00 %	-
Iceberg lettuce	4857	9147	14004	65,32 %	NOK 376 221
Various lettuce	3233	3491	6724	51,92 %	-
Other vegetables	4900	15637	20537	76,14 %	-

Figure 18: Marked in tonnes for vegetable sales and sales value in Norway 2017[31]

Fruits	Norwegian	Import	Total	Percentage imported	Sales (1000 NOK)
Bananas	0	86403	86403	100,00 %	NOK 1 479 721
Apples	6909	46693	53602	87,11 %	NOK 1 094 539
Oranges	0	35112	35112	100,00 %	NOK 505 835
Melon	0	30333	30333	100,00 %	NOK 362 766
Tangerines	0	31494	31494	100,00 %	NOK 620 463
Grapes	0	25400	25400	100,00 %	NOK 1 005 430
Pear	159	17422	17581	99,10 %	NOK 268 571
Peach	0	9973	9973	100,00 %	NOK 13 997
Avocado	0	12421	12421	100,00 %	NOK 791 220
Pineapple	0	5350	5350	100,00 %	NOK 50 422
Lemon	0	10278	10278	100,00 %	NOK 60 045
Mango	0	7011	7011	100,00 %	NOK 198 160
Plum	1763	3808	5571	68,35 %	NOK 189 498
Kiwi	0	4099	4099	100,00 %	NOK 130 329
Cherries	447	1960	2407	81,43 %	NOK 193 421
Grapefruit	0	1278	1278	100,00 %	NOK 18 472
Other fresh fruits	139	5888	6027	97,69 %	-

Figure 19: Marked in tonnes for fruit sales and sales value in Norway 2017[31]

Top vegetables for total sales (tonnes)

Vegetable	Amount
Carrot	41021
Tomato	38873
onions	28747
cucumber	25904
other vegeta	20537
pepper(papr	19095
iceberg lettu	14004

Top imported vegetables

Vegetable	Amo
tomatoes	23631
pepper	18993
other vegeta	15637
iceberg lettu	9147
cucumber	8270
broccoli	7918
champignon	7392

Top fruits for total sales (tonnes)

Fruit	Amount
Bananas	86403
apples	53602
oranges	35112
tangerines	31494
melon	30333
grapes	25400
pear	17581

Top imported fruits

Fruit	Amo
Bananas	86403
apples	46693
oranges	35112
tangerines	31494
melon	30333
grapes	25400
pear	17422

Top vegetable sales

Vegetable	Total sales (1000 NOK)	Kg price
Tomato	NOK 1 601 121	NOK 40,00
cucumber	NOK 940 532	NOK 61,00
carrot	NOK 851 393	NOK 16,90
pepper	NOK 728 612	NOK 55,80
onions	NOK 540 488	NOK 31,80
iceberg lettuce	NOK 376 221	NOK 42,62
broccoli	NOK 303 815	NOK 19,75

Top fruit sales

Fruit	Total sales (1000 NOK)	Kg price
Bananas	NOK 1 479 721	NOK 25,60
apples	NOK 1 094 539	NOK 12,60
grapes	NOK 1 005 430	NOK 37,80
avocado	NOK 791 220	NOK 109,67
tangerines	NOK 620 463	NOK 32,90
oranges	NOK 505 835	NOK 16,45

Top herb sales

Hebs	Total sales (1000 NOK)	Kg price
Basil	NOK 47 040	NOK 1 145,00
Coriander	NOK 42 998	NOK 1 240,00
Parsley	NOK 31 871	NOK 1 240,00
Dill	NOK 26 331	NOK 1 240,00

Figure 20: Norwegian marked[31][95]

The figures show a marked evaluation of the most popular fruit and vegetables in the Norwegian marked in 2017. Where three key points can be analyzed. The most popular Norwegian fruit and vegetables, the highest import rates, and the sales price of the plants. It should be noted that the kilogram prices can vary depending on the season, is highly dependent on the demand of the public, and is normally seen fluctuating substantially. The values from the marked in 2017 can be used as a forecasting of future demands as the trends the last ten years have been relative stable[31]. Additionally, for the market price, There has been a slight increase in the vegetables the last couple of years, while fruits have seen a relatively large increase which can be expected to continue following a linear trend[31]. Either way, a closer look at current market prices should be carried out by the management team before choosing the final product.

8.3 Ideal plants for Northern Norway aquaponic production

To determine the ideal plants for Nordic regions the following four steps should be followed to decide the plant species:

1. Economical viability
2. Design of the aquaponic system - space restrictions - Inside or outside production
3. Main type of vegetable (leafy green plants or fruity plants)
4. Nutrient and water parameters match with the aquatic species

Norway could profit from a variety of vegetables, herbs, and fruits. It is vital that the producer chooses fruits and vegetables that can provide a profit and ideally a fast return on investment due to the high investment cost of aquaponics. Due to Northern Norway's climate, harsh weather and the low percentage of arable land, utilizing an indoor farm has previously been established. Thereby, another factor needs to be explained, space restrictions. Many of the fruity trees grow very large and have powerful root systems, bananas, for instance, have such a strong root system that they can push the walls of the media bed until they break through them[96]. Following is to decide whether as a producer, you want to produce leafy green plants or fruity plants. For most systems ideally in the setup time, leafy greens are preferred, and when the biological filter has had the time to balance the system, fruity plants with higher nutrients requirements can be grown if desired. This is something that can be coordinated with the fishes growth cycle because the moments before the salmon and trout are transferred to sea the waste emission is at its highest and more or higher nutrient demanding plants can be grown (see section 3.2.2). The last factor to consider is the nutrient and water parameter match with the aquatic species. The water parameters for salmon and trout were mapped in section: 4.6 together with the nutrient emission from the fish and how it connects with the fish feeds nutrients and the feed rate ratio.

Economical viability

The economical viable plants for an aquaponic system aimed at profitable production in Northern Norway can be achieved by analyzing the data in figure: 18, 19 and 20) summarized in table 4. It is clear tomatoes, peppers, iceberg lettuce, cucumber, broccoli, and cauliflower are vegetables that will provide the system with a solid and safe choice, as both the demand for these are relatively high and today they all have high import rates. The viable fruits are bananas, apples, oranges, tangerines, melons, grapes, and pear, all possible choices with high demand and very high import rates. The same goes for the herbs. Where basil, parsley, coriander are viable options. Besides the demand and import rate, the price of the plants has a crucial function in the decision process. With tomatoes, peppers, cucumber and lettuce having relatively high prices among the vegetables, avocado, and grapes having relatively high rates among the fruits and all herbs having a high value. Even though the pricing of various plants is higher, it is not the only aspect to consider when looking at the economics. Both the number of crops grown in an area, number of harvest a year and nutrient requirement must be taken into consideration[6].

Table 4: Viable plants accounting for marked demand, import rates, and sales prices

Vegetables	**Fruits**	**Herbs**
Tomato	Bananas	Basil
Peppers	Apples	Parsley
Cauliflower	Oranges	Coriander
Broccoli	Tangerines	-
Lettuce	Melons	-
Cucumber	Grapes	-
High priced fruit and vegetable		
Scallions	Cherries	
Garlic	Plum	
Aspargus	Avocado	

Design of aquaponic system
It was early stated that an indoor facility protected from the environment is required in Northern Norway, ideally built in combination with already existing hatcheries. Which mean there are minimal restrictions to growing conditions such as environmental effect including sunlight, wind, and rain. However indoor facility brings along space restrictions that larger fruit trees are not optimized for. Bananas, apples, oranges, and tangerines are large and might not fit in most facilities. However, these can be grown if there is enough space. Another possibility is growing in greenhouses, however, in colder regions, it would be beneficial to site the aquaponic inside a facility with sufficient isolation to minimize heat loss[97].

High versus low nutrient demand
Following is the decision between leafy plants and fruity plants. Leafy vegetables normally require less nutrient, have shorter growing cycles, and have an all over higher demand, while fruity plants normally have a longer production period requiring a higher amount of nutrients and potentially produce less marketable yield, but provides values that are normally higher than leafy vegetables[98]. It is advised to use plants with low nutrient requirements in the first phase of the aquaponic life stage. After, when the system is balanced, the biofilter has built up a sufficient bacterial colony to support the plant, and the workers are more comfortable with the routines and system other higher demanding plants such as fruity plants can be chosen. Plants with higher nutrients demand should normally be planted earliest 3-6 months after the system first is operational[6]. Often these are less forgiving in terms of living conditions and requirements. For instance, if a malfunction would occur for a short period, there is a larger

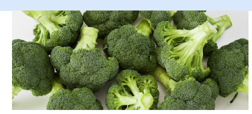
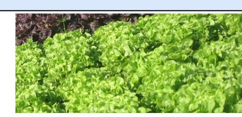
chance the leafy plants would be able to endure with the event as they are more forgiving, while the consequence on the fruity plants could be more severe.

Which means tomato, peppers, cauliflower, cucumber, melons, grapes scallions, garlic, asparagus, cherries, plums, avocado being unfit in the first phase. Where all of the herbs and various lettuce types can be grown with ease.

Nutrient and water parameter match

The optimal parameters for salmon and trout species were specified earlier, by combining these parameters with the most viable leafy plants: Lettuce, and herbs (basil, parsley, chard) and fruity vegetables (tomato, pepper, cucumber, broccoli and cauliflower) as seen in table: 5, the optimal plants can be predicted.

Table 5: Potential plants [6][99][100][101][102][103][104][105][106]

Plant Fruity	**Temperature Day**	**Night**	**pH**	**Germination Temp.**	**Time**	**Growing bed**	**Picture**
Tomato	13-16°C	22-26°C	5.5-6.5	20-30°C	4-6 days	Media bed DWC	
Peppers	22-30°C	14-16°C	5.5-6.5	22-30°C	8-12days	Media bed	
Cucumber	22-28°C	18-20°C	5.5-6.5	20-30°C	3-7 days	Media bed	
Cauliflower	20-25°C Growth 10-15°C flowering		6.0-6.5	8-20°C	4-7days	Media bed	
Broccoli	13-18°C		6-7	25°C	4-6	Media bed	
Leafy plants							
Lettuce	15-22°C 24°C+ (flowering)		6-7	13-21°C	3-7days	Media bed DWC NFT	
Basil	18-30°C Optimal: 20-25°C		5.5-6.5	20-25°C	6-7days	Media bed DWC NFT	
Parsley	15-25°C		6-7	20-25°C	8-10days	Media bed DWC NFT	

From section 4.6 Salmon and trout had the following pH and temperature requirements:

- Salmon

  - Optimal temperature: 13°
  - Vital temperature: 6-18°
  - pH: 6.2-7-8

- Trout
  - Optimal temperature: 14-16°
  - Vital temperature: 10-18°
  - pH: 6.5-8

In addition the bacteria briefly explained in 2.4.2 consisted of two main groups the AOB, and the NOB, which both have certain temperature and pH requirements[6].

- AOB - Ammonia oxidizing bacteria
  - pH: 7.2-7.8
  - Temperature: 17-34°
- NOB - Nitrite oxidizing bacteria
  - pH: 7.2-8.2
  - Temperature: 17-34°

Looking at both the fish and bacteria's temperature and pH levels and comparing it to the plants there are some plants better fit than others. Most plants can be used if only looking at the pH and temperature. These values can be modified with ease if needed. However, the higher temperature and pH variations, the more energy, and addition of acid/bases are required, which increases the price of the system. Therefore a relative match would be preferred. For the first phase of the production period, leafy plants should be grown. Lettuce is the ideal choice if only looking at pH and temperature. Where both parsley and basil could be produced, however with larger temperature and pH regulations. For the fruity plants, tomato and pepper could both work, with minimal heating required, and a slight addition of base to increase the pH level. Broccoli is another option with low temperature conditions, except for the germination period. However, this is only for a short amount of time, the pH requirement is also higher than most of the other fruity plants, requiring only small changes in pH. Cauliflower and cucumber, both popular vegetables in Norway, but with higher temperature conditions than the others and on a first look there are better options. The same goes for broccoli due to the low price seen earlier.

To summarize one type of lettuce for the initial phase alternatively parsley or basil, while tomatoes, peppers, or broccoli for the second. All were having steady high demand in the Norwegian market, and very high import rates, meaning a Norwegian produced organic product competitive with the imported merchandise, which in most cases would be a safe choice.

8.4 Further consideration with aquaponic

The plant and fish have been mapped, together with a basic understanding of the functioning of aquaponics. Although the success of the facility can not solely be dependent on the market demand and import rate of the vegetables. The success of an aquaponic facility is dependent on multiple other factors: one of the major activities is conducting a comprehensive cost analysis upon certain economic, environmental, logistical/managerial, and social conditions[6].

8.4.1 Economic

To further the work of aquaponic into a commercial scale. The economics needs to be thoroughly investigated and scientifically based, to commence a profit evaluation the process of subtracting all variable expenses from revenues and indicating the amount from sales to cover the fixed costs and profit[89].

The producer needs to evaluate multiple parts, and it imperative they assess in the right way. The entire system, both the fish and the plant production need to be competitive to other producers and imported products, which means an investigation of the ”window of opportunity” is required, i.e., the duration the price level of the fish and plant products are higher than average, for instance, due to seasonal demand. Additionally operating an aquaponic facility increases the dependency(fish and plant interconnected), which again increases the economic risks[89]. With having the facility directed to commercial scale, there are essential considerations. The principle economics of scale[6] is one. Small scale farmers can not reap the benefits of the principle in the same matter as large scale commercial ventures can. The next chapter discusses the economic aspect with the plants yielding the highest potential by calculating the variable costs related to growing them. Ideally, wholesale prices should be used in the calculations for a more correct estimation of the profit margin.

8.4.2 Environmental

There are many environmental aspects to consider. The Norwegian climate, especially in Northern Norway. We suffer from short and relatively cold summers and long winter season usually six months or more. Allowing farmers to either shut down the production during winter seasons or pay the price of high energy cost related to significant heating[6]. Due to the long winter season having the aquaponic system shut down for more than half the year would be very inefficient. For salmon and trout it would not be a problem as these are already adapted to the Norwegian climate and thrive in cold water, it is the plant and bacteria that require higher temperature, and additional research might be needed to grow plants that are eligible to the cold climate.

As already discussed since the system has to be built indoor, most of the environment effect can be neglected. However, during some parts in the summer months, the temperature can

[6]Economics of scale is a principle where companies take cost advantages of efficient production[107]

increase significantly, resulting in abnormal high temperature in the water or inside the facility Often it would not be a problem for the bacteria, but it could affect the fish or the plants limiting the vegetable yield and selection or the fish, and cooling system might be needed.

8.4.3 Logistic

Logistics pose an important role. It is clear from previous sections that the concept of aquaponics, fish production poses a huge role therefore obvious building large scale aquaponics system where there are no hatcheries or other larger land based fish farm would not be beneficial. Especially since the concept of aquaponics is meant to be used in combination with already existing hatcheries in Northern Norway today.

Another important factor is access to water and electricity. Water is not an issue in Norway, and in combination with the already existing hatcheries with RAS technology water connection is already established in the facilities. It is the electricity needed to run an aquaponics facility that has to be considered further (discussed further in the next chapter). Even if electricity is crucial in the aquaculture with RAS technology, it is even more important the electricity is stable and connected to a reliable power grid[6]. It can't be stressed enough how vital constant, reliable power is to power the continuously running pumps, heating, lighting, and every other function that requires power. Besides, commercial scales facility can not solely depend that the power is continuously functioning, they need highly reliable back up systems able to power the entire facility in the case of a power out.

Utilizing the local product is an important factor for success, both in the setup period and the operation period. As previously mentioned, the facility requires constant monitoring of the water quality and many various testing kits are needed (water, ph, temperature, etc.). Failing to either find or utilize local products will severely increase the cost, making it harder to develop a cost effective way of food production[6]. Finally, there are the expertise and management factors. The aquaponic system requires expertise personnel in various fields in the system, from a biological engineer, automation engineer, fish/plant experts, construction, mechanical, data, and much more. Since aquaponics is such a complicated process where not only experts in hydroponics are required, but also in a recirculating aquaculture system, high demanding personnel are required to have an overall higher level of understanding of the integrated ecosystem. One of the main challenges seen with aquaponics is the complexity, very few have appropriate knowledge today, partially because the concept is relatively new.

8.4.4 Social

Finally, it is the social aspect. The Norwegian consumers are somewhat patriotic as we prefer Norwegian produced food, as can be seen from the recent year where it has been an increasing demand for locally produced food over imported products. The Norwegian consumers prefer and take more and more interest in how the food is processed and traded, and the consumer opinion is given a significant impact on the food policies something that has given root to the information mark ”savior Norway”, making it easier for Norwegians to recognize and purchase locally produced food[32]. While on the topic of consumer preferences. Together with locally produced products gaining momentum, also organically produced food are seen increasing[108]. That together with ”savior Norway” has a food labeling mark ”Debio Økologisk” (Oecological) printed on organically produced food that Norwegian consumers can look for. To summarize there are a marked for Norwegian produced food, and if given the opportunity between imported products and Norwegian produced food most people would prefer and choose the Norwegian product as long as the price is competitive with the imported products.

Figure 21: Illustration of the the labeling for ”Nyt Norge”[109]

Figure 22: Illustration of the labeling for ”Debio økologisk”[110]

Food safety is an important issue that states that everyone should have access to sufficient and safe food, not only local but also abroad. The Norwegian government works to increase the agricultural output of Norwegian food production focusing on increasing and maintaining the self sufficiency[32].

9 Cost-benefit analysis

There are a substantial amount of costs associated with an aquaponic facility. With possible plants mapped for an aquaponic facility, and a marked evaluation of the highest demanded and imported plants as seen in figure: 5. The following sections further explain the potential revenue the different crops poses by performing a cost-benefit analysis.

9.1 Electricity cost

Aquaponics uses a substantial amount of electricity with its various operations, such as water heaters, lighting, air blowers, water pumps, and fans[97]. Naturally, from the high energy use, there originate substantial expenses. Most very hard to calculate without knowing every aspect of the facility. An important activity is the calculation of the electricity cost that each of the potential plants requires, how much energy is required to heat the water, but also the lighting requirement of the plants by the help of LED lamps. From the literature, it is clear that LED lamps can be costly to operate, due to their low efficiency of turning electrical energy into photon energy. However, in recent year the LED efficiency has been significantly improved and is expected to improve even further in the future, making it a viable method of artificial lighting for plant production.

9.2 LED lights cost

There are many factors to consider before and while using LED lamps to grow plants. First, discussing the coverage area of LED. Increasing the wattage does not necessarily correspond to larger growth area, but it can be used as a rough estimate. Naturally, it is a broad specter of LED's to choose. By assuming the facility uses an average LED lamp, it will draw approximately 32 watts per square feet of growth space[111][34]. Even though for even better results and optimized growth lamps using 50 or 80 watts per square feed should be used.

- 1 meter of plant growing area = 3.2808399 feet.
- 1 x 1 feet uses 32 watts.
- 3.2808399 x 3.2808399 feet would use approximately 344 watts.

To calculate the total watt usage of operating the LED lights, the watt needs to be converted to kWh. It is done by multiplying the total watt by the hours the light is on, then divide by 1000.

$$kWh = \frac{Power(W) * Time(hrs)}{1000} \tag{1}$$

Then for calculating the total electricity cost of the LED lights:

$$Price = kWh * cost\ per\ KwH \tag{2}$$

LED lights have the advantage of a long life span and a low electricity price, at the expense of a rather larger investment cost. LED lights have an average lifespan of 50 000 hours[112]. To paint a bigger picture, the costs of the lights every year can be added by the help of depreciation. By investigating SSB the electricity prices for high intensive energy manufacturing business activity excluding taxes being 31.8 øre/kWh in the 4th quarter of 2018[113].

9.3 Heating cost

Heating is another important cost to consider. The heating depends on the efficiency of the heater if it is operated by gas or electricity, and what the electricity/gas prices are in the local area. The formula given for calculating the energy for heating the water is given by: [114]

$$Q = m * c * \Delta T \tag{3}$$

- Q = heat energy (Joule)
- m = mass of the liquid (grams)
- c = Specific heat capacity of the liquid (Joule/grams)
- ΔT = $T_i - T_f$ = Temperature variation

Then to calculate the energy output from the heating Joule must be converted into kWh[115]:

$$1\ J = 2.7778 * 10^{-7} kWh \tag{4}$$

The mass of the liquid is dependent on the growing bed used. As seen, there are three basic types of growing beds, media bed, DWC, and NFT. DWC, as explained previously, are large rafts where the water retention time is between one and four hours. Which is the time the water uses to refill the tank completely[6]. The tank volume of a square meter tank, with an average depth of 20cm[116] gives a volume of 100 cm * 100 cm * 20 cm = 200 000cm^3 = 0.2m^3. Then with the knowledge that 1 litres = 0.001 m^3, 0.2m^3 = 200litres. By having a 2 hours retention time, and a water tank holding 200litres, the flow rate is calculated by:

$$flow\ rate = \frac{volume}{hours} \tag{5}$$

$$Flow\ rate = 100 litres/hour$$

9.4 Revenue of crops

The different plant selection naturally varies in terms of requirement. By accounting for the following factors, the plant income can be calculated: Plant productivity per square meter, growth duration, and wholesale prices per kg. Then the different plants are compared to each other with associated costs and income to determine which have the highest potential to be grown in a Northern Norway aquaponic facility. Notable is that calculating the heating and lighting costs are only a small part of the facility costs and that other processes require electricity, water related costs, biofilter costs, and mineralization are just a few examples.

Another highly important factor is collecting the sale prices for the various vegetables and fruits. The prices vary a lot depending on the customer demands, and the amount produced. Retail prices would not give an accurate picture as these are exceptionally higher than the wholesale prices. Therefore the producer prices are collected from the Norwegian Agriculture Agency instead. Due to the high fluctuations from week to week, data was collected from week 20 and 30 in 2018, and week 19 and 20 in 2019 and then by taking the mean values the prices summarized in table: 6 was obtained.

Table 6: Producer prices for various aquaponic plants[117]

Plants	Prices (NOK)
Iceberg lettuce (per head 470 grams)	10.86
Basil (kg)	412
Tomatoes (kg)	18.07
Parsley (kg)	446

Table 7: Growing condtions for lettuce, parsley, basil, and tomatoes

Growing conditions						
Plants	**Growth time**	**Germination**	**Lights**	ΔT		**Plant spacing**
Lettuce	28 days	5 days	12 hours	5		25-40 cm 6-16 heads/m^2
Basil	38 days	6 days	15 hours	9		15-25 cm 16-36 plants/m^2
Parsley	25 days	10 days	8 hours	7		15-30 cm 11-36 plants/m^2
Tomatoes	75 days	5 days	16 hours	2	11	3-5 plants/m^2

9.4.1 Lettuce

BBy then calculating $1m^2$ of plant growing area for lettuce. First of all, lettuce requires around 10-14 hours of light exposure each day (12 hours average)[118]. The time lettuce takes to grow depends on the type of lettuce grown as there are many different types. For iceberg/crisphead lettuce, which also is the most popular in Norway, the growth time is higher than other types of lettuce due to the head takes longer to mature. Normally iceberg can be grown in 24-32(28) days in addition to 3-7(5) days germination in hydroponic system[6].

- **Lighting cost:**

$$\frac{344\ watt \cdot (12\ hours \cdot 365\ days)}{1000} = 1506.72\ kWh$$

Then with a price of 31.8 øre/kWh:

$$1506.72\ kWh \cdot 31.8\ øre = \underline{47.91\ NOK}$$

By growing lettuce in DWC, with $T_i = 13^oC$, $T_f = 18^oC$, $\Delta T = 5^oC$'

- **Heating cost:**

$$Q = 100 litres/hour \cdot 4186 \cdot 5 = 2093000J = 0.5813kWh$$

Then calculating the annual energy demand.

$$0.5813 * 24hours * 365days = 5092.2kWh$$
$$5092.2kWh * 31.8øre = \underline{161.9NOK}$$
$$Total\ cost = 47.91 + 161.9 = \underline{\underline{209.8\ NOK}}$$

With a lighting cost of 47.91 NOK and heating cost of 161.9 NOK. With an annual electricity cost of 46.73 NOK + 157.9 NOK = 209.8 NOK for one $1m^2$ of lettuce

- **Potential revenue:**

The next consideration is to determine how much lettuce is produced. Normally the plant spacing is higher than other types of lettuce at around 25cm - 40cm (6-16 heads per m^2)[119], where each head weights approximately 470 grams[120]. The price of each head of lettuce naturally varies. However, from data from The Norwegian Agriculture Agency, one head is approximately 10.86 NOK[117].

$$\frac{365\ days}{33\ days} = 11.06\ productions\ each\ year$$
$$6 \cdot 11.06 = 66,4\ heads$$
$$66.4\ heads \cdot 10.86\ NOK = 721.1\ NOK$$

$$\frac{365\ days}{33\ days} = 11.06\ productions\ each\ year$$
$$16 \cdot 11.06 = 177\ heads$$
$$Total\ cost = 177\ heads \cdot 10.86\ NOK = \underline{\underline{1922\ NOK}}$$

9.4.2 Parsley

Parsley and basil discussed next are unique in the regard that they are biennial and annual respectively, but both are treated as annual for best results. Annual plants mean that they produce leaves the entire growing season[6]. Parsley together with basil is a popular choice of herbs to grow as it has both high demand and value. Parsley prefers light exposure up to 8 hours a day, while it usually takes 20-30 days to grow in addition to roughly ten days germination.

- **Lighting cost:**

$$\frac{344\ watt \cdot (8hours \cdot 365\ days)}{1000} = 1004.5\ kWh$$

Then with a price of 31.8 øre/kWh giving:

$$1004.5 \cdot 31.8\ øre = 31.94\ NOK$$

- **Heating cost:**

By growing parsley in DWC, with $T_i = 13^oC$, $T_f = 20^oC$, $\Delta T = 7^oC$

$$Q = 100 litres/hour \cdot 4186 \cdot 7 = 2930200J = 0.813945kWh$$

Then calculating the annual energy demand.

$$0.813945 \cdot 24\ hours \cdot 365\ days = 7130.1\ kWh$$
$$7130,1\ kWh \cdot 31.8\ øre = 226.7\ NOK$$
$$Total\ cost = 31.94 + 226,7 = \underline{\underline{258,64\ NOK}}$$

- **Potential revenue:**

Parsley has approximately plant spacing of 15-30cm, or 11 - 36 plants pr m^2. The weight of 1 plant of parsley is very hard deciding on, as it varies substantially, but a rough estimate is 20-25 grams per plant sold by Kolonial[95], and a price of 550 NOK per kg calculated from data from The Norwegian Agriculture Agency[117][121].

$$\frac{365}{30} = 11.86\ harvest/year$$
$$20\ grams \cdot 11\ plants \cdot 11.86 = 2609.2\ grams$$
$$2.609kg \cdot 446NOK = 1163NOK$$

$$\frac{365}{30} = 11.86\ harvest/year$$
$$25\ grams \cdot 36\ plants \cdot 11.86 = 10674\ grams$$
$$10674kg \cdot 446NOK = 4760NOK$$

9.4.3 Tomatoes

Tomatoes is a popular fruity vegetable to grow in aquaponics. Tomatoes require a lot of sunlight and as an approximation for optimal yield fruity plants require up to 16 hours of light a day[122]. It usually takes 70-80 days til the first harvest[6], with a germination period of 5 days.

- **Lighting cost:**

$$\frac{344\ watt \cdot (16\ hours \cdot 356\ days)}{1000} = 1959.4\ kWh$$

Then with a price of 31.8 øre/kwH giving:

$$1959.4 \cdot 31.8\ øre = 62.3\ NOK$$

Tomatoes can be grown in either DWC or media beds, with $T_{i1} = 13^oC$, $T_{f1} = 15^oC$, $\Delta T = 2^oC$, and $T_{i2} = 13^oC$, $T_{f2} = 24^oC$, $\Delta T = 11^oC$ Q = 100litres/hour in DWC.

- **Heating cost:**

$$Q1 = 100litres/hour \cdot 4186 \cdot 2 = 837200J = 0.23255kWh$$
$$Q2 = 100litres/hour \cdot 4186 \cdot 11 = 4604600J = 1.2791kWh$$

Then calculating the annual energy demand:

$$0.23255 \cdot 12\ hours \cdot 356\ days = 993.45kWh$$
$$1.2791 \cdot 12\ hours \cdot 356\ days = 5464.31kWh$$
$$6457.76\ kWh \cdot 31.8\ øre = 205.4\ NOK$$
$$Total\ cost = 62.3 + 205.4 = \underline{\underline{267.7\ NOK}}$$

With an annual electricity cost of 62.3 NOK + 205.4 NOK = 267.7 NOK for one $1m^2$ of Tomaotoes.

- **Potential revenue:**

Tomatoes can be planted with a plant spacing of 40-60cm meaning 3-5 plants per m^2[6]. Where the yield of each plant naturally varies depending on growing conditions. Although average yield of tomato plants under relatively good growing conditionss are 15 pounds or 6.8kg per plant. Then with a price of 18.07 NOK per kg, giving 18.07 NOK[123][117].

$$\frac{365}{80} = 4.45\ cycles\ per\ year$$
$$6.8kg \cdot 3\ plants \cdot 4.45\ cycles = 90.78\ kg$$
$$90.78\ kg \cdot 18.07 = 1640.4\ NOK$$

$$\frac{365}{80} = 4.45\ cycles\ per\ year$$
$$6.8\ kg \cdot 5\ plants \dot{4}.45\ cycles = 151.3\ kg$$
$$151.3\ kg \cdot 18.07 = 2733.9\ NOK$$

9.4.4 Basil

Basil is one of the most popular herbs grown in aquaponic system due to both high demand and high value, it requires around 5-6 weeks to grow (35-42 days) in addition to 1 week germination period[6]. Requiring at least 14-16 hours light exposure each day[124].

$$\frac{344watt * (16hours * 365days)}{1000} = 2009KwH$$

Then with a price of 31.8 øre/kwH giving:

$$2009 * 31.8\ øre = 63.88\ NOK$$

By growing basil in DWC, with $T_i = 13^oC$, $T_f = 22^oC$, $\Delta T = 9^oC$

- **Heating cost:**

$$Q1 = 100 litres/hour \cdot 4186 \cdot 9 = 3767400J = 1.0465kWh$$

Then calculating the annual energy demand

$$1.0465 \cdot 24\ hours \cdot 365\ days = 9167.3kWh$$
$$9167.3\ kWh \cdot 31.8\ øre = 291.5\ NOK$$
$$Total\ cost = 63.88\ NOK + 291.5\ NOK = \underline{\underline{355.8\ NOK}}$$

The price of each plant varies. The producer can choose to harvest either the entire plant or simply just the leaves. By assuming the plants are approximately 20-25 grams. Data from Kolonial showed that both parsley and basil had a very similar price, of 1240 and 1145 respectively[95]. However The Norwegian agriculture agency did not display producing prices for basil, therefore an approximation is used to calculate the producer price.

- Basil producer price = x NOK
- Basil marked value = 1145 NOK
- Parsley marked value 1240 NOK
- Parsley producer price = 446 NOK

$$\frac{x\ NOK}{1145\ NOK} = \frac{446\ NOK}{1240\ NOK}$$
$$x = \frac{446\ NOK \cdot 1145\ NOK}{1240\ NOK} = 412\ NOK$$

This is by no means considered a real/accurate value, just an approximation to be able to calculate the potential revenue with as close as possible values.

- **Potential revenue**

Basil require a plant spacing of 15-25 cm, around 16-36 plants per m^2. Like parsley each plant provide around 20-25 grams[95], and with an calculated price of 412 NOK per kg.

$$\frac{365}{40} = 9.125\ cycles\ per\ year$$
$$20\ grams \cdot 16\ plants \cdot 9.125\ cycles = 2920\ grams$$
$$2,920\ kg \cdot 412 = 1203\ NOK$$

$$\frac{365}{40} = 9.125\ cycles\ per\ year$$
$$25\ grams \cdot 36\ plants \cdot 9.125\ cycles = 8212.5\ grams$$
$$8.212\ kg \cdot 412\ NOK = 3383\ NOK$$

9.5 Results and comparison

A comparison of the plants are summarized in table below:

Table 8: Summary of the costs, income and profit of some of the plants showing the highest potential

Plants	Costs C (NOK)	Income I (NOK)	Profit P = I - C (NOK)
Lettuce	210	1321	1111
Parsley	259	2961	2702
Tomatoes	267	2187	1920
Basil	356	2293	1937

Herbs and greens are often the most appropriate crops for growing indoor[125], As seen from the table there are clearly the herbs parsley and basil that provides the highest profit margin and thus highest potential to be grown in Northern Norway aquaponic with 2702 NOK and 1937 NOK respectively. Lettuce and tomatoes still yielding a relatively high value both show potential at 1111 NOK and 1180 NOK, although they can not be compared to the value of the herbs. Important to consider is that these values are by no means scientifically based data. However with the knowledge that herbs such as basil and parsley provides a good and profitable yield, it is natural to utilize these plants in the further planning of the facility

9.6 Calculations of annual plant yield

However, the initial calculation does not account for the nutrient requirement of the plants. To get an overall idea of the actual profit an aquaponic system can provide, the feed rate ratio can be used to balance the system and calculate the number of plants related to the amount of fish in the system. Even if strictly using Rakocy feed rate ratio is considered highly inaccurate, and should only be considered a guide, or to be used small scale system it can still give an idea of the daily and yearly production quantity. To be able to calculate the plant quantity, the amount of fish needs to be determined. Firstly, the fish density is a very important parameter in the aquaculture, normally fishing density is between 10-20 fish per square meter[6]. However, it is possible to have fish densities up to $25m^2$[88]. By assuming the aquaponic facility is built together with a hatchery such as Astafjord smolt, they have multiple tanks, with a collected tank volume of 3500 m^3[126], then assuming all tanks working at optimal capacity with a fish density of 15kg/m3. Then 3500*15 = 52500 kg fish. Fish in a system eats roughly 1-2 percent of their body weight each day. However, younger the fish the higher percent of their body mass they consume[6]. Then calculating the balance between the fish and plant with an assumed feed rate of 60g/m2. Summarized:

- Fish density = 15kg/m^3
- tank volumes = 3500 m^3
- Feed rate ratio = $60gram/m^2$
- Fish feeding percent = 1-2 %

- Fish volume: 3500 * 15kgm^3 = 52500 kg

$$Feed\,per\,day = \frac{52500\;kg}{100} * 1\% = 525\;kg\,per\,day\; = 525000\;grams\,per\,day$$
$$Feed\,per\,day = \frac{52500\;kg}{100} * 2\% = 1050\;kg\,per\,day\; = 1050000\;gram\,per\,day$$

Then by having a feed rate ratio of 60g/m^2 directed at the leafy plants: parsley, basil, and lettuce

$$m^2\;of\;plant\;growing\;area = \frac{525000\;grams}{60\;g/m^2} = 8750\;m^2$$
$$m^2\;of\;plant\;growing\;area = \frac{1050000\;grams}{60\;g/m^2} = 17500\;m^2$$

For tomatoes, as it is a fruity plant as seen it required a slightly higher feed rate, by then assuming a feed rate of 80g/m^2.

$$m^2\;of\;plant\;growing\;area = \frac{525000\;grams}{80\;g/m^2} = 6562\;m^2$$
$$m^2\;of\;plant\;growing\;area = \frac{1050000\;grams}{80\;g/m^2} = 13125\;m^2$$

This are however only approximations, then by combining the annual m^2 prices calculated previously for parsley, basil, lettuce, and tomatoes:
Fish feed percentage of 1%

$$Parsley = 8750m^2 \cdot 2707\;NOK = 23.6 millions$$
$$Basil = 8750m^2 \cdot 1937\;NOK = 16,9 millions$$
$$Lettuce = 291166m^2 \cdot 1111\;NOK = 9.7 millions$$
$$Tomatoes = 6562m^2 \cdot 1920\;NOK = 12.5 millions$$

Fish feed percentage of 2%

$$Parsley = 17500m^2 \cdot 2707\;NOK = 47.3 millions$$
$$Basil = 17500m^2 \cdot 1937\;NOK = 33,9 millions$$
$$Lettuce = 17500m^2 \cdot 1111\;NOK = 19,4 millions$$
$$Tomatoes = 13125m^2 \cdot 1920\;NOK = 25.2 millions$$

Looking at these number by themselves aquaponics might seem like secure way and highly profitable business. This is also the case if everything is working as intended. However accounting for all the additional expenses such as taxes and additional operation costs related to aquaponics (as only heating and lighting are included in these calculations) the profit will be significant lower. Additionally, crop fatality, diseases, harvesting cycle of the fish, or other fish related factors can critically affect the crop productivity and thus the profit. Also, in the first phase it can not be expected these numbers as the biofilter still is adjusting and building up the nitrate levels, and due to the learning curve of the employers. Additionally since there are high start up cost (planning, material, building, coordinating and everything that comes along a project) it imperative the business starts making money in the early phase.

9.7 Energy required per gram biomass for parsley, basil, lettuce and tomato

As lighting and heat are roots to a substantial cost, it is interesting to analyze the amount of energy that is required to produce one gram of biomass of plants. As already mentioned, the amount of plants produced varies substantially. Therefore, mean values are used in the approximation, which can be seen from table: 9. Both the required energy for heating and lighting are calculated, showing what is expected. That tomato and lettuce have a much lower cost per gram of biomass, while parsley and basil cost substantially more in terms of electricity to produce the same amount of mass.

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Table 9: Energy required for one gram of plant biomass

Energy per gram biomass					
Plants	Production	Lighting costs		Heating costs	
		Energy	Total energy	Energy	Total energy
Basil	$\frac{8215.5+2920}{2} =$ 5556 g	2009 kWh	360.9 Wh	9167.3 kWh	1646 Wh
Parsley	$\frac{2609.2+10674}{2} =$ 6641 g	1004 kWh	151.2 Wh	7130.1 kWh	1073 Wh
Lettuce	$\frac{6.4+177}{2} =$ 121.7 heads = $121.7 \cdot 470$ g = 57.19 kg	1506 kWh	26.34 Wh	5092.2 kWh	89 Wh
Tomato	$\frac{90.78+151}{2} =$ 121.04 kg	1960 kWh	16.18 Wh	6457.7 kWh	53.3 Wh

10 Discussion

When investigating the potential of aquaponics, there have been many factors to take into considerations throughout the report. After analyzing both the plant, fish, and bacteria, there were especially tomato, pepper, broccoli, lettuce, parsley, and basil that showed great potential. However, growing an apparent high demanded plant does not necessarily mean the system will succeed. Hydroponics is a highly complex process on its own, by including aquaponics the complexity doubles. Indeed the profit potential increases, resource waste is reduced, and the ecological footprint is reduced, but so, the risks, complexity, and setup/managing costs are increased. Therefore with the large risks, economic viability alone is not adequate to venture on with an aquaponic project, and other factors should be included. Logistic, environmental concerns and social conditions are imperative to consider. One of the reason, for instance, Norway have had such success with aquaculture, might be due to logistic. Customers demand both quality, stability, and reliability in their fish suppliers. That sometimes can be hard to get from wild fish[71]. While looking at the perspective of aquaponics. By including environmental concerns such as the cold climate and building an indoor facility. Logistic factors such as reliable local accessibility to water, existing facilities, electricity, and proper expertise to manage the system, Then, social factors, such as playing on Norwegians patriotic behavior, identifying the product as locally produced food, creating a brand that is known for high quality, and ensured food security. With all the mentioned criteria outlined, there are a definite potential for aquaponics. Although, without a cost analysis of the plants values towards cost and income there are still only speculations.

10.1 Cost-benefit analysis

Through the analysis and review, four main vegetables were chosen for the cost-benefit analysis. Even if pepper, broccoli, and many more showed potential. The reasoning they were excluded was partly because of time constraints, and because the result would be too inaccurate. As gathering the producer price was unavailable, and as the plant yield varied substantially, even more than for some of the analyzed plants. Which means there would be very hard to gather an accurate value for the production. Therefore to provide best possible variability in the results the most popular plants according to demand was chosen in the different categories (leafy/fruity): one leafy vegetable (lettuce), one fruity plant (tomato) and two herbs (parsley and basil). During the calculations, there have been many assumptions by rounding off numbers, and settling mean values, because there are basically impossible to calculate accurate results without knowing every aspect of the growing process (i.e., number of plants grown, yield per plant and growth time). In addition to many of the plants don't have published wholesale prices (basil for instance). Ideally, empirical data should be collected and analyzed to provide the best and most accurate values.

As seen from the initial cost-benefit analysis, it was basil, parsley, and tomatoes that provide the highest potential. Parsley and basil being leafy plants and being ideal for growing in both the initial and secondary phase of the biofilter establishment and tomatoes being a fruity plant more fit for the second phase. However, there should be conducted additional research before planning and building a large scale aquaponic facility. There are still a considerable amount of expenses that should be considered, such as additional electricity costs, raw material(seedlings, additional nutrient additions), facility design, fish related costs and water costs related to the replenishing of the lost water. Additionally, a closer more accurate mapping of the Norwegian marked and demand needs to be completed as well as establishing wholesale prices for the analyzed plants. For instance, when certain crops have the highest demand based on season and mean values over a larger amount of choices.

By using Rakocy feed rate as an approximation, the profitability of the plant production can be seen in the secondary cost-benefit analysis. These are very interesting results. If assessing only the initial results, tomatoes proved to be equally profitable to basil with the electricity cost included. However, this is not the case. Tomatoes are fruity plants and are require more nutrients as the feed rate ratio are 80g/m^2 as opposed to 60g/$m^{"}$. Meaning even though the annual price of tomatoes is the same as basil, the same amount of plants cannot be produced due to the increased nutrient demand of tomatoes. Tomatoes produce 12.5 million or 25.2 million opposed to basil's price of 16.9 million or 33.9 million, even though they almost produce the same if only looking at one square meter. Obviously, from the values, it would be safe to say that aquaponic is highly profitable. However, as mentioned, there are many other costs to take into considerations before establishing the profit strictly from these values. Anyways, it is clear that if everything is working as intended, there are considerable profits to earn even with included heating and lighting costs.

As both the fish and the plant have been successfully mapped, the two main requirements are fulfilled to decide one of the most important parameters in an aquaponic system. The feed rate ratio, as defined in section: 7. The feed rate ratio gives the producer the exact amount of plant to grow with the amount of fish, or more correctly, the amount of feed the fish consume. Even if setting the feed rate between 60-100g/m^2 as proposed by Rakocy and done in the cost analysis in sec: 9.6 which would enable the producer to balance and measure up the system and visualize how the system actually would look, it would not be accurate and scientifically correct. It could be adequately in a small scale system, but in a large scale commercialized venture optimized and carefully chosen values tailored for the fish and plant are required. Thus, the values calculated are a very rough estimate, but can not even remotely be used as documentation for an accurate cost analysis. As seen, by following Lennard's approach and balancing the nitrogen, it is no specific feed rate given. Even if many of the aquaponic parameters already have been mapped, i.e., environmental and water quality parameters, FCR, growing bed. Additional values such as exact feed amount and content used, plant area, spacing, and filtration method must be investigated. Only then the feed rate ratio could be calculated and further used to balance the plant and fish in the aquaponic system.

10.2 Aquaponics potential

With salmon, trout and rainbow trout being proven to be the most extensive farmed species, and parsley and basil being viable plant species with related growing bed (DWC). With farming in Northern Norway, there are high start-up cost related to most projects, and to succeed an indoor controlled environment would be preferred due to the environmental factors in the Arctic climate (unfavorable climate, harsh soil, and weather). As seen through the work, due to the higher cost of an indoor facility, the discussed hydroponics is an ideal way to counteract some of the extra cost, with its increased production rate(intensity). Giving higher yields, and thus a higher profit. An initial facility will be directed to the various hatcheries we have in Norway today, with the possibilities for an extension to future larger land-based aquacultur[7]. There are risks towards accidents in the facilities. As the system is closed and a power shortage, a nonfunctioning pump, or other vital equipment could result in catastrophic ramification, and wipe out an entire batch of both plant and fish. To counteract the risk of a malfunction a proposal of including DAPS instead of traditional RAS is suggested to counteract the seriousness of an unforeseen event or error by isolating the plant and fish section of the facility. Normally it is debatable if it is required as good routines, surveillance, reliable power, and a reliable backup system would ensure the points above. However, it is very well suited in combination with Lennard's method and feed rate ratio. As the method utilizes mineralization to add dissolved solid waste through the additional sump in the DAPS system.

[7]More and more are being built. Example. Lerøy, recently built one of the worlds largest land-based RAS facility[127]

11 Conclusion

Aquaponics in Northern Norway is an interesting theme with a definite potential if managed properly. As seen through the literature review and the report, an aquaponic system has many components that all have to be satisfied. The plants, fish, and bacteria together act as an ecosystem where all three parts are equally important for the system to function. It is clear when developing a system; it is no blueprint for success. The system depends entirely on the individuals growers vision/conception. Each system has to be carefully assembled in order to utilize the available resource. The main challenge is that the concept is new, and there is a very high start-up cost (facilities, electricity, expertise management, and raw materials) with making a fully commercialized aquaponics facility. Given the existing hatcheries with already established water connections, most equipped with RAS technology, there is a definite potential for the development of an aquaponic facility integrated with the existing technology. It would save a substantial amount of investment and setup cost, as only the hydroponic part needs to be included. Additionally, it enabled for a possible extension to future land based aquaculture facilities.

Important is that aquaponics is not fit for every place and time, and the benefits have to be measured towards the cost before making a final decision to move forward. To be able to make this decision, the Norwegian fish species have been mapped, with salmon, trout, and rainbow being the most extensive farmed. Salmon and trout being cold water species, requiring a high protein diet, which again result in a relatively high nutrient emission from the fish itself. The optimal living condition of salmon and trout have been mapped, with temperature and pH levels given the primary focus, even though the remaining three still have a central role (DO, TAN, hardness). These values have been used to determine which plants have the highest potential to grow in Northern Norway. This decision has been taken together with three key points. First, the economic viability of the plants (marked demand, import rates, and sales prices), facility design, and nutrient match (fruity of leafy plants) was analyzed. Then by executing a cost-benefit analysis of the potential plants by calculating overall profit from the income and costs of heating and lighting each square meter of plants require annually. Showing parsley, basil, and tomatoes to be the more profitable with the annual price per square meter being 2707 NOK, 1937 NOK, and 1920 NOK respectively. However, the real potential was obtained when utilizing Rakocy's feed rate ratio. The annual profit the facility can expect was calculated. With a ratio of 60 g/m^2 for the leafy plants(basil, parsley, and lettuce) and 80g/m^2 for the fruity plants (tomato) and a tank volume of 3500 m^3 simulating Astafjord smolt collected tank volume. Resulting in basil and parsley being the most profitable plants, and tomatoes being less profitable due to the increased nutrient demand, even though all of the plants showed a clear profitable result. Although, most expenses and taxes were excluded beside heating and lighting costs.

Additionally, with Arctic agriculture it is clear that there are high start up cost related to most project, and in order to succeed, an indoor controlled environment would be preferred due to the environmental factors in the Arctic climate (unfavourable climate, harsh soil and weather). As seen through the work, due to the higher cost of an indoor facility, the discussed hydroponics is an ideal way to counteract some of the extra cost, with its increased production rate(intensity). Giving higher yields, and thus a higher profit.

11.1 Further work

As mentioned through the report, there are a lot of assumptions towards values related to the calculations of the plants. Thus a further and more detailed study should be made with higher accuracy ideally with empirical data collected. Additionally, a larger sample size should be analyzed as there still might be other herbs, vegetables, or fruits that can provide equal or better profit than parsley and basil. Furthermore, aquaponics is a huge process, and with the time constraint of the thesis naturally, not every aspect with aquaponics can be analyzed. Therefore to establish the full potential of aquaponics a comprehensive cost analysis of every fixed and variable cost needs to be fulfilled together with the calculation of the potential revenues the different types of plants and fish can bring. Important is that this is carried out with the highest possible accuracy, by forecasting the demand, and future market values. Additionally, the thesis can be used as a reference, with more detailed values collected, to map the actual profit margin, with appropriate components, and then finally simulate the entire process before actually building a facility.

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Appendices

A List of abbreviations

CEA	Controlled environment agriculture
DAPS	Decoupled aquaponic system
LED	Light emitting diode
MTB	Maximum allowed Biomass
RAS	Recirculating aquaculture system
Ref	Referring to
Sec	Section
SS	Suspended solids
SSC	Static solution culture